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a summary of field activities and

current research by the geological branch,

mineral resources division

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FOREWORD

In July 1985 British Columbia and Canada signed a $10 million, five-year Mineral Development Agreement (MDA) to assist mineral exploration and development in the province. Under the terms of the agreement, $7.2 million will be spent over the next five years to carry out geological, geochemical, and geophysical surveys. Due to the timing of the signing only $380 000 was spent on field projects in 1985; mostly on expanding and providing full field support to existing Geological Branch field programs. Major field programs were undertaken in 1985 in the Alice Arm area (*see* Dawson and Alldrick) studying stratigraphy, structure, and controls of mineralization; in the Vavenby area (*see* Schiarizza) studying the northward extension and the massive sulphide potential of the Eagle Bay Formation; and in the Chilko Lake area (*see* McLaren) studying geology, geochemistry, and resource potential. In addition, the Regional Geochemical Stream Sediment program was boosted to cover two full 1:250 000 map sheets (*see* Boronowski and Johnson). Projects reported on in the volume that received MDA funding are identified in the text.

In the 1986 field season, MDA funding will greatly expand our field program, and we will initiate a program of regional 1:50 000-scale geological mapping.

Some 1985 field projects by Geological Branch staff on active exploration 'plays' will be reported on in the publication *Exploration in British Columbia*, 1985. Beginning with the 1985 volume, *Exploration in British Columbia* will be expanded in scope to include field descriptions by Branch geologists of selected mineral deposits that are undergoing exploration. Our aim is to publish this volume by the following June after each exploration year.

It is hoped that by timely publication of the annual volumes, *Geological Fieldwork, A Summary of Field Activities and Current Research* and *Exploration in British Columbia*, that the exploration industry and the interested public will be kept well informed on field and research projects undertaken by Geological Branch staff and on cooperative projects with the University of British Columbia and other universities in Canada.

This volume was edited and compiled by Bill McMillan. Bill's enthusiasm and dedication to this task is gratefully acknowledged.

W. R. SMYTH
Chief Geologist
Geological Branch
Mineral Resources Division

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THE CANADA/BRITISH COLUMBIA MINERAL DEVELOPMENT AGREEMENT

By G. R. McKillop, W.R. Smyth, and B. McRae

Canada and British Columbia signed a historic five-year agreement on July 30, 1985 designed to stimulate and assist the province's mineral industry. This Mineral Development Agreement (MDA), is valued at $10 million and extends until 1990.

Mining is one of the driving forces of the British Columbia economy, ranking second only to forestry — 1984 production was valued at almost $2.5 billion. Until recently copper, molybdenum, lead, zinc, and coal have been the major commodities of interest in British Columbia but shifting world markets have resulted in a new emphasis on precious metals, polymetallic deposits, and certain industrial minerals. The Canada/British Columbia Mineral Development Agreement is intended to assist the provincial mining industry's adaptation to this emerging environment, largely by improving the geological database and by infrastructure assistance.

The MDA is a sub-agreement of the Canada/British Columbia Mineral Economic and Regional Development Agreement (ERDA) signed in November 1984. The federal and provincial governments have each committed $5 million to mineral development programs to be managed by a four-member committee appointed by the federal and provincial ministers. Most of the projects are supervised by the provincial government with about 6 per cent of the work being carried out by the federal government.

The MDA is made up of three components: Promotion of British Columbia Mineral Potential; Financial Assistance for Mine Development; and Management, Public Information, and Evaluation. The following table outlines the five-year budget for the whole program.

CANADA/BRITISH COLUMBIA MINERAL DEVELOPMENT AGREEMENT FIVE-YEAR BUDGET

	$
Promotion of B.C. Mineral Potential	
Geoscientific surveys	6 750 000
Geoscience data systems	450 000
Market, technology, and feasibility studies	750 000
Total	7 950 000
Financial Assistance for Mine Development	1 800 000
Management, Public Information, and Evaluation	250 000
Grand Total	**10 000 000**

PROMOTION OF MINERAL POTENTIAL

Promotion of British Columbia Mineral Potential is by far the largest component and is divided into a number of sub-components, each designed to expand the geoscientific database in British Columbia. This expanded database will enable appropriate targeting of exploration and development programs designed to lead to the opening of new mines. Some of the sub-components are:

1. **Regional Geochemical Surveys and Interpretation**
   The intention is to complete geochemical surveys to National Geochemical Survey standards, at the rate of one 1:250 000 map sheet per year. Map sheets 93G/W 1/2 and 93H/E 1/2 were sampled in 1985, with results due to be released in June 1986. These surveys are in addition and complementary to the usual annual geochemical survey undertaken by the British Columbia government.
   A geochemist is being hired under the agreement to re-interpret existing regional geochemical data and to conduct smaller orientation and follow-up surveys.
2. **Geophysical Surveys**
   Geophysical surveys will be delivered or managed by the federal government. Projects being considered are airborne magnetometer, gradiometer, and electromagnetic (EM) surveys.
3. **Geological Mapping**
   Geological mapping at 1:50 000 scale to aid and encourage exploration is the main thrust of this sub-component. Funding will also enable more and more comprehensive deposit-scale mapping projects to be undertaken. Mapping is to be done by Ministry of Energy, Mines and Petroleum Resources' staff and by contractors under close Ministry supervision to ensure high standards. Emphasis for selection of 1:50 000-scale mapping areas is on known or perceived economic mineral potential and indequate current geological base maps. At least eight 1:50 000 map sheets are to be completed during the term of the agreement
4. **Industrial Minerals Investigations**
   The MDA is improving funding of studies to evaluate and promote the potential for various industrial mineral commodities in British Columbia, ranging from phosphate to rare earths.
5. **Geoscience Data Systems**
   MDA funding is contributing to the updating and redesign of the existing computer-based mineral deposits file (MINFILE). Other computer-based mineral-related data files are being considered for funding.
6. **Market, Technical, and Feasibility Studies**
   This sub-component supports two types of programs: mineral supply forecasts and mineral economic data development for government use to guide mineral policies; and the Mineral Opportunitites Program. This program will cost-share projects initiated by industry to identify market potential for minerals, and also to examine the feasibility of introducing new techniques and technologies into mineral development.

FINANCIAL ASSISTANCE FOR MINE DEVELOPMENT

The financial assistance for mine development component provides aid to the private sector in funding environmental, engineering, and design studies for off-site infrastructure requirements. Examples of this type of assistance provided in 1985 are cost-shared studies for the Omineca and Mount Klappan access roads. Construction of the Omineca road will permit development of the Lawyers gold property by SEREM Inc. and will stimulate additional mineral exploration and development in the Toodoggone region. The Mount Klappan road study is preparatory to a production decision by Gulf Canada Resources Inc. for its proposed 1.5-million-tonne-per-year anthracite coal project in northwestern British Columbia.

MANAGEMENT, PUBLIC INFORMATION, AND EVALUATION

The third component, Management, Public Information, and Evaluation, provides for coordination and administration of the

British Columbia Ministry of Energy, Mines and Petroleum Resources, Geological Fieldwork, 1985, Paper 1986-1.

various projects, monitoring of contractors, evaluation of results, and provision of public information. A program manager has been hired under this component.

The following table summarizes the budget for the 1985/86 fiscal year. This budget is smaller than one-fifth of the five-year budget because the agreement was not signed until July 30, halfway through the 1985 field season.

1985/86 BUDGET SUMMARY

	$
Promotion of B.C. Mineral Potential	
Geoscientific Surveys:	
Geochemical surveys	150 000
Geochemical interpretation	25 000
Metallogenic mapping	175 000
1:50 000 mapping	42 000
Industrial minerals	30 000
Geoscience Data Systems:	
MINFILE	35 000
Market, Technical, and Feasibility Studies:	
Mineral supply forecasting	10 000
Mineral economic data development	24 000
Mineral opportunities program	160 000
Total	651 000
Financial Assistance for Mine Development	
Mount Klappan Coal:	
Pre-engineering	60 000
Detailed engineering/design	300 000
SEREM/Lawyers gold-silver:	
Pre-engineering and detailed engineering/design	116 000
Total	476 000
Management, Public Information, and Evaluation	
Management, public information, and evaluation	50 000
Total	50 000
Grand Total	**1 177 000**

Most MDA studies are proposed and supervised by the Mineral Resources Division of the British Columbia Ministry of Energy, Mines and Petroleum Resources in consultation with its Technical Liaison Committee. This committee is made up of representatives from the mining and exploration industry of British Columbia, the Geological Survey of Canada, and the University of British Columbia. Committee involvement allows for public input toward project definition and evaluation. Individuals are also encouraged to submit comments.

MDA funding is available to support proposals submitted by the private sector to provide support for market, technical, and feasibility studies that are of general benefit to the mining industry of the province. All MDA projects must result in a written report that can be made public. A short period of confidentiality may be negotiated for cost-shared projects.

Rapid dissemination of information is a priority for all MDA projects. Each mapping project will produce an open file map as an annual update. All projects will be reported in the Ministry publication *Geological Fieldwork*. Fourteen projects, partially or completely funded by the MDA in 1985, are reported in this volume. Major projects will be published in bulletin or paper format upon completion.

In summary, the Mineral Development Agreement provides a unique opportunity to update and expand the province's geoscientific database, introduce new mining and processing technology, improve infrastructure, and provide public input. Both government and industry can benefit from active participation in the program.

For more information on the Canada/British Columbia Mineral Development Agreement, contact Greg McKillop at (604) 387-5975 or by mail at Mineral Resources Division, Ministry of Energy, Mines and Petroleum Resources, Parliament Buildings, Victoria, B.C. V8V 1X4.

LIST OF SYMBOLS USED ON GEOLOGICAL MAPS AND FIGURES

DRIFT-COVERED AREA .... (LEFT BLANK)

GLACIAL STRIAE (DIRECTION OF ICE MOVEMENT KNOWN, UNKNOWN); NUMBERS INDICATE RELATIVE AGE, 1 BEING OLDEST ....

END MORAINE ....

MINOR MORAINES, RIB MORAINES, WASHBOARD MORAINES, "ANNUAL" MORAINES, TILL RIDGES TRANSVERSE TO ICE FLOW (IRREGULAR, STRAIGHT) ....

DRUMLINS, DRUMLINOID RIDGES (DIRECTION OF ICE MOVEMENT KNOWN, UNKNOWN) ....

CRAG AND TAIL HILLS AND RAMPS ....

LINEAR GLACIAL FEATURE ....

ESKER (DIRECTION OF FLOW KNOWN, UNKNOWN) ....

RAISED BEACHES ....

LIMIT OF MARINE OR LACUSTRINE SUBMERGENCE (WELL MARKED, ASSUMED) ....

DUNES ....

AREA OF SAND DUNES ....

LANDSLIDE SCAR ....

ESCARPMENT, CIRQUE ....

ROCK OUTCROP, AREA OF OUTCROP, PROBABLE OUTCROP ....

GEOLOGICAL BOUNDARY (DEFINED, APPROXIMATE, ASSUMED, GRADATIONAL, DIP INDICATED) ....

INTRUSIVE CONTACT WITH YOUNGER UNIT INDICATED ....

UNCONFORMITY (DEFINED, ASSUMED) ....

LIMIT OF GEOLOGICAL MAPPING ....

BEDDING, TOPS KNOWN (HORIZONTAL, INCLINED, VERTICAL, OVERTURNED) ....

BEDDING, TOPS UNKNOWN (HORIZONTAL, INCLINED, VERTICAL, DIP UNKNOWN) ....

BEDDING, GENERAL TREND (DIP UNKNOWN, TOPS UNKNOWN; DIP AND TOPS KNOWN; DIP KNOWN, TOPS UNKNOWN) ....

BEDDING, ESTIMATED DIP (GENTLE, MODERATE, STEEP) ....

IGNEOUS FLOW BANDING (INCLINED, VERTICAL) ....

PRIMARY IGNEOUS LAYERING, TOPS KNOWN (HORIZONTAL, INCLINED, VERTICAL, OVERTURNED) ....

PRIMARY IGNEOUS LAYERING, TOPS UNKNOWN (HORIZONTAL, INCLINED, VERTICAL) ....

STRIKE AND DIP OF PILLOWS, TOPS KNOWN (HORIZONTAL, INCLINED, VERTICAL, OVERTURNED) ....

STRIKE AND DIP OF PILLOWS, TOPS UNKNOWN (HORIZONTAL, INCLINED, VERTICAL) ....

VOLCANO ....

FLOW CONTACT ....

ROOF PENDANT (UNIT NUMBER INDICATED; TOO SMALL TO MAP SEPARATELY) ....

BRECCIA OF VARIOUS ORIGINS ....

LIST OF SYMBOLS USED ON GEOLOGICAL MAPS AND FIGURES—Continued

SCHISTOSITY, CLEAVAGE, FOLIATION; (HORIZONTAL, INCLINED, VERTICAL, UNKNOWN AGE) ....

S_1 ....

S_2 ....

SCHISTOSITY, GNEISSOSITY, CLEAVAGE, FOLIATION, GENERAL TREND ....

GNEISSIC FOLIATION OR BANDING (HORIZONTAL, INCLINED, VERTICAL, DIP UNKNOWN) ....

SHEARING AND DIP ....

AXIAL PLANE OF MINOR FOLD (INCLINED, VERTICAL, DIP UNKNOWN) ....

AXIS OF MINOR FOLD (HORIZONTAL, INCLINED, VERTICAL) 0 30 90

LINEATION OF UNKNOWN AGE (HORIZONTAL, INCLINED, INCLINED BUT PLUNGE UNKNOWN, VERTICAL) 0 30 90

TYPE OF LINEATION DENOTED BY LETTER:

MINERAL LINEATION .... M

S INTERSECTIONS .... S

MICROCRENULATIONS C

BOUDIN AXES .... B

DEFORMED CLASTS .... D

IGNEOUS INCLUSIONS I

RODDING, MULLION STRUCTURE .... R

METAMORPHIC AGGREGATES .... A

DEFORMED PILLOWS .... P

AGE OF LINEATION AND OF MINOR FOLD AXES

L_1 ....

L_2 ....

SENSE OF VERGENCE OF MINOR STRUCTURES (USED WITH MINOR FOLD AXES SYMBOL OR LINEATION S INTERSECTION SYMBOL; READ LOOKING ALONG THE ARROW) ....

MINERAL ISOGRAD ....

OTHER ALTERNATIVES WHEN MORE THAN ONE MINERAL ISOGRAD ....

FOLD ....

STRUCTURAL TREND (FROM AERIAL PHOTOGRAPHS) ....

LINEAMENT (FROM AERIAL PHOTOGRAPHS) ....

FAULT (DEFINED, APPROXIMATE, ASSUMED) ....

FAULT (INCLINED, VERTICAL) ....

FAULT (SOLID CIRCLE INDICATES DOWNTHROWN SIDE; ARROW INDICATE RELATIVE MOVEMENT) ....

THRUST FAULT (DEFINED, APPROXIMATE, ASSUMED; TEETH IN DIRECTION OF DIP; TEETH INDICATE UPTHRUST SIDE) ....

ZONE OF NUMEROUS IMBRICATE THRUST FAULTS ....

FAULT ZONE, SHEAR ZONE (WIDTH INDICATED) ....

LIST OF SYMBOLS USED ON GEOLOGICAL MAPS AND FIGURES—Continued

SHEARING AND DIP

TECTONIC SLIDE

VEIN FAULT (DEFINED, ASSUMED)

MINERALIZED BED OR SEAM (HEMATITE) — hem hem

DYKE, VEIN, OR STOCKWORK (DEFINED, APPROXIMATE, ASSUMED; DIP INDICATED) — 30

JOINT (HORIZONTAL, INCLINED, VERTICAL)

ANTICLINE (DEFINED, APPROXIMATE, ASSUMED)

ANTIFORM

SYNCLINE (DEFINED, APPROXIMATE, ASSUMED)

SYNFORM

ANTICLINE AND SYNCLINE (OVERTURNED)

ANTIFORM OR SYNFORM

BOX ANTICLINE, BOX SYNCLINE

FOSSIL LOCALITY — Ⓕ

LOCALITY WHERE AGE HAS BEEN DETERMINED, IN MILLION OF YEARS — Ⓐ 1400

LOCATION OF MEASURED SECTION

GRAVEL PIT OR QUARRY (ACTIVE, ABANDONED)

BORROW PIT (ACTIVE, ABANDONED)

OPEN PIT MINE OR QUARRY

ROCK DUMP OR TAILINGS

ROCK QUARRY (ACTIVE, ABANDONED)

MINE (LEAD, ZINC) — Pb Zn

MINE, ABANDONED (LEAD, ZINC) — Pb Zn

MINERAL PROSPECT: MINERAL OCCURRENCE (MANGANESE) — 3 Mn

PLACER DEPOSIT (GOLD) — Au

DRY WELL (ABANDONED)

SHOW OF OIL AND GAS (ABANDONED)

SHOW OF GAS (ABANDONED)

GAS PRODUCER

OIL PRODUCER

OIL AND GAS PRODUCER

TRACE OF COAL SEAM

LOCATION OF DRILLING

SHAFT, RAISE, WINZE

SHAFT (ABANDONED)

TRENCH

OPEN CUT

ADIT OR TUNNEL

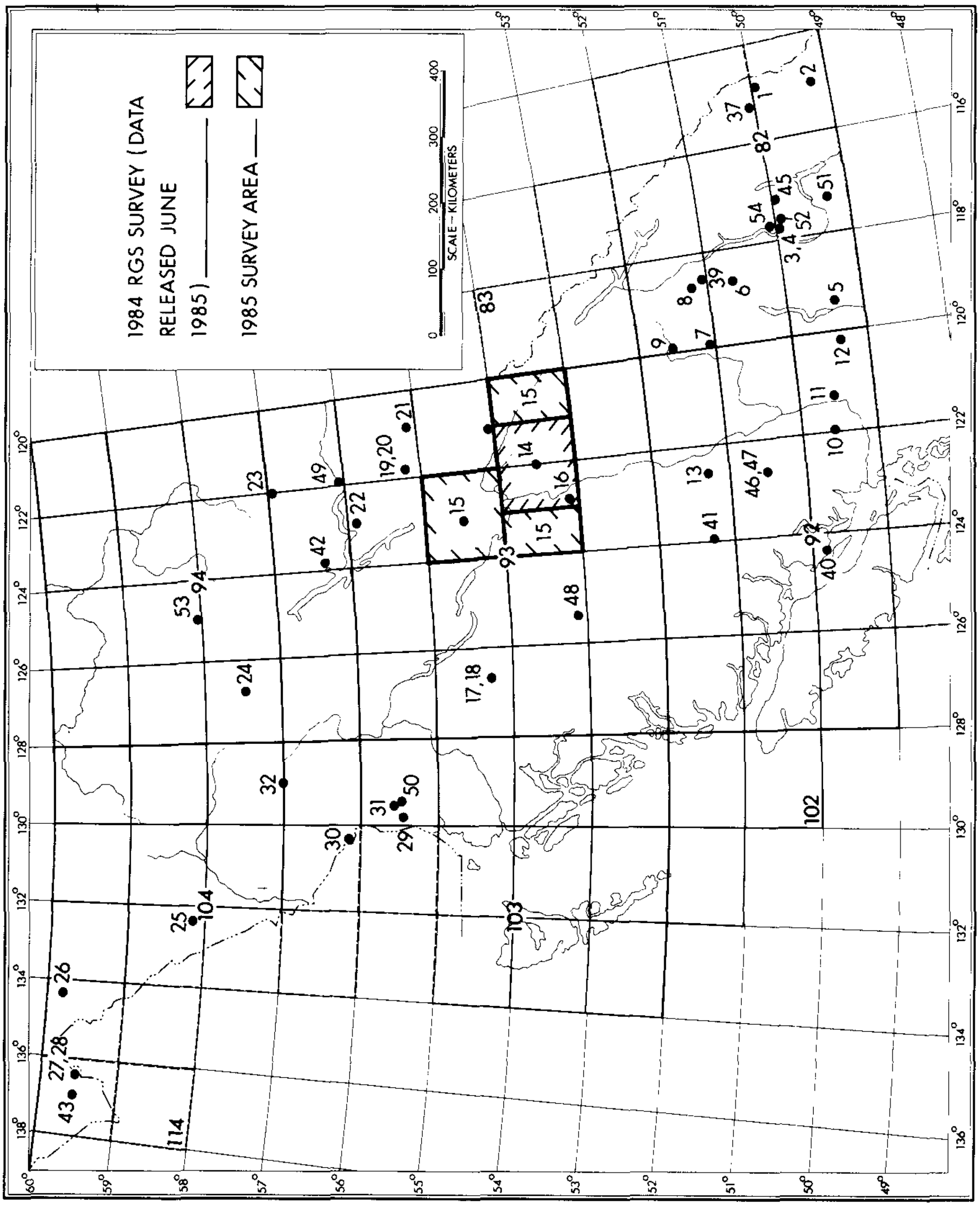
ADIT OR TUNNEL (CAVED)

BOREHOLE — BH BH 2

DIAMOND-DRILL HOLE — DDH

SINKHOLE — SH

GOSSAN — G G G


1984 RGS SURVEY (DATA RELEASED JUNE 1985)
1985 SURVEY AREA
0 100 200 300 400
SCALE - KILOMETERS

Project and Applied Geology

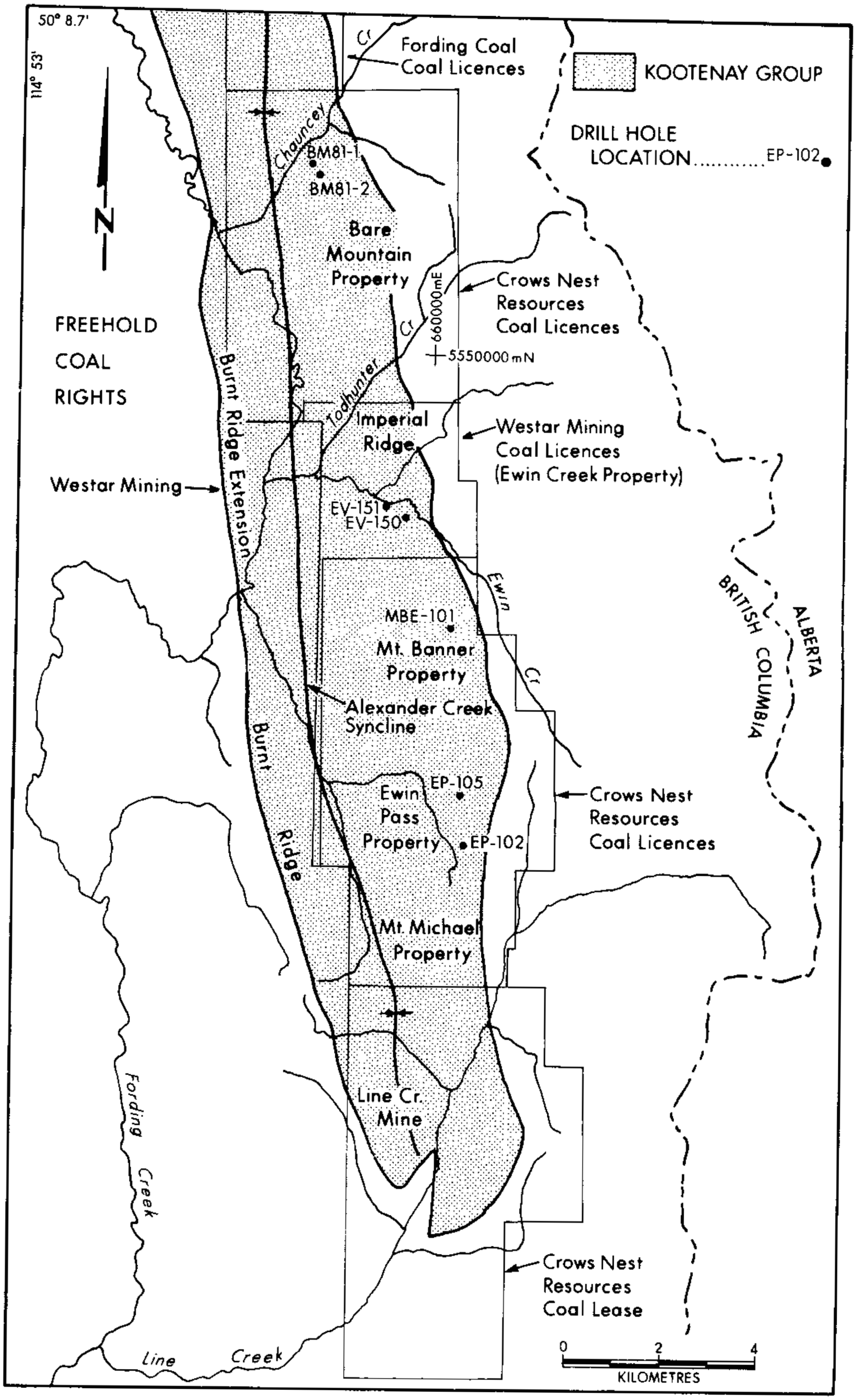


Figure 1-1. Drill hole and property location map for a portion of the Elk Valley Coalfield.

CORRELATION AND COMPARISON OF TWO COAL-BEARING ZONES BETWEEN EWIN PASS AND BARE MOUNTAIN ELK VALLEY COALFIELD SOUTHEASTERN BRITISH COLUMBIA (82G/15, 82J/2)

By D. A. Grieve and P. R. Elkins

INTRODUCTION

Regional correlation methods in the southeastern British Columbia coalfields are not well established. Preliminary conclusions presented here represent the first stage of an attempt to correlate specific horizons throughout the Elk Valley Coalfield. Seven exploration drill cores, spanning a north-south distance of 14 kilometres and representing four exploration properties, were logged in detail. These properties are, from south to north, Ewin Pass, Mount Banner, Ewin Creek, and Bare Mountain (Fig. 1-1).

It was hoped, at the outset, that tonsteins would form a conspicuous and common lithology within the drill cores examined. Tonsteins are effective local correlation tools at two Elk Valley Coalfield locations and are postulated to have potential for regional correlation (Grieve, 1984). Unfortunately, only one band was found which is texturally similar to tonsteins described in the previous study; there are also three, kaolinite-rich grey clay bands which are probably also a variety of tonstein. One possible reason for the dearth of these units is that coal zones had been removed from the cores examined.

The study area is in the south half of the Elk Valley Coalfield, which has recently been mapped in detail (Grieve and Fraser, 1985). The Elk Valley Coalfield is one of three separate fields in southeastern British Columbia. The major structure of the coalfield is the north-south-trending Alexander Creek syncline, which persists along the 100-kilometre length of the field. Thus there is great continuity of structure in the Elk Valley Coalfield and consequently excellent potential for regional correlation. The cores examined, for example, represent a continuous belt of strata on the east limb of the Alexander Creek syncline and east of the trace of the Ewin Pass thrust fault.

Economic thicknesses of coal in southeastern British Columbia are contained in the non-marine Mist Mountain Formation of the Jurassic-Cretaceous Kootenay Group. It is underlain by the Morrissey Formation, the basal unit of the Kootenay Group.

To date, five of the seven core logs have been corrected to true thickness and plotted in detailed and generalized form. Several potential marker horizons have been analysed by X-ray diffraction. One new regional coal seam correlation is herein proposed and a stratigraphically well-defined horizon (base of the Mist Mountain Formation) is compared at difference locations.

Petrographic analysis of vitrain samples collected will be carried out at a later date.

METHODS OF STUDY

The core logging system of Research Planning Institute, Inc. (RPI) was utilized in this study (Ruby, *et al.*, 1981). The RPI system uses three-digit codes to represent rock type, composition/colour, and sedimentary structures; suffixes modify sedimentary structures, and identify penecontemporaneous deformation, cement type, and presence of coal banding/spar. This method is readily applicable to Kootenay Group strata and it offers adequate degrees of detail, speed, and consistency.

Individual units within core were measured to the nearest centimetre. Intervals representing sampled coal horizons were taken from company logs. Units thinner than 5 centimetres were not measured separately, with the exception of tonsteins and other very distinctive lithologies. Logs were converted to true thicknesses using core-bedding angles. Sections were first plotted at large scale and then generalized for inclusion here (Fig. 1-2).

DESCRIPTIONS OF COMMON LITHOLOGIES AND INFERRED DEPOSITIONAL ENVIRONMENTS (MIST MOUNTAIN FORMATION)

Depositional environments of lithologies described below are based on core appearances as well as their similarity to units seen in the field and described by Gibson (1985) and Donald (1984).

INTERMIXED SHALES AND SANDSTONES (ISAS)

The most common lithology consists of intermixed shales and sandstones (ISAS) of the RPI system (Ruby, *et al.*, 1981). These range in their proportion of sandstones to shales from 'wavy-bedded sandstone with interbedded shale' (highest ratio, roughly 2:1 to 1:1), to 'lenticular-bedded sandstone streaks in shale' (lowest ratio roughly 1:2). In addition, units of massive, churned, burrowed, or rooted sandy shale exist, in which layering was either not present or not preserved. The sandstone in ISAS units ranges from fine grained in the sandstone-dominant varieties to very fine grained in the shale-dominant varieties. The shales are predominantly siltstones and silty mudstones. ISAS units are commonly burrowed and/or rooted and may be convoluted or slumped. Coal banding is also a common feature.

ISAS units occur as two distinct types, within or overlying thick sandstone units and within generally fine-grained sequences. The first type is believed to represent low energy portions of fluvial point-bar deposits; the other, splay deposits.

SHALE

Lithologies classified as 'shale' in the RPI system include siltstone, silty mudstone, mudstone, and shale. The predominant 'shale' variety encountered in this study is dark grey silty mudstone, which is generally faintly to well laminated, commonly contains coal streaks and bands, and locally is burrowed and/or rooted. Mudstones and shales are generally black in colour, are faintly laminated or massive, and contain coal streaks or bands and roots. They are closely related in position to coal seams. Densely rooted seatearths are uncommon; they do not occur at the base of major coal seams, but rather within fine-grained sequences that underlie carbonaceous shale.

Distinctive, massive, brownish black, hard mudstone units up to several tens of centimetres in thickness were noted in most of the cores, most conspicuously in the upper portion of BM81-1. Two samples polished and examined under reflected light contain uniformly dispersed fine detrital vitrinite. Thus they are carbonaceous

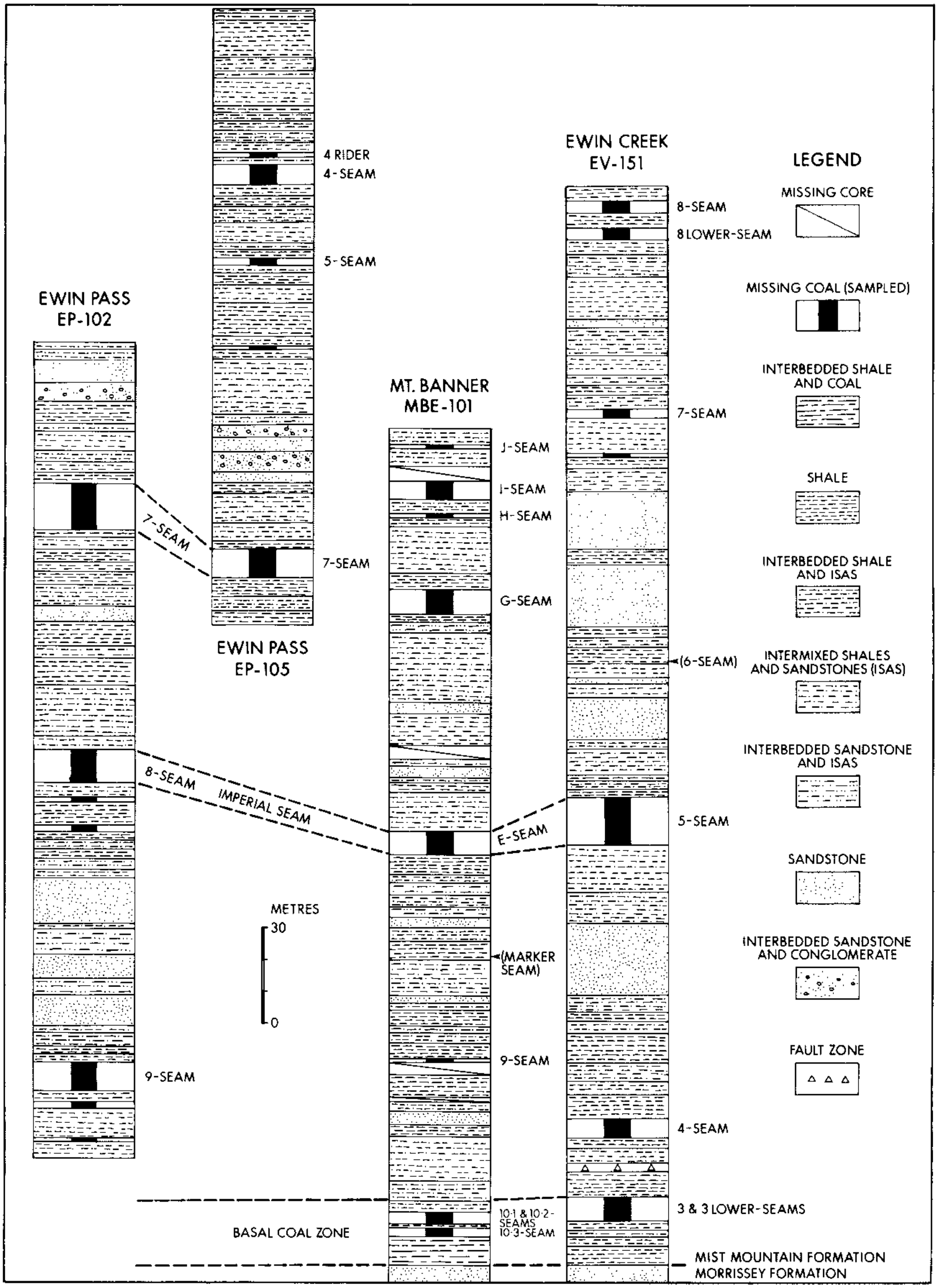


Figure 1-2. Generalized drill core logs from Ewin Pass, Mount Banner, and Ewin Creek.

shales but are not related to oil shale, as first thought, because they are devoid of liptinitic material.

Shale units occur either as a thick monotonous series or interbedded with ISAS units or coal seams. They may underlie thick sandstone units but never directly overlie them. They are thought to represent overbank flood deposits; the thickest series of shaly material developed are at relatively large distances from fluvial channels where the influx of sandy splay sedimentation was rare.

SANDSTONE

Sandstone units in the Mist Mountain Formation are predominantly lithic arenites and range from fine grained to very coarse grained and conglomeratic. They display flaser bedding, ripples, and all scales of planar and trough crossbedding. Massive and parallel laminated units are also common. They are frequently carbonaceous, particularly the massive varieties, and have irregular lenticles of coal spar. Mudstone rip-up clasts frequently occur, particularly near the bases of thick sandstone units. The basal contact of sandstone units is always abrupt and frequently scoured.

Sandstone has two distinct occurrences, the more common being thick (2 to 20-metre) sequences of predominantly medium-grained sandstone with a gross fining-upward profile that is overlain by ISAS units. These are inferred to represent fluvial point-bar deposits of large meandering channel systems. The other occurrence is as thin (<1 metre) rippled, fine-grained beds within series of ISAS units. These probably represent proximal portions of splay deposits.

COAL

All except the thinnest coal seams had been removed from cores examined. Those observed ranged from bright and banded to dull and massive. Coal seams, thick and thin, are generally closely associated with fine-grained units. They represent swamp and marsh environments (Gibson, 1985).

CONGLOMERATE

Conglomerate was observed only within the sandstone unit above 7-seam on Ewin Pass (cores EP-102 and EP-105). It consists of rounded chert pebbles in a coarse lithic arenite matrix. Individual bands range from stringers of pebbles to beds up to 1.2 metres in thickness. They are inferred to be part of the channel deposits represented by the sandstone unit. Those in which pebbles are in contact and matrix is sparse may be channel lag deposits.

TONSTEINS

Three narrow, 1 to 2-centimetre-thick, bands with distinctive light grey colour and extremely fine grain size were noted. Kaolinite is the dominant mineral in all cases so they are probably tonsteins. One band occurs 6 metres above the base of the Mist Mountain Formation in core BM81-2, the other two occur in the basal 1 metre in cores EV-150 and EV-151 (Fig. 1-3). In EV-151 another 3-millimetre-thick kaolinitic grey clay band overlies the first by half a metre.

In core BM81-1 a 5-centimetre-thick dark brown to black fine-grained unit was noted near the top of the core (core not plotted to date). This band is similar to tonsteins noted previously in southeast coalfields (Grieve, 1984); it is characterized by a blocky fracture with vitreous fracture surfaces and visible graupen (sub-spherical kaolinite bodies) up to 1 millimetre in diameter. It is composed of kaolinite with minor gorceixite. The latter mineral is a constituent of some previously analysed tonsteins in southeastern British Columbia (Grieve, 1984; Grieve, unpubl.). Petrographic analysis of these bands will be carried out.

BRIEF DESCRIPTIONS OF SECTIONS

To date logs from cores EP-102, EP-105, MBE-101, EV-150, and EV-151 have been plotted in detail. These represent the Ewin Pass, Mount Banner East, and Ewin Creek properties (Fig. 1-1). The basal portion of core BM81-2 from Bare Mountain has also been plotted for discussion here. Generalized sections were derived from the five completed detailed sections (Fig. 1-2). In generalizing data for these sections, units less than 2 metres in thickness were not plotted, excepting coal seams and shale partings, for which 1 metre was the minimum thickness. Grouping of units, necessitated by these minimum thicknesses, was somewhat arbitrary, thus the appearance of the sections on Figure 1-2 are partly an artifact of the generalization process; they should not be used for rigorous paleoenvironmental interpretation.

EP-102: This core consists of approximately 265 metres in true thickness (Fig. 1-2). Seven coal zones had been removed for sampling; these range from 1 metre to 15 metres in thickness (Fig. 1-2). The three thickest seams are named 9, 8, and 7-seam, from oldest to youngest, while the other four seams are unnamed (P. Gilmar, personal communication, 1985). This nomenclature represents the company's correlation of seams from Ewin Pass to Line Creek mine. The bottom of the hole was probably about 35 metres above Morrissey Formation (P. Gilmar, personal communication, 1985), therefore the zone corresponding to 10A and 10B-seams at Line Creek was not drilled.

A conspicuous series of three channel sandstone deposits interbedded with probable crevasse splay sandstones and siltstones occurs between 9 and 8-seams. One channel sandstone occurs between 8 and 7-seams and a channel deposit of sandstone interbedded with conglomeratic sandstone and conglomerate occurs above 7-seam, near the top of the hole.

EP-105: This core consists of approximately 194 metres true thickness; the lowest 72 metres overlaps with the strata contained within EP-102. Five seams, ranging from 1 to 9 metres in thickness, had been removed; four are named, from oldest to youngest, 7, 5, 4, and 4 rider. Therefore, 7-seam and the conglomeratic unit overlying 7-seam are common to EP-102 and EP-105. Seams 4 and 4 rider form the most significant coal zone above 7-seam, with a combined thickness of 9 metres. There are no channel deposits above the conglomeratic unit.

MBE-101: This core consists of approximately 290 metres true thickness, of which 30 metres belongs to the Morrissey Formation. Several portions of the core are missing or misplaced, due to vandalism. Thirteen seams had been sampled, ranging from 25 centimetres to 8 metres in thickness; nine seams are 1 metre or more. Six thin seams, numbered 10-6 to 10-1, occur in the basal 14 metres of the Mist Mountain Formation (Fig. 1-3). The other seams are named, from oldest to youngest, 9, marker, E, G, H, I, and J. Channel sandstone units are relatively scarce and thin. Two occur between 9-seam and E-seam and two more occur between E-seam and G-seam.

EV-151: This core consists of a maximum 354 metres true thickness, but contains a 2.5-metre fault zone 44 metres above the base, which probably caused a small but unknown amount of repetition. The base of the core contains 14 metres of Morrissey Formation. Eleven seams were removed for sampling, ranging from 60 centimetres to 15 metres in thickness; seven seams are greater than 1 metre. The thickest seams are named, from oldest to youngest, 3 (consisting of two benches named 3 and 3 lower), 4 (which has a thin unnamed rider), 5, 7, 8 lower, and 8. All the rest are unnamed, with the exception of 6-seam. Prominent channel sandstone units occur between 4 and 5-seams, 5 and 6-seams, and 6 and 7-seams.

EV-150: This core contains 302 metres true thickness of strata, of which 44 metres belongs to the Morrissey Formation. Moreover, the interval between 4 and 5-seams has been thickened by approximately 60 metres as a result of thrust faulting. Consequently, all

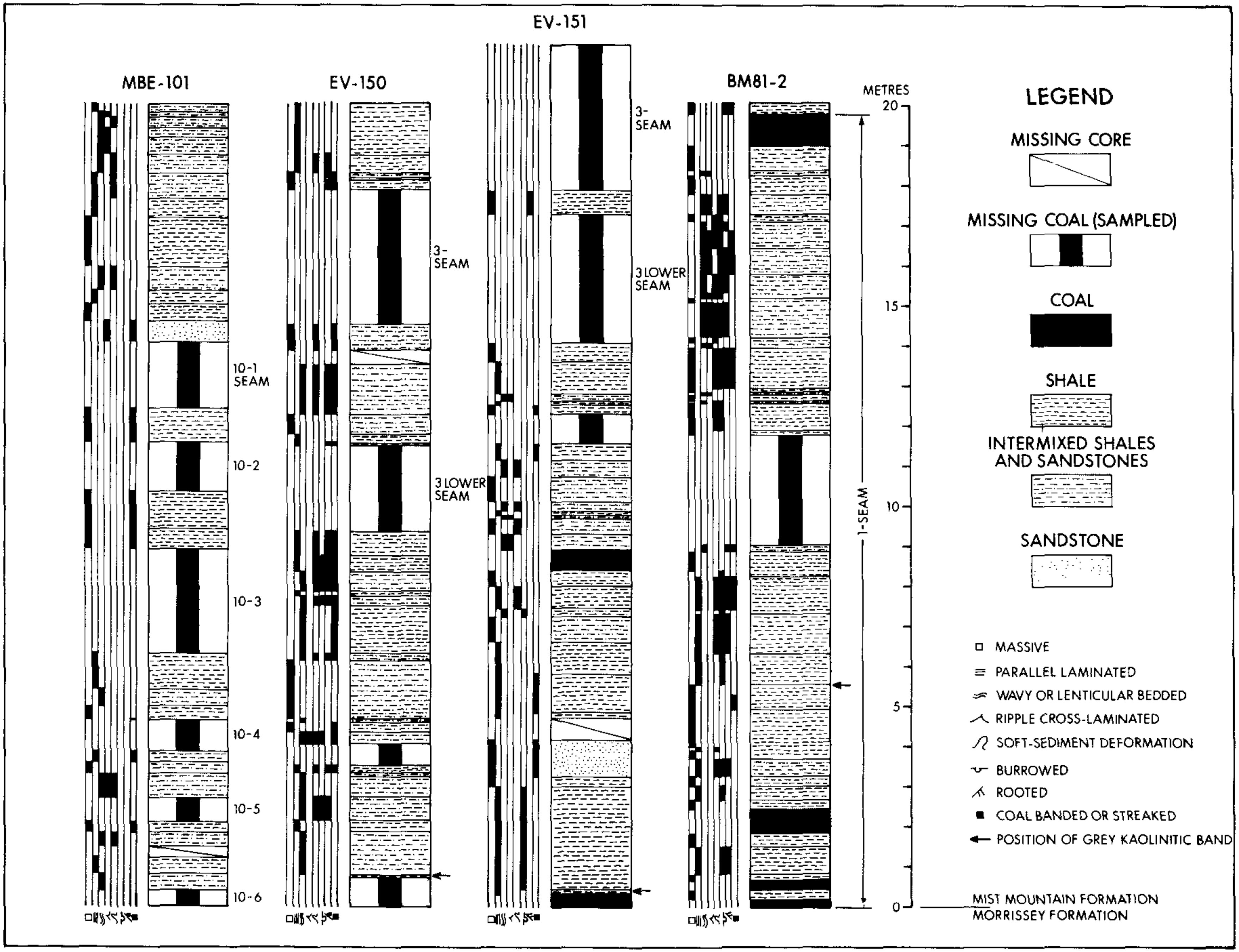


Figure 1-3. Detailed drill core logs of the basal coal zone from Mount Banner, Ewin Creek, and Bare Mountain.

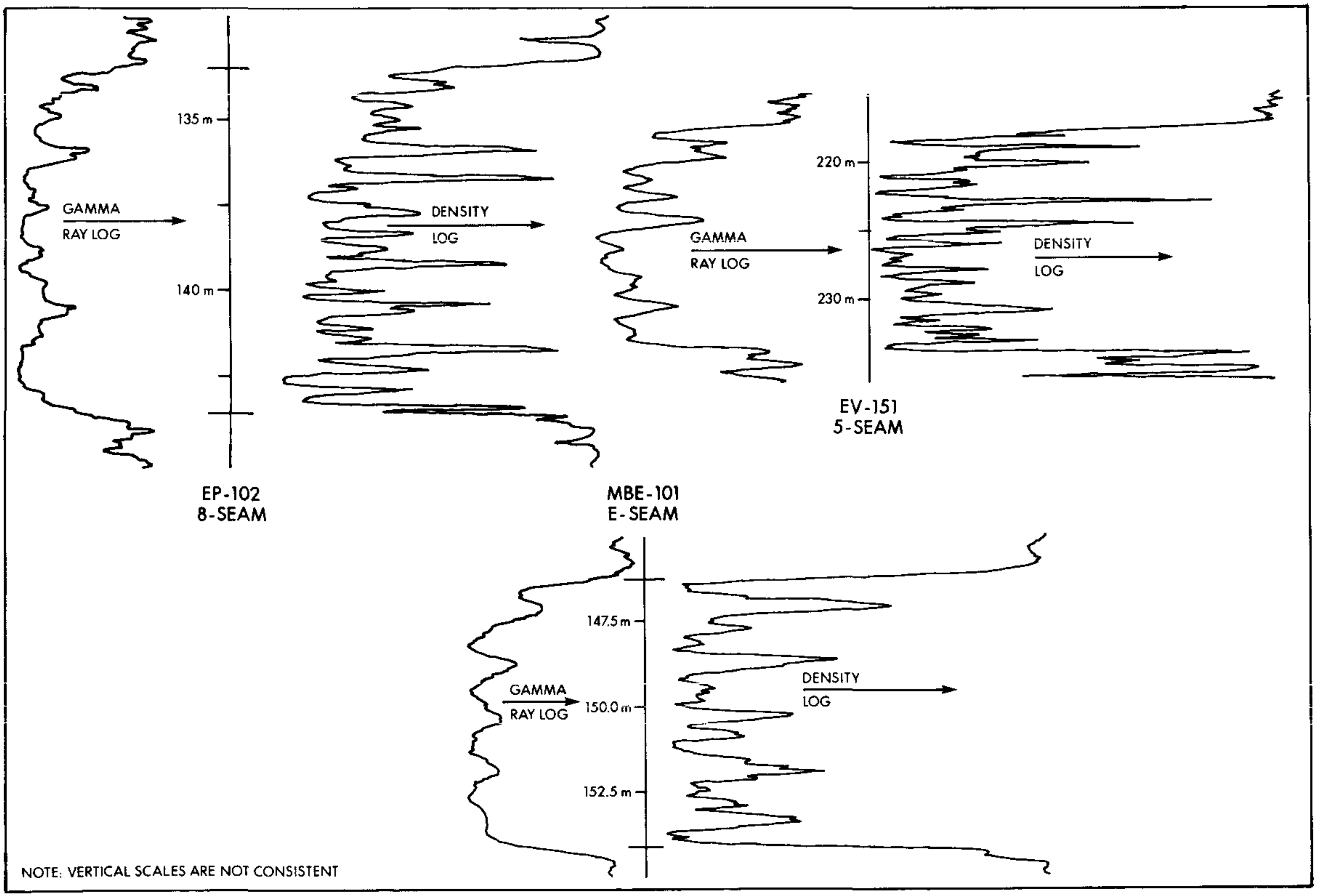


Figure 1-4. Gamma ray and density logs of the Ewin Pass 8-seam, Mount Banner E-seam, and Ewin Creek 5-seam (proposed Imperial seam).

Mist Mountain Formation strata contained in this core are also found in EV-151. However, it serves as a useful basis for comparison of equivalent horizons. For example, 3 and 3 lower-seams are separated by 3 metres of strata in EV-150, compared with 60 centimetres in EV-151.

CORRELATABLE HORIZONS

BASAL COAL ZONE

The Morrissey-Mist Mountain contact is one of only two readily identifiable stratigraphic horizons in the southeast coalfield (the other is the Kootenay Group-Cadomin Formation contact) and, because it marks the base of coal occurrences, it is an extremely important one. The correlation of the coal zone which normally occupies the basal portion of the Mist Mountain Formation in southeastern British Columbia (Gibson, 1985) is therefore self-evident. Economically this zone is extremely important as it accounts for several of the important producing seams in southeastern British Columbia.

Four of the seven cores logged in this study contain the basal coal zone. Large-scale plots of the basal 20 metres of these cores are shown on Figure 1-3. The 20-metre cutoff was chosen arbitrarily, but in all cases this interval contains most of the coal which can reasonably be assigned to the basal zone. The section of EV-151 has been extended slightly to include the top of 3-seam.

A few generalizations about Figure 1-3 can be made. Each section contains four to six separate seams. If 3 and 3 lower-seams in EV-151 are combined, then the thickest individual seam is 7.4 metres thick, with a 60-centimetre shale parting. The remainder of the seams range from 20 centimetres to 3 metres in thickness. In all cases a thin, 20 to 70 centimetres, seam rests directly on the Morrissey Formation sandstone. Direct correspondence of other individual seams between different areas is not obvious.

Interbedded strata within the basal coal zone are mainly shales and shale-dominant varieties of ISAS units. They are massive to well laminated and may be rooted, burrowed, and/or distorted. Coal banding and coal spar are also very common features, especially in proximity to coal seams. One thin carbonaceous sandstone occurs in EV-151 and MBE-101. The strata immediately overlying the basal coal zone are also fine grained and are not distinguishable from clastic rocks within the zone.

Kaolinite-rich grey clay bands at equivalent positions in EV-150 and EV-151 are clearly correlatable (Fig. 1-3). Correlation with a similar band in BM81-2 is possible, as the upper surface of the Morrissey Formation is known to have local relief of several metres.

The depositional environment of the basal coal zone has been described as an interdeltaic coastal marsh and swamp within the lower coastal plain. Initial sedimentation occurred directly on the beach ridge-dune facies of the upper Morrissey Formation (Gibson, 1985).

The basal coal zone described here correlates with the lower part of unit I on Fording Coal Ltd.'s Eagle Mountain property, north of the study area (Donald, 1984). At that locality all the coal within unit I, comprising Fording Coal Ltd.'s 1, 2, and 3-seams, appears to lie well within the basal 20 metres of section and 1-seam rests directly on the Morrissey Formation. Coals of unit I are too thin to form mineable reserves in the current operations area.

At Line Creek mine, on the other hand, the basal coal zone contains 10A and 10B-seams, with the former resting directly on the Morrissey Formation. These seams figure prominently in Crows Nest Resources Ltd.'s current production.

IMPERIAL SEAM

The name Imperial seam was applied to the thickest seam on Imperial Ridge in the Ewin Creek property north of Ewin Creek (Grieve and Fraser, 1985, section A-B). On the ridge summit it attains a thickness of 10.5 metres with very little interbanded shale. It has been traced northward with some confidence in the field from Ewin Creek to Bare Mountain, a strike distance of 5.9 kilometres (Grieve and Fraser, 1985, sheets 8 and 9).

This seam is 5-seam, on the Westar Mining Ltd.'s property, and it was intersected in both EV-150 and EV-151 (Fig. 1-2). The true thickness of the Imperial seam in these holes is 15 metres. According to Huryn (1982) the bottom 12 to 13 metres of this seam contains very little interbanded shale. The roof and floor rocks in EV-151 are black coal-streaked and banded shales, while in EV-150 they are black, coal-banded, laminated shales.

In moving to the south, the Imperial seam is tentatively correlated with E-seam in core MBE-101 (Fig. 1-2). This correlation is based on three lines of evidence:

(1) Relative thickness and position of E-seam with respect to overall stratigraphy.

(2) Similarity of roof and floor lithologies to those in the EV cores.

(3) Similarity of geophysical logs to the EV drill holes (Fig. 1-4).

E-seam in MBE-101 is 7.4 metres in thickness and contains very little interbanded shale. As was the case in the EV cores, the seam here is about 130 metres stratigraphically above the base of the Mist Mountain Formation and between the two most prominent channel sandstone-bearing horizons (Fig. 1-2). Roof and floor rocks are massive, coal-banded, black to dark grey shales.

Moving further southward, the Imperial seam is tentatively correlated with 8-seam in core EP-102. The latter seam is 150 metres above the base of the Mist Mountain Formation and is the first major seam above the most significant concentration of channel sandstone units in the section. The seam is 10.3 metres thick and contains 50 centimetres of shale in 5 interbands (Beavan, 1981). Roof and floor rocks are laminated, black, coal-banded shales. The geophysical response of this seam is similar to that of E-seam in MBE-101 (Fig. 1-4).

Existence of the Imperial seam in the BM81 cores to the north has not been established as the logs have not yet been plotted. Given the proximity of these holes to the most northerly mapped outcrop occurrence of the seam, it is expected to be present.

In any event, the proposed correlation of the Imperial seam extends roughly 13.5 kilometres from EP-102 in the south to Bare Mountain in the north. Field mapping of the Ewin Pass 8-seam has already established its continuity between Mount Banner and Ewin Pass and also through the Mount Michael property to the south (Grieve and Fraser, 1985, sheets 5, 6, and 7). Addition of the Mount Michael property extends the proposed correlated extent of the Imperial seam 3 kilometres southward. Even more significantly, if Crows Nest Resources Ltd.'s correlation of 8-seam at Ewin Pass with 8-seam in Line Creek mine is correct then the Imperial seam may account for the major part of reserves and production at the Line Creek mine. If this is the case the name '8-seam' would be preferable to 'Imperial seam' throughout the study area.

DISCUSSION

Preliminary assessment of data has identified two coal zones which can be correlated between Bare Mountain in the north and the Ewin Pass area in the south. In the case of the basal coal zone the correlation is not helpful because the Mist Mountain-Morrissey Formations contact is very easily mapped and also readily identified in core and geophysical logs.

Correlation of the Imperial seam is based on its relative stratigraphic position, its thickness and lack of significant shale interbands, the nature of its roof and floor rocks, the nature of its geophysical response, and the results of geological mapping. None of these criteria, in themselves, are diagnostic, but in combination they offer reasonable precision; in combination with proximate analysis results, they are the ones used by industry to correlate coal seams within individual properties and occasionally between different properties. We have not applied proximate analysis in this case, because of known regional rank variations along strike in the Elk Valley Coalfield (Grieve and Pearson, 1985; Grieve and Fraser, 1985). Between Ewin Pass and Mount Banner, for example, the reflectance of the basal coal zone increases from less than 1.3 per cent to greater than 1.5 per cent ($\bar{R}_o$ max), an increase which will have a significant effect on volatile matter yields and other properties. The possibility of this sort of change should always be taken into consideration.

The grey kaolinitic band in the basal coal zone in cores EV-150, EV-151, and BM81-2 may represent a continuous horizon. In any event, its impact as a correlation tool is severely limited by its position within the only readily correlatable horizon in southeast coalfields.

The tonstein near the top of core BM81-1 occurs in the upper Mist Mountain Formation and is stratigraphically higher than strata contained in other cores in this study. One of the authors (D. A. Grieve) has previously sampled a kaolinitic band from a coal outcrop at a similar stratigraphic position on the Burnt Ridge Extension property and Gibson (1985, p. 26) notes the occurrence of a tonstein in a coal seam in the uppermost Mist Mountain Formation on the Greenhills Range. In general, however, this study has not furthered attempts to correlate strata in southeastern British Columbia using tonsteins.

CONCLUSIONS

Seven drill cores from the east limb of the Alexander Creek syncline in the Elk Valley Coalfield were logged in detail. The Mist Mountain Formation contained in these cores consists of an interbedded series of intermixed shale and sandstone (ISAS) units, shale, sandstone, coal, and minor conglomerate. They encompass a range of non-marine sedimentary environments, with the coarse clastics probably representing fluvial point-bar and channel deposits, ISAS units representing low-energy portions of point bars and splay deposits, and fine-grained units representing floodplain deposits. Coal seams, which were deposited in marsh and swamp conditions, had been largely removed from the core. Conspicuous potential marker bands were generally absent, although kaolinitic bands, probably tonsteins, were found at similar stratigraphic positions in three of the cores. The position of these bands, all within 6 metres of the base of the Mist Mountain Formation, limits their usefulness, because the basal Mist Mountain Formation is a readily identified unit.

The basal Mist Mountain Formation or basal coal zone is a 20-metre-thick interval containing four to six coal seams that range from 20 centimetres to 7.4 metres in thickness; one rests directly on the Morrissey Formation sandstone.

Coal seam 5 on Westar Mining Ltd.'s Ewin Creek property has been tentatively correlated with E-seam on Crows Nest Resources Ltd.'s Mount Banner property and with 8-seam on Crows Nest Resources Ltd.'s Ewin Pass property. The term 'Imperial seam' is applied to this correlated unit because the unit corresponds with the Imperial seam mapped by one of us (D. A. Grieve) on Imperial Ridge and Bare Mountain (Grieve and Fraser, 1985). However, the term '8-seam' may be preferred if correlation by Crows Nest Resources Ltd.'s staff of Ewin Pass 8-seam with Line Creek 8-seam is correct. The latter seam is currently a major product from the Line Creek mine.

Further analysis of results will be carried out to attempt further correlations and comparisons of strata in the Elk Valley Coalfield.

ACKNOWLEDGMENTS

We wish to thank L. Samuelson of Westar Mining Ltd. and T. Hannah and P. Gilmar of Crows Nest Resources Ltd. for permitting and arranging access to their company's core.

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FLATHEAD RIDGE COAL AREA SOUTHERN DOMINION COAL BLOCK (PARCEL 82) SOUTHERN BRITISH COLUMIBA*
(82G/7)

By D. A. Grieve and W. E. Kilby

INTRODUCTION

The Dominion Coal Block consists of two parcels of federally owned land, totalling 20 235 hectares in area, in the Crowsnest Coalfield of southeastern British Columbia (*see* Grieve and Kilby, 1985). Parcel 82 is the more southerly of the two, and at 18 211.5 hectares (45,000 acres) it is by far the larger (Fig. 2-1).

The coal-bearing Kootenay Group crops out on two major areas of Parcel 82: along Flathead Ridge in the southwest and in the Mount Taylor area in the northeast; it lies at depth beneath the intervening portion. The subject of this study is the Flathead Ridge portion of the parcel, which is bounded on the northwest by Morrissey Creek (Fig. 2-1).

Flathead Ridge runs in a general northwest-southeast direction at an elevation of 1 980 to 2 225 metres. It has a steep scarp face on its southwestern flank (up to 70 per cent grade) and a relatively gentle slope on its northeastern flank. Minimum elevation in the study area is 1 070 metres along Morrissey Creek. The only readily accessible part of the study area is Morrissey Creek, which is connected to Highway 3 by approximately 5 kilometres of good-quality second-

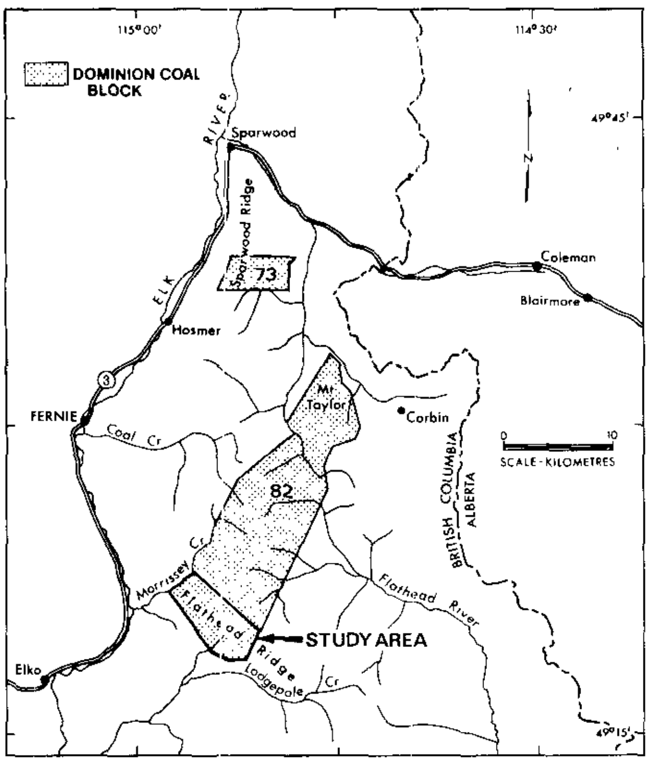

Figure 2-1. The Crowsnest Coalfield area, showing locations of Parcels 73 and 82 of the Dominion Coal Blocks.

ary road. Difficult four-wheel drive access to the top of Flathead Ridge is available on the natural gas pipeline access road, which connects with the Lodgepole forestry road.

OBJECTIVES OF PRESENT STUDY

The objectives of the current study are: to construct a digital deposit model of the Flathead Ridge to allow resource calculations of A- and B-seam coal utilizing existing data supplemented by minor fieldwork; and to summarize available exploration and production history, stratigraphy, structure, and coal quality information.

We have chosen to concentrate on these upper seams because exploration carried out in the study area focused on this stratigraphic interval and provides adequate information for a reasonable analysis. Also, the structure of the lower seams is more complicated and not well explored.

PREVIOUS WORK

Crow's Nest Pass Coal Company operated the Morrissey Colliery immediately north of Morrissey Creek, outside of Parcel 82, between 1902 and 1909. This was the shortest lived of the three collieries developed by the company at the turn of the century. The reasons for its early demise were hazardous mining conditions and poor coking properties of the coal due to its high rank.

There is no evidence of major exploration activity south of Morrissey Creek prior to 1964. At that time the British Columbia-based Pacific Coal Limited (P.C.L.) acquired coal rights to the Flathead Ridge portion of Parcel 82, naming their property the Fernie Coal Mine. The company was funded by Japanese interests; their objective was to prove up reserves of low-volatile coking coal for the Japanese steel industry. The first year of exploration, supervised by consultant D. D. Campbell, was focused on the Morrissey valley. Ten diamond-drill holes, totalling approximately 1 675 metres, were drilled. This program continued into 1965 with the completion of two more holes (300 metres). This information is not on file with the Provincial Government. Further work in 1965 was carried out by Nittetsu Mining Consultants Co., Ltd. Adits were driven for bulk samples in two of the lower seams (K1 and K5) along Morrissey Creek, and surface mapping was carried out along Flathead Ridge. A preliminary feasibility study was completed at this time. Exploration work in 1966 and 1967 was concentrated on A- and B-seams. By this time P.C.L. had acquired coal rights to a 7 458-hectare area, and the scale of exploration increased considerably. Work was performed by Nittetsu Mining Co., Ltd. and Toyo Menka Kaisha, Ltd. Seven drill holes were cored for a total of 1 599 metres, nine adits in A- and B-seams were driven and sampled, and more than 29 kilometres of new road was built; most roads were along the traces of A- and B-seams. Detailed mapping, supplemented by trenching, was carried out over the entire property. Drill core and bulk samples were provided to several Japanese steel concerns for testing of washability and coking potential.

The general conclusions of this assessment work were that B-seam throughout the property and A-seam locally are superior

* This project is a contribution to the Canada/British Columbia Mineral Development Agreement.

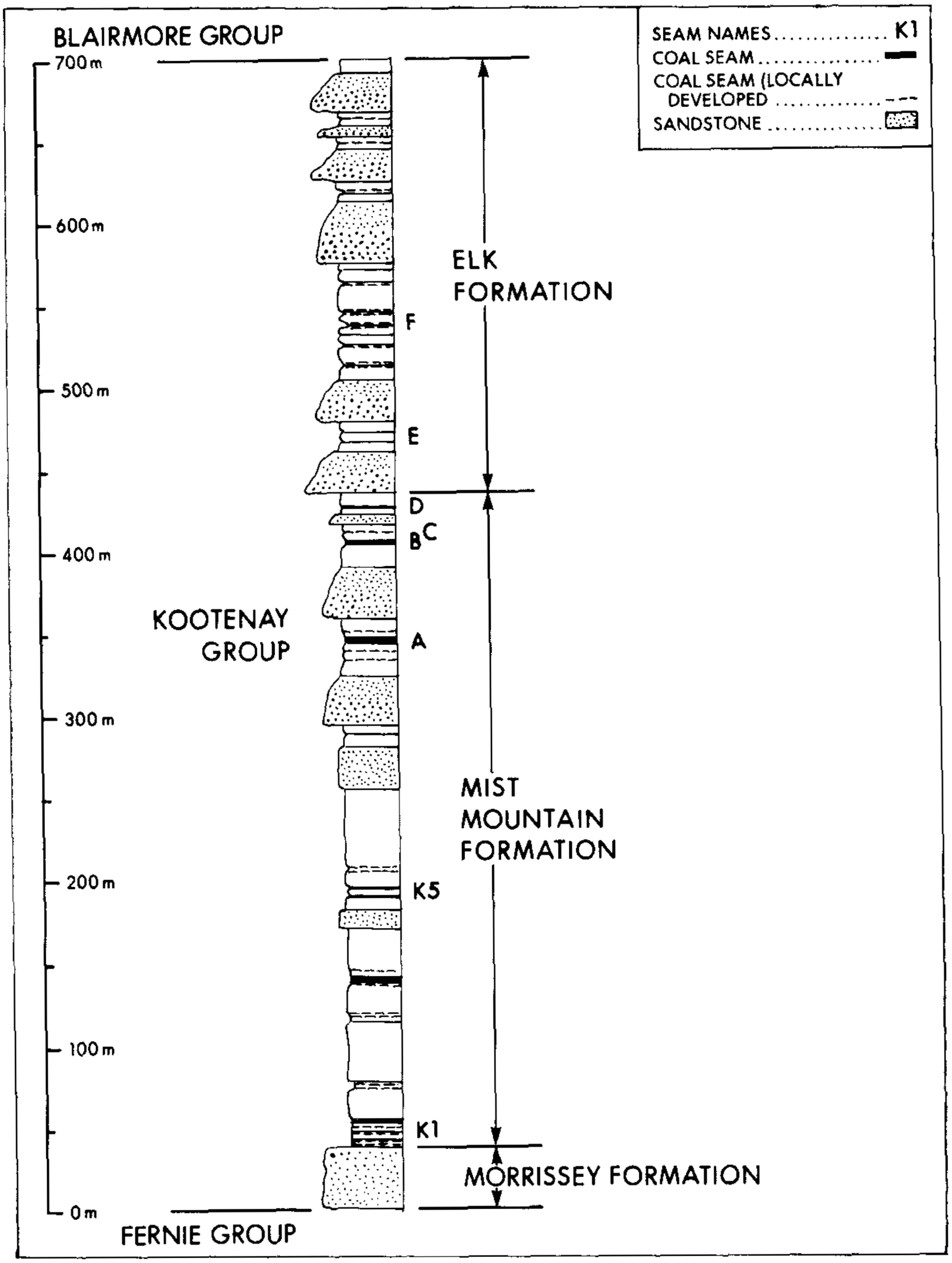

Figure 2-2. Generalized composite stratigraphy of the Kootenay Group in the study area (modified after Aihara, 1970).

coking coals, and that they are present in significant quantities. A 1968 feasibility study by Nittetsu for P.C.L. reiterated that the coal was economically mineable and equal to other western Canadian coking coals contracted to Japan at the time. In 1968 or 1969, however, Nittetsu withdrew from the project and Mitsui Mining Co., Ltd. obtained permission from P.C.L. to further evaluate the property. In 1969 they carried out a geological survey, aided by trenching. A few differences in structural interpretation and seam correlation were noted. Further exploration was proposed but never carried out. In 1971-1972 the Provincial Government, at the request of the Federal Government, revoked the coal rights.

Results of the exploration projects carried out between 1965 and 1969 are contained in the following reports: Nakayama, *et al.* (1966), Harada, *et al.* (1967, 1968), and Aihara (1970). Results of the 1968 feasibility study are contained in Shiokawa (1968). All are on file with the Geological Branch of the British Columbia Ministry of Energy, Mines and Petroleum Resources. Individual reports will not be specifically referenced in the following discussions.

Two government surveys of the study area were carried out in the late 1970's. Between 1977 and 1980 N. C. Ollerenshaw of the Geological Survey of Canada mapped all of Parcel 82 at 1:50 000 scale (*see* Ollerenshaw, 1981b). D. E. Pearson and D. A. Grieve of the British Columbia Ministry of Energy, Mines and Petroleum Resources mapped Flathead Ridge in 1978 at 1:10 000 scale, concentrating on the surface traces of coal seams (*see* Pearson and Grieve, 1981, Sheets 3 and 4). In conjunction with this mapping, coal samples were collected for petrographic analysis.

STRATIGRAPHY

Flathead Ridge is underlain by a sequence of sedimentary rocks belonging to the Jurassic Fernie Group, Jurassic-Cretaceous Kootenay Group, and Lower Cretaceous Blairmore Group. Marine shales of the Fernie Group are in gradational contact with the overlying littoral Morrissey Formation, basal sandstone of the Kootenay Group. Morrissey Formation is abruptly overlain by the non-marine coal-bearing Mist Mountain Formation, host to economic coal seams in southeast British Columbia. This in turn is gradationally overlain by the Elk Formation, a non-marine unit which contains thin coal seams and a higher proportion of channel sandstones and conglomerates than the underlying Mist Mountain (Fig. 2-2). The Elk is overlain by the non-marine Cadomin Formation, basal unit of the Blairmore Group. The Cadomin Formation in the study area consists of a series of conglomerates separated by maroon and greenish mudstones (Ollerenshaw, 1981a). It is overlain by greenish and maroon mudstones interbedded with sandstone and conglomerate of the Lower Blairmore.

There are two readily identified marker horizons within the study area. One is the Morrissey Formation, whose outcrops form a relatively consistent bluff; the Morrissey marks the lower limit for coal occurrences (Fig. 2-2). The other is the Cadomin Formation, which delineates the top of the Kootenay Group. The contact between the Mist Mountain and Elk Formations, which probably represents the transition from a meander plain to a braid plain environment (Gibson, 1985), is usually defined as the lowest channel deposit above the highest economic coal seam in the Mist Mountain Formation. This horizon can be mapped with some certainty throughout the study area.

The Mist Mountain Formation is approximately 400 metres thick in the study area and on average it contains 10 coal seams. Seams were numbered upward from K1 to K5, and then A, B, and so on (Fig. 2-2). Initial quality results on seams K1 and K5 from Morrissey Creek revealed that the rank of these seams was too high to be attractive. This led the company to focus on two more promising seams, A and B, in the upper half of the Mist Mountain Formation (Fig. 2-2). A-seam underlies B-seam by 25 to 45 metres. In outcrop it ranges from 3.5 to greater than 15 metres total thickness at the northwestern end of the ridge (No. 3 to No. 8-9 ridges); it is from 2.6 to 7.7 metres thick at the southeastern end (TA-2 to Ridge No. 21; *see* Fig. 2-3 for location references). Between it is less than 1.6 metres thick with numerous partings. In drill core thicknesses range from 2.68 (J-6) to 17.77 metres (J-3). Lower splits of A-seam exist in the area southeast of Ridge No. 17. The upper of these (A1) ranges from 2.34 to 3.05 metres in thickness, while the lower (A2) ranges from 1.82 to 3.36 metres; both appear to be increasing in thickness to the southeast. Thickness of A-seam coal ranges from 60 to 100 per cent of total seam thickness, but is generally greater than 90 per cent, omitting the central area mentioned previously. The AL-seam is located just below the A-seam in the northwest portion of the area. AL-seam thickness ranges from 2.0 to 6.0 metres.

B-seam thickness ranges in outcrop from 1.73 to 5.86 metres and in drill core from 3.64 metres (J-2) to 7.32 metres (J-3). An upper split, named BU-seam, outcrops on Ridge No. 11 and extends southeastward; it ranges from 1.25 to 2.51 metres in thickness. Thickness of B-seam coal is generally greater than 80 per cent but ranges from less than 60 to 100 per cent of the total seam thickness.

Both A-seam and B-seam are characterized by rapid thickness changes and variations in the numbers and thicknesses of partings.

Seam K1 (basal seam) ranges from 3.06 metres in thickness at the pipeline, to greater than 15 metres in Morrissey Creek. Seam K5 has a thickness of greater than 5 metres in Morrissey Creek area, but unfortunately the company was not successful during exploration in correlating this or other lower seams with seams along the ridge. Thicknesses of other coal seams were measured only locally, but available data suggests that in the vicinity of the pipeline and the pipeline road (Ridge Nos. 16 to 20), the section between seams K1 and A contains three coal seams which are greater than 1 metre in thickness. The thickest of these, which apparently lies within 20 metres stratigraphically of the top of the K1 seam, is reported to be 6.52 metres thick on Ridge No. 20, and includes a 3.47-metre section of coal without partings at the top. Pearson and Grieve (1981, section L-M) also report a 5.1-metre seam about 115 metres above the base of the Mist Mountain Formation on Ridge No. 16. Coal seams stratigraphically higher than B-seam are thin, although again data are sparse. Pearson and Grieve (1981, section L-M) found three closely spaced seams with a combined total thickness of 5.8 metres near the top of the section on the pipeline (Ridge No. 16). The equivalent (?) horizon on Ridge No. 3 contains a 3.27-metre seam with 2.68 metres of coal.

The Nittetsu reports concluded that seam K1 probably sustains thickness adequate for mining throughout Flathead Ridge; they speculated that two or three other seams are thick enough for mining, at least locally.

STRUCTURE

Flathead Ridge is in the southwestern part of the Crowsnest Coalfield. The Fernie Basin, the coalfield's fundamental structure is a complex synclinorium in the Front Ranges of the Rocky Mountains. Strata on Flathead Ridge lie in the west limb of the McEvoy syncline, a doubly plunging fold at the middle of the south end of the Fernie Basin.

Ollerenshaw (1981b) notes a regional décollement or 'preferred detachment interval' within the Mist Mountain Formation. The strata below this interval are affected by 'tight, low amplitude folds of relatively short wavelength, cut by numerous thrust faults,' while those above are characterized by 'broader, gentle folds of low amplitude and relatively long wavelength cut by fewer thrust faults but numerous normal faults' (Ollerenshaw, 1981b, p. 147). Within the study area this décollement occurs below A-seam and was identified as the Flathead Ridge normal fault by Pearson and Grieve (1981, Sheet 3) and the Morrissey Retrothrust by Ollerenshaw

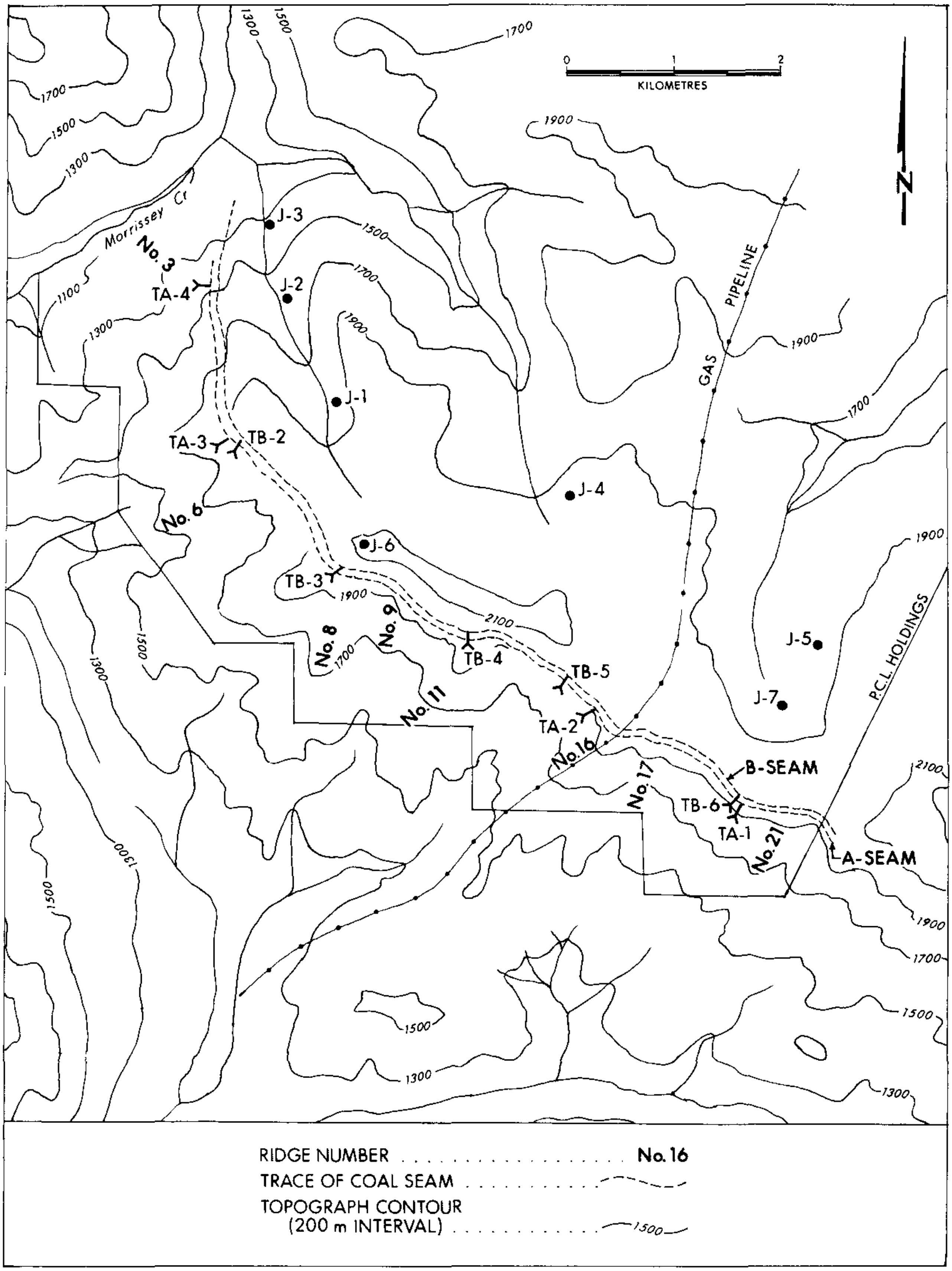

Figure 2-3. Flathead Ridge area, showing traces of A and B-seams, 1966-1967 drill hole locations, adit sites, ridge numbers, and southeastern boundary of P.C.L. holdings (after Aihara, 1970).

TABLE 2-1
COMBINED RESULTS OF FLOAT-SINK TESTS (B-SEAM)*
(Source: Mitsui Report)

Raw Coal Ash (%)	23.2	23.2	23.2
Clean Coal Ash (%)	7.0	8.0	9.0
S.G. (g/cc)	1.53	1.60	1.68
Calculated Yield (%)	70.0	75.0	77.0
Revised Yield** (%)	65.0	70.0	72.0

* based on samples TB-2, TB-3, TB-4, and TB-6
** allowing 5% dilution during mining

(1981b). Both studies cited traced the fault from Morrissey Creek southeastward along the face of Flathead Ridge to a point roughly halfway between the creek and the southeastern boundary of Parcel 82 (Fig. 2-3). Ollerenshaw (p. 151) speculated that the fault continues through to the boundary, but is hidden in bedding of the Mist Mountain Formation. Pearson and Grieve concluded that the fault changes orientation suddenly, cuts rapidly up section, and affects the continuity of A- and B-seams; in the present study no field evidence was found to support this interpretation and the interpretation of Ollerenshaw has been adopted. Disturbances in strata in the vicinity of A- and B-seams are considered to be local in extent.

The structure of the upper Mist Mountain Formation and higher strata on Flathead Ridge is monoclinal. On the southwest face of the ridge average strike of strata is 130 degrees with dips of 20 degrees northwest. In the area behind (northeast of) the ridge line, the strike is the same but the dip flattens to 10 degrees northwest. Minor structures include predominantly small-scale, low displacement northeast-dipping thrust and normal faults.

In contrast, strata beneath the Morrissey fault are intensely folded; fold-axes trending northeast-southwest, and the strata are also affected by northeast-dipping thrust faults.

COAL QUALITY

Extensive tests of Flathead Ridge coal were carried out by up to six prospective purchasers in Japan. Results are summarized in following text.

WASHABILITY

Float-sink tests of bulk samples were performed in conjunction with both the Nittetsu and Mitsui studies. Data in Table 2-1 are summarized from the latter source, and deal with B-seam only. Results from samples TB-2, 3, 4, and 6 were combined. Yields were calculated on the assumption that the plus 0.5-millimetre fraction would be washed with heavy medium cyclones and the minus 0.5-millimetre fraction by froth flotation. As Table 2-1 shows, yields of 70.0, 75.0, and 77.0 per cent are calculated based on clean coal ash contents of 7.0, 8.0, and 9.0 per cent respectively. Allowing 5 per cent dilution during mining, the yields reduce to 65.0, 70.0, and 72.0 per cent respectively.

STEEL MILL TESTS

Six Japanese steel mills were provided with cleaned bulk samples for testing; the results recorded in the Nittetsu reports were later reproduced in the Mitsui report. Summaries for A- and B-seam samples are displayed in Tables 2-2 and 2-3.

Clean B-seam has average volatile matter contents ranging from 23.3 to 19.2 per cent, decreasing from southeast (TB-6) to northwest (TB-2). Lowest Free Swelling Index (FSI) values (6.5 to 7.5) are associated with TB-2, while other sites tend to be in the 8.0 range. Lowest average fluidity also occurs at TB-2 (48 dial divisions per minute) with the highest being at TB-4 (708 ddpm). Sulphur values are in the 0.5 per cent range, and heating values are near 33.5 MJ/kg. Drum index values are all above 92 per cent. The Nittetsu report concludes that B-seam is a superior coking coal.

Clean A-seam has average volatile matter contents ranging from 21.2 to 17.5 per cent, decreasing from southeast (TA-1) to northwest (TA-4). FSI at 3 to 4.5 and fluidity values are low at TA-3 and TA-4 relative to TA-1, where FSI is 6 to 7.5. Sulphur and calorific values are very similar to those of B-seam. Drum index values are low at TA-3 and TA-4, but are equivalent to B-seam at TA-1. The conclusion was drawn that superior quality coking coal could be found in the southeast end of the ridge, but that coal at the northwest end is semi-coking coal. Unfortunately TA-2 results were not reported. It was suggested that A-seam from the northwest might be blended with B-seam from the central or southeast part of the ridge to increase reserves of acceptable quality coking coal.

Two other seams, K1 and K5, were bulk sampled at Morrissey Creek. Clean coal volatile matter content of K1 averaged 14.4 per cent at 8.5 per cent ash, while those of K5 averaged 16.1 per cent at 8.8 per cent ash. FSI values of K1 ranged from 3 to 4, while those of K5 ranged from 3.5 to 5. Heating values of K1 averaged 32.85 MJ/kg, and those of K5, 32.64 MJ/kg. Average drum indices of 54.2 and 84.6 per cent respectively were obtained. This material appears to be potential semi-coking coal at best; it might be better described as thermal coal, especially in the case of K1.

RANK DISTRIBUTION

The Japanese survey reports conclude that the tendency of clean coal volatile matter contents and related coking properties to decrease from southeast to northwest (toward Morrissey Creek) in all seams represents a definite trend in carbonization. This trend, or

TABLE 2-2
SUMMARY OF TEST RESULTS AT JAPANESE STEEL MILLS (A-SEAM)*

Sample	Moist %	Ash %	Volatile Matter %	Fixed Carbon %	S %	Kcal/kg	FSI	Drum Index (+15mm)	Fluidity (ddpm)
TA-1	1.3 (avg)	4 5	21.2	73.0	0.41	8 178	6-7.5	91.9	47
	1.0-1.5 (range)	4.15-4.8	20.75-21.8	72.0-73.6	0.38-0.42	8 060-8 322		89.9-94.4	1.95-225
TA-3	1.1	6.5	20.0	72.8	0.28	8 017	3.5-4	58.0	6
	0.8-1.4	6.4-6.6	19.5-20.9	71.3-73.9	0.27-0.29	7 900-8 230		50.0-63.9	2.4-9
TA-4	1.2	6.6	17.4	74.8	0.45	7 965	3-4.5	49.1	11
Upper	0.8-1.4	6.4-6.8	17.2-17.7	74.4-75.0	0.41-0.50	7 930-7 990		36.0-70.2	1.48-20
TA-4	1.2	5.8	17.5	75.6	0.36	8 027	3-4.5	44.2	4
Lower	0.8-1.4	5.1-6.3	17.4-17.6	74.9-76.7	0.34-0.40	8 010-8 050		(only value)	1.6-7

* washed coal

TABLE 2-3
SUMMARY OF TEST RESULTS AT JAPANESE STEEL MILLS (B-SEAM)*

Sample	Moist %	Ash %	Volatile Matter %	Fixed Carbon %	S %	Kcal/kg	FSI	Drum Index (+15mm)	Fluidity (ddpm)
TB-6	1.8 (avg)	6.8	23.3	68.4	0.48	7 985	7.5-8.5	93.9	186
	1.7-1.9 (range)	6.7-7.2	22.3-24.06	67.8-69.21	0.44-0.56	7 900-8 070		93.0-95.4	66-412
TB-5	1.3	6.3	21.0	71.8	0.50	8 070	8-9	94.0	336
	1.2-1.17	6.1-6.73	20.1-21.71	71.3-72.1	0.48-0.53	7 990-8 140		93.5-94.8	206-758
TB-4	1.3	6.8	21.9	70.3	0.40	8 013	8-9	94.3	708
	1.1-1.5	6.6-6.9	21.3-22.8	70.0-70.5	0.38-0.42	7 930-8 080		93.3-94.9	390-1235
TB-3	1.5	6.2	20.6	72.0	0.50	8 077	7-8	94.0	98
	1.3-1.7	6.0-6.4	20.2-20.91	71.6-72.74	0.49-0.52	7 950-8 220		93.4-94.4	52-220
TB-2	1.1	7.0	19.2	72.7	0.57	7 993	6.5-7.5	92.8	48
	0.6-1.4	6.4-7.9	18.4-20.1	71.9-73.2	0.54-0.60	7 890-8 090		91.4-94.7	2.9-113

* washed coal

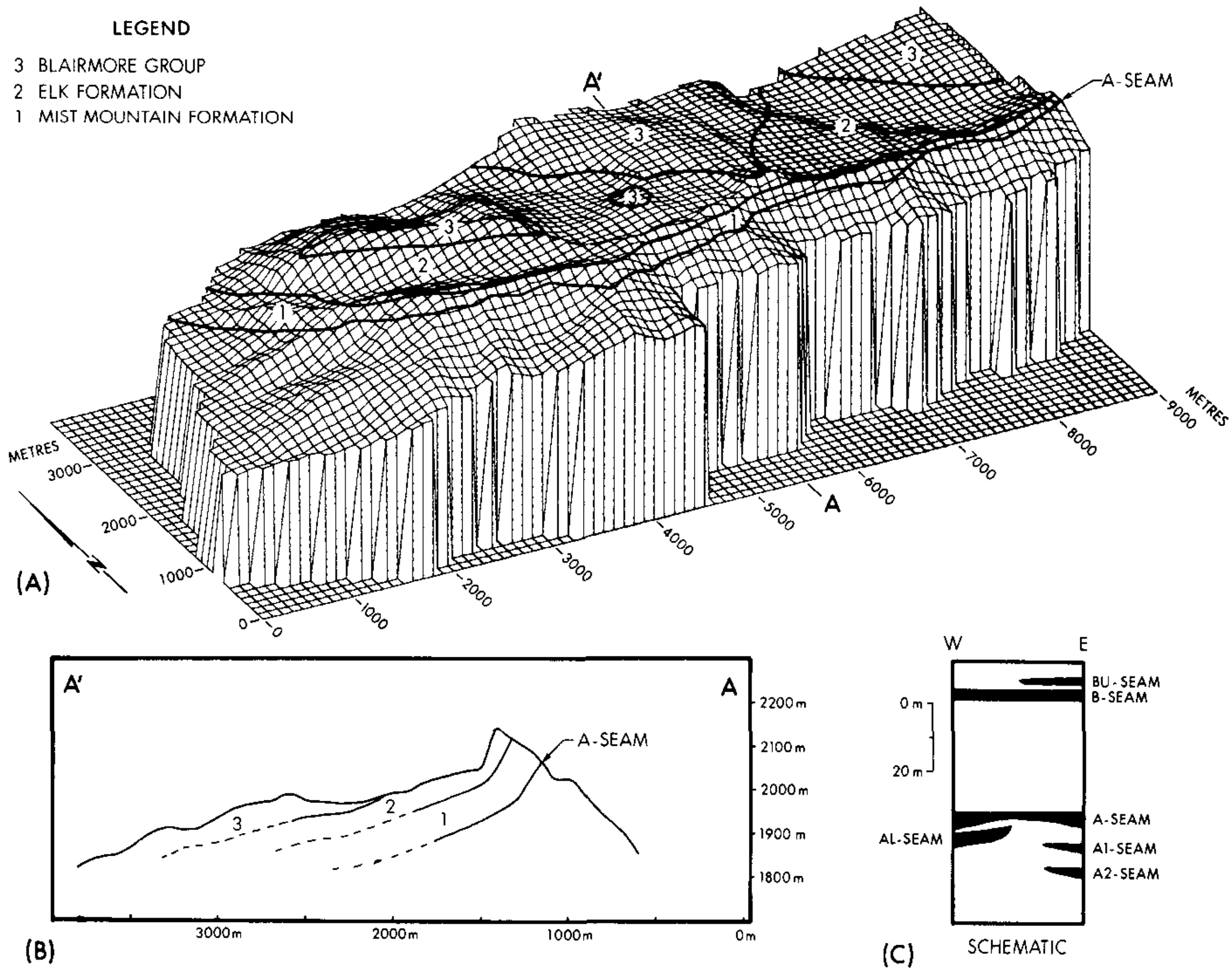

Figure 2-4. (a) Isometric display of model topography with major geological contacts illustrated. (b) Vertical cross-section displaying the shape of the ridge crest; subsurface geology is approximate. (c) Schematic display of seams described by the model.

rank gradient, is corroborated by the work of Pearson and Grieve (1981, 1985). Vitrinite reflectance values from coal samples collected in the field are highest at the north end of Flathead Ridge at Morrissey Creek; they decrease in both directions along strike. Rank values in the Morrissey Creek section are further enhanced by down-dip increases noted in the Crowsnest Coalfield (Pearson and Grieve, 1985). The net result is that essentially the entire Mist Mountain section at the level of Morrissey Creek contains coals of low-volatile bituminous rank ($\bar{R}_o$ max>1.51 per cent). A value of 1.85 per cent was obtained on the basal seam on Ridge No. 3, near the K1 adit. $\bar{R}_o$ max decreases to 1.71 per cent for the same horizon at the base of Ridge No. 6, and to 1.62 per cent in the vicinity of the pipeline. In other words, at least some portion of outcropping Mist Mountain Formation is low-volatile in rank throughout the length of the study area, and with rank values increasing down-dip in all cases.

Reflectance in A- and B-seams ranges from approximately 1.3 per cent at the southeast end of the property, to 1.4 per cent on Ridge No. 6, to greater than 1.5 per cent in the Morrissey Creek valley. Therefore, these seams are predominantly medium-volatile bituminous at their outcrop locations, except at the extreme northwest end of the property where, because the elevation is low, outcrops are down-dip extensions of those along the ridge. The high rank of coal in Morrissey Creek was a major contributing factor to the permanent closure of the Morrissey Colliery in 1909, and is an important factor to consider here. Remember that A-seam is not a good quality coking coal at adits TA-3 or TA-4 (or in drill hole J-3). B-seam appears to maintain its quality as far as adit TB-2 (and drill hole J-1), but unfortunately there are no sample locations north of TB-2, and drill hole J-2 did not intersect B-seam. Results of testing of B-seam in J-3 were not reported.

PROPOSED MINING METHOD

The feasibility report of the Pacific Coal Limited property by Nittetsu Mining Co., Ltd. was submitted at the end of four years of exploration. The underground mining plan envisaged the main mine entrance to be at elevation 1 160 metres on the southeast side of Morrissey Creek, with the main level developed along the strike of the seam. Longwall mining was selected as the most feasible method to exploit the dip of the seams (10 to 20 degrees) and to ensure maximum recovery, ventilation, and productivity. The property is very close to rail; the proposed mine entrance described here, for example, is less than 6 kilometres east of the Canadian Pacific Railway line. Normal annual production rate was projected to be 1 million tonnes. The Mitsui interim report based its revised recoverable reserve calculations on the assumption that room-and-pillar mining would be utilized where possible, that is, where the dip was sufficiently low, presumably in the lowest, most northeast portion of the mine.

COMPUTER DEPOSIT MODEL

The Flathead Ridge area was modelled using the grid surface technique in which each deposit characteristic of interest is represented by a grid of values covering the whole deposit. A variety of techniques were employed to construct the digital surfaces depending upon data characteristics. This section of the paper discusses data collection, grid building, and deposit model analysis. Software utilized in this project were the Data Handler and Grid Handler modules of Cal Data Ltd.'s Geological Analysis Package, which was donated to the Geological Branch.

The first step in the modelling procedure is to select the size of area to be modelled, the resolution, and the orientation of the model grid. In this study a 90 by 39 rectangular grid consisting of 100-metre grid squares was constructed which covers 35 square kilometres (Fig. 2-4). Due to the orientation of the strata (130 degrees), the grid was oriented northwest-southeast, so grid north is actually 41 degrees east of north. A new coordinate system was used during modelling; it was parallel to the model grid with the origin in the southwest corner of the grid. Once the size and shape of the model were selected, the required information was entered into the computer and corresponding surfaces calculated. The objective of this model was to determine coal tonnages and their distribution within the study area. To arrive at these answers the following parameters were entered and/or described by grid surfaces:

(1) topographic position,
(2) seam elevations,
(3) seam thicknesses,
(4) seam areal positions, and
(5) distances from nearest data points to each grid mode.

The following section discusses determination of the grid surfaces for each of these parameters.

Topographic data was collected from an existing 1:5000-scale contour map with 5-metre contour intervals which was provided with the Harada, *et al.* (1968) report. A digitizing tablet connected to an IBM XT was utilized for this function. Data was digitized along lines through the centre of the columns of the model grid; data was recorded wherever a significant (to define all breaks in slope) contour crossed the line. The values at the centres of each of the model grid squares was then determined by linear interpolation between data points along the digitized lines. The advantages of this method are that a high degree of accuracy is obtained for the grid values, and the raw data is retained in a format that is useable if grid square sizes are changed. The disadvantage is that data collection is labour intensive, requiring about 16 hours of digitizing effort in this case. The resultant grid was stored in Grid Handler format.

Seam positioning within the deposit is the most complex problem of most modelling exercises. First the geology of the deposit must be solved, then the configuration of the seams digitially represented and stored.

Data used for this purpose were bedding orientation and seam position in outcrops, boreholes, trenches, and adits. Outcrop orientation data was collected by means of the digitizing tablet with the COD (Coal Outcrop Digitizer) program developed by one of the authors (W. E. Kilby). The resultant information consisted of an outcrop identifier, easting and northing coordinates, elevation, dip direction and dip of strata, formation code, and type of measured feature. This data was then stored in Data Handler format. Borehole, trench, and adit data were collected manually from the various reports. Seam name, position of the seam top, coal thickness, and information source type were recorded for each seam encountered in a trench, adit, or borehole. In addition, the collar and end of hole positions were recorded for boreholes. Six seams were incorporated into this model. Two seams, A and B, are found throughout the entire model area. The other four seams, AL (A lower), BU (B upper), A1, and A2, are of limited extent (Figs. 2-4c and 2-6).

B-seam, the upper of the two continuous seams, was positioned first because it was described by the largest number of well-spaced data points. A down-plunge projection technique was used to arrive at the digital surface describing the position of the top of the B-seam (*see* Gold, *et al.*, 1981). Figure 2-5a is a profile section oriented normal to projection direction, it shows the positions of all B-seam data and the pitch lines of outcrop orientation data. The initial projection orientation was obtained by interpreting outcrop orientation data on a pi-diagram. The projection direction should be parallel to the fold-axis or 90 degrees away from the maximum concentrations of the poles to bedding. After initial selection of the projection direction, minor orientation adjustments were made on a trial and error basis to minimize the scatter of B-seam data points. Upon selection of the best projection orientation, which was 30 degrees trend with 0 degree plunge, the position of the seam was

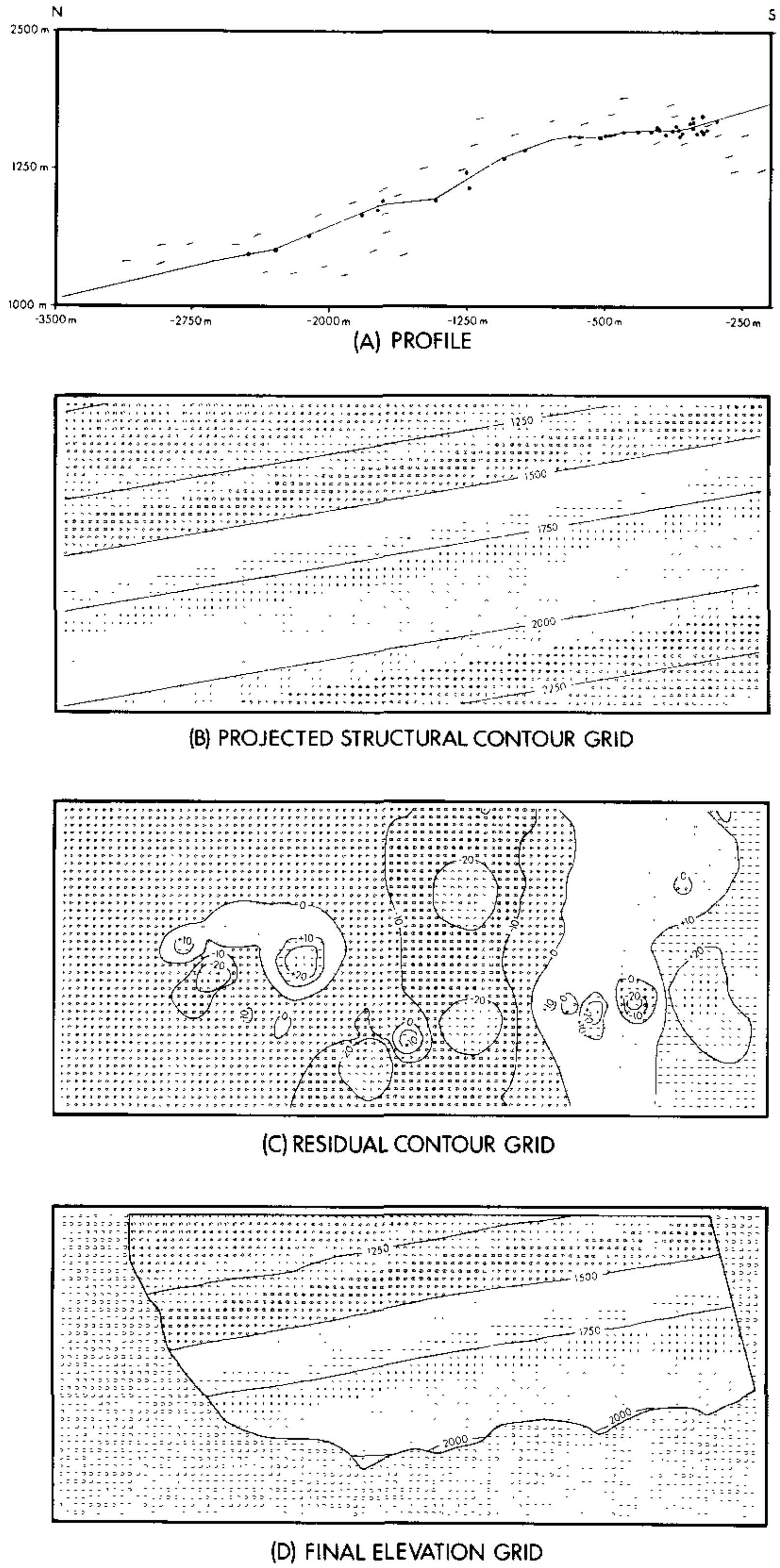

Figure 2-5. (a) Down-plunge projection profile of B-seam data (dots) and selected outcrop orientation data (pitch lines). Interpreted B-seam position also shown. (b) B-seam structural contour grid obtained by projecting interpreted B-seam position line from (a) parallel to the projection direction. (c) Residual grid, obtained by gridding the difference between B-seam positional data and the B-seam structural contour grid. (d) Final B-seam position grid obtained by subtracting the residual grid from the grid displayed in (b). This grid has been trimmed at outcrop and property boundaries.

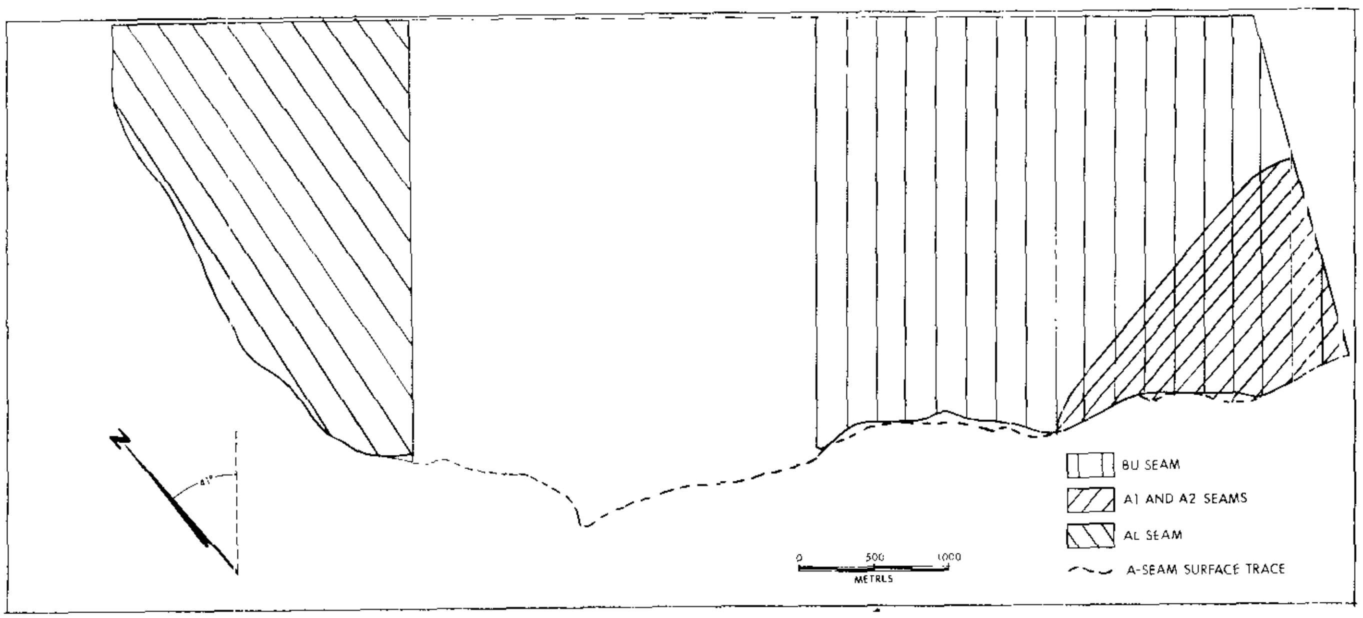

Figure 2-6. Areal distribution of seams used in the digital deposit model. A and B-seams are found over the whole area with only minor differences in outcrop traces.

manually traced onto the profile. This line was then digitized and projected parallel to the selected projection direction so that its position at each grid centre could be calculated. The result was a surface which had the cross-sectional shape of the seam trace on the profile and oriented parallel to the projection direction (Fig. 2-5b). This surface reflects the general structure of the seam but, because it is artificial, does not necessarily coincide with any of the B-seam data. To solve this problem a residual grid was constructed and added to the down-plunge projection (dpp) grid. The residual grid was calculated by an inverse distance squared weighting, moving average algorithm. The raw data for this calculation is the difference in elevation between the actual data position and the position contained in the ddp grid (Fig. 2-5c). The grid used to make evaluation calculations was generated by adding the residual grid to the dpp grid; this resulted in a surface which retains the authors' interpretation of the general structure but also honours all data points (Fig. 2-5d).

A-seam was positioned by determining a grid of A-seam to B-seam distances and subtracting this grid from the B-seam position grid. Only four widely spaced boreholes provided useable information for this purpose. A grid was constructed from these raw data by the inverse distance squared ($1/d^2$) moving average technique.

Once these two seam position grids were determined, they were trimmed by removing those grid squares which represented seam positions above the topographic surface.

The four minor seam position grids were obtained in a similar manner except that constant inter-seam interval thicknesses were used for each seam. These interval thicknesses were + 1, − 1, − 8, and − 16 metres for B-BU, A-AL, A-A1, and A-A2 respectively. The same outcrop trim lines were used for these minor seams as for the associated continuous seams, which is acceptable due to the steepness of the ridge face and the scale of the model.

Seam thickness grids for all the seams were obtained by a $1/d^2$ moving average algorithm. Total coal thickness within seams rather than actual seam thicknesses were used in these calculations. Semi-variograms were determined for the thickness data, but due to the limited number and poor distribution of data points these plots were of little use. The method used actually results in a smooth version of results obtained by the polygon method. In one borehole an exceedingly thick B-seam intersection of 17.11 metres was arbitrarily reduced to 10 metres as it was felt that this anomalous thickness was not depositional, but due to local structure and should not influence too great an area of the model. Some trench data did not expose the entire seam and thicknesses were reported as a value followed by a ' + ' sign. Only the reported thickness values were used, thus seam thickness values are on the conservative side.

A series of grids or templates, which mark the area of the model underlain by each seam, were constructed. These template grids contained a '1' in each grid point underlain by the seam and a '0' in areas where the seam was not present (Fig. 2-6). The A- and B-seams were only absent in areas where the seams were removed by erosion. The four minor seams had subsurface terminations in addition to the erosional terminations.

Finally a series of grids containing the distance to the nearest data point from each grid square centre for each seam were constructed. These grids are used to categorize tonnage values because geostatistical parameters such as those in Kilby and McClymont (1985) were unobtainable; the quality of the raw data was inadequate to define these parameters (Fig. 2-7).

Upon completion the Flathead Ridge model contained 37 digital surfaces describing the five deposit variables selected. Additional surfaces describing other parameters could be added to the model.

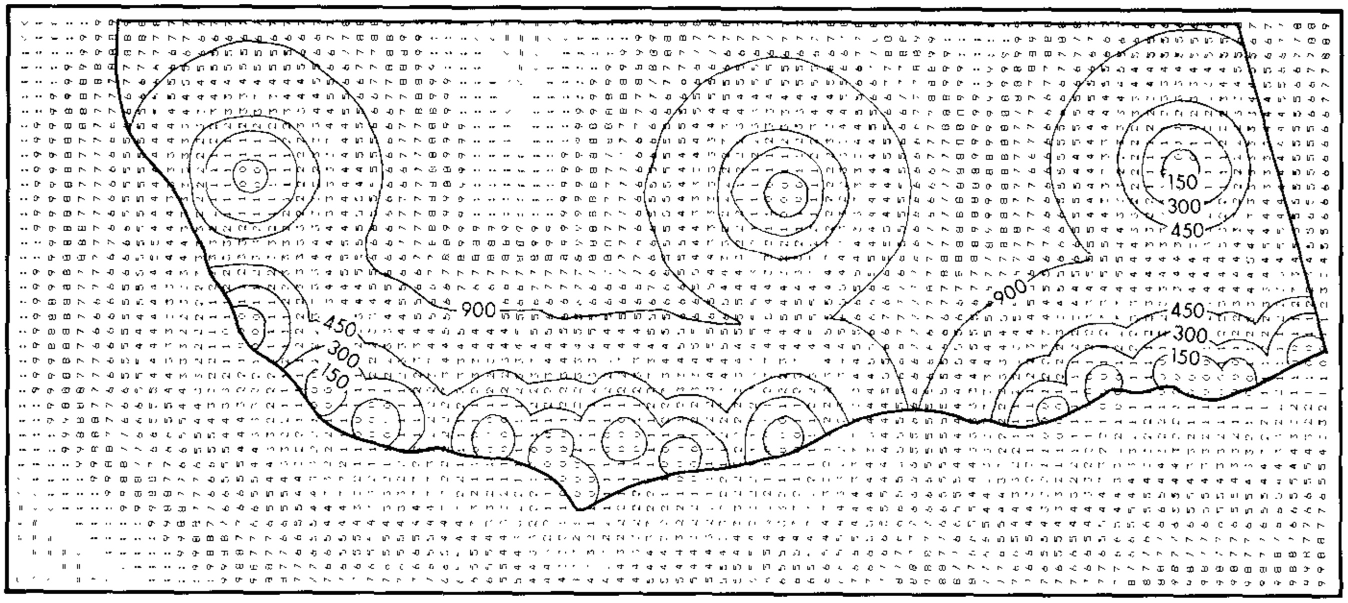

Figure 2-7. B-seam distance grid, showing the minimum distance to the nearest data point.

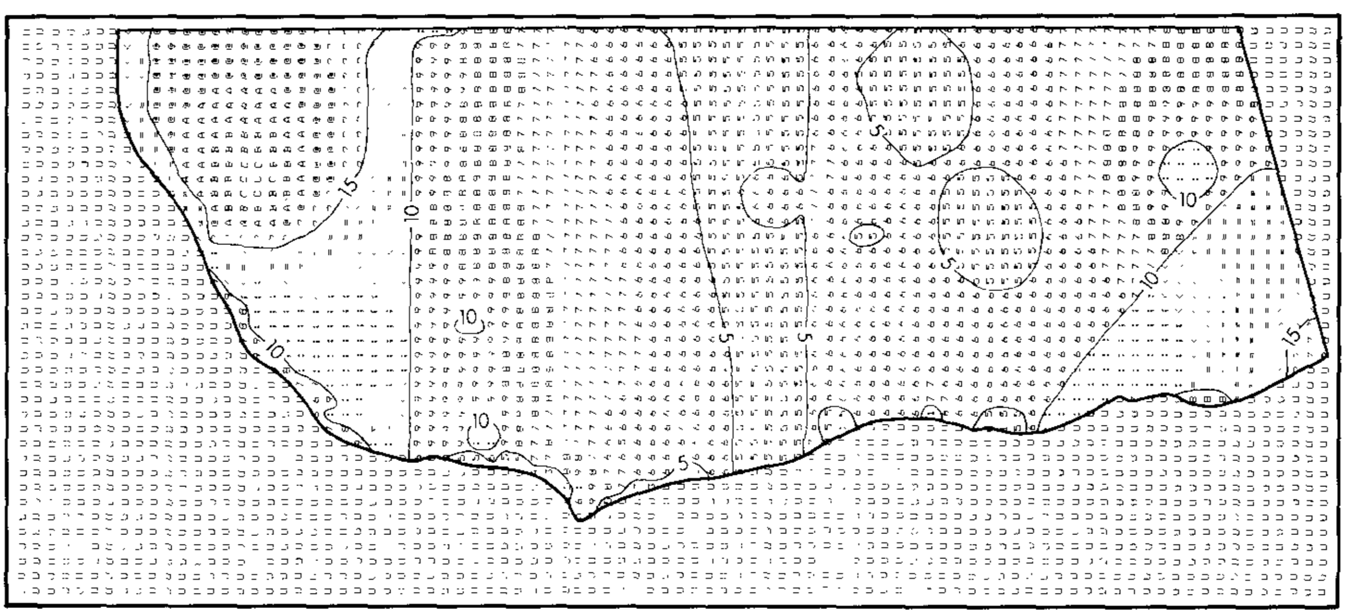

Figure 2-8. Total coal grid shows the distribution of total coal thickness from the six seams used in the model.

MODEL ANALYSIS

The digital model describes coal seam position, thickness, and distance from the nearest data point within the study area. As such it can be used to answer a variety of questions related to the coal resources. The following section describes the techniques used to extract these answers from the model and presents some of the results.

How much coal is in the deposit in the various confidence categories? To answer this question the seam thickness grids for each seam were assessed. Coal thickness values at each grid square which fell within the acceptable boundaries contained in the template grids, and which fell within a specified distance from the nearest data point, contained in the distance grids, were summed. A minimum seam thickness of 1.3 metre was used in these calculations. The three distance intervals which were selected to correspond with the categories of measured, indicated, and inferred were 0 to 150 metres, 150 to 300 metres, and greater than 300 metres respectively. A coal specific gravity of 1.3 g/cc was used in the calculations; each grid square was 100 by 100 metres, therefore there would be 13 000 tonnes per vertical metre of coal per grid square. The results of this calculation are presented for each seam in Table 2-4.

TABLE 2-4
RESERVES AND RESOURCES, FLATHEAD RIDGE

Seam	Measured (Tonnes)	Indicated (Tonnes)	Inferred (Tonnes)	Total (Tonnes)
A	6 286 130	12 815 100	86 778 000	105 879 000
AL	1 023 340	3 253 450	17 920 200	22 197 000
A1	673 532	1 067 230	3 283 410	5 024 170
A2	634 593	1 052 550	3 472 390	5 159 530
B	8 390 460	11 628 200	69 645 700	89 664 300
BU	463 211	351 411	1 040 260	1 854 880
Total	17 471 266	30 167 941	182 139 960	229 778 880

Where is the coal? This question was answered by constructing a total-coal map. This procedure required only summing all the seam thickness grids. The result is a map of coal thickness over the deposit (Fig. 2-8).

What is the vertical waste-to-coal ratio distribution, that is, is there any open pittable material? To answer this query two preliminary sets of information were required: total coal distribution, and total waste material distribution over the area. The total coal distribution was determined in the preceding section. Total waste is the amount of material between the topographic surface and the base of the lowest mineable seam less the total thickness of coal in the interval. At each grid point the lowest coal seam present was determined from the seam elevation grids. The thickness of the seam at that position was then subtracted from the seam top elevation to obtain the lowest elevation to be considered at each grid centre. This value was then subtracted from the corresponding topographic elevation stored in the topography grid. The resulting waste-to-coal grid obtained was a map of the vertical ratio of the volume of rock to the volume of coal (Fig. 2-9). To convert these data to the more conventional bank cubic metres (BCM) per tonne of coal, one multiplies by the inverse of the coal specific gravity. As seen from this map, there are 2.85 square kilometres of Parcel 82 with vertical volume ratios of less than 10 to 1; these areas are found at either end of the study area. However, additional drilling would be required to confirm these ratios because some seam positions were obtained by projections over significant distances.

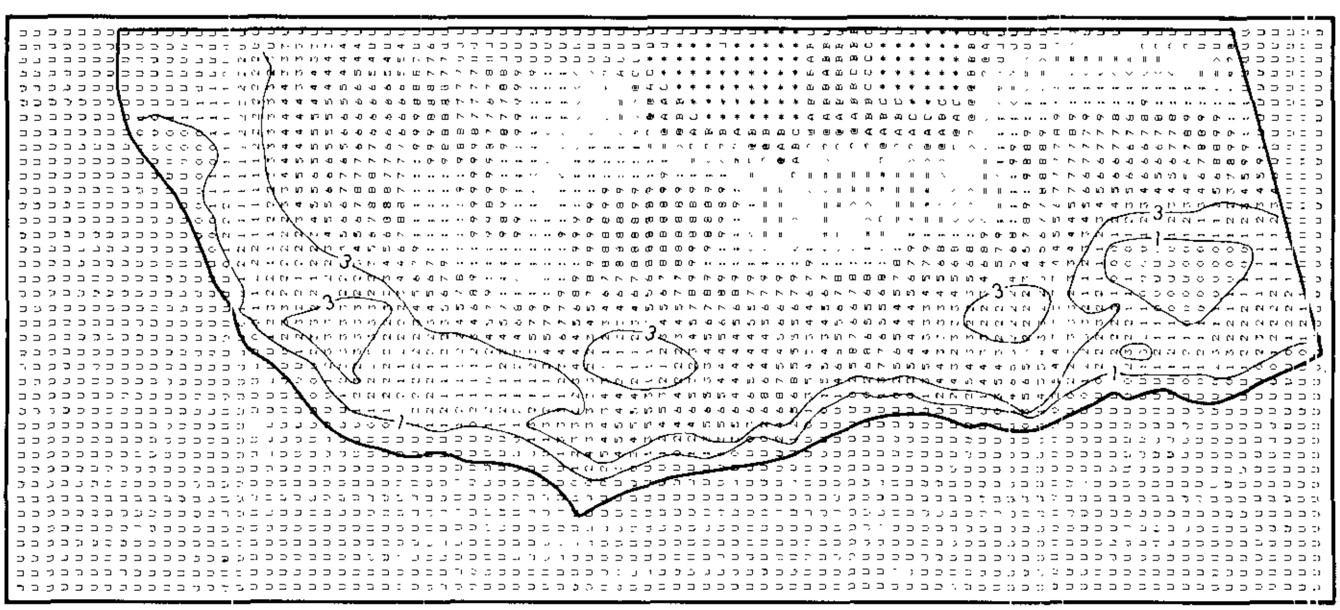

Figure 2-9. Waste-to-coal ratio map shows the distribution of the vertical ratio of non-coal to coal in the area.

CONCLUSION

The model is based on limited poorly distributed data, yet the study indicates that the Flathead Ridge area contains considerable coal resources. Significant tonnages of this coal may already be placed in the measured and indicated categories as defined by Energy, Mines and Resources Canada and the British Columbia Ministry of Energy, Mines and Petroleum Resources. In addition, several portions of the area hold significant volumes of medium to low-volatile coal that could be extractable by open pit methods. The area is well situated with respect to infrastructure.

ACKNOWLEDGMENT

Digitizing of topographic data was performed by H. Oppelt.

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A COMPARISON BETWEEN THE GEOCHEMISTRY OF THE GOLD-RICH AND SILVER-RICH SKARNS IN THE TILLICUM MOUNTAIN AREA (82F/13, 82K/4)

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INTRODUCTION

Gold and/or silver-bearing skarns are found in the Tillicum and Grey Wolf Mountains area, approximately 30 kilometres south of Nakusp in southeastern British Columbia (Fig. 3-1). The skarn mineralization is spatially and probably genetically associated with a suite of deformed, often schistose diorite sills that intrude a highly deformed, metamorphosed, volcano-sedimentary succession of uncertain age (*see* Ray and Spence, this volume). The skarns are divisible into gold-rich and silver-rich types (McClintock and Roberts, 1984; Ray, *et al.*, 1985). The former is best represented by auriferous mineralization at the Heino-Money zone, situated 150 metres northwest of Tillicum Mountain; while the mineralization at the defunct Silver Queen mine, situated 900 metres southwest of Grey Wolf Mountain (Fig. 3-1), is an example of a silver-rich skarn.

This report summarizes whole rock and trace element analytical results from two drill holes; one hole (TM 82-16) intersects the auriferous skarn at the Heino-Money zone; the other (hole SQ 84-10) intersects the silver-rich skarn at the Silver Queen mine.

GEOLOGY OF THE TILLICUM MOUNTAIN-GREY WOLF MOUNTAIN AREA

The supracrustal rocks hosting the skarn-related mineralization form an easterly trending, 5-kilometre-wide roof pendant which, to the north, west, and south, is intruded and hornfelsed by various granitoid stocks of Jurassic to Eocene age (Hyndman, 1968; Parrish, 1981). A synopsis of the regional geology is presented by Ray and Spence (this volume); other geological publications relevant to this area include those by Cairnes (1934), Little (1960), Kwong and Addie (1982), McClintock and Roberts (1984), Roberts and McClintock (1984), Kwong (1985), and Ray, *et al.* (1985). The sedimentary rocks are predominantly a metamorphosed succession of siltstone, calcareous siltstone, arkose, and wacke, with lesser amounts of basalts, tuff, and locally organic-rich argillite (Fig. 3-1). The volcanic-argillite suite at Tillicum Mountain is believed to be relatively older than the calcareous sedimentary succession around Grey Wolf Mountain; however, no evidence of either a structural break or an unconformity is evident (Ray, *et al.*, 1985; Ray and Spence, this volume). The country rocks are intruded by swarms of deformed, sill-like bodies of diorite that vary from 1 to over 100 metres in width (Fig. 3-1). These intrusive rocks are widely distributed throughout the district and are spatially, and probably genetically, related to gold and silver-rich skarn mineralization in the area. The sills are generally leucocratic, porphyritic diorites to quartz diorites that are characterized by abundant plagioclase phenocrysts up to 1 centimetre in diameter. Biotite, which forms less than 10 per cent by volume, is the commonest and most widespread mafic mineral; some rare, more mafic sills contain appreciable quantities of hornblende.

Igneous textures and euhedral feldspar phenocrysts are preserved in the central portions of the larger sills but the margins are generally schistose with highly flattened feldspar crystals. In thin section, margins of the oligoclase phenocrysts are frequently partially recrystallized, and rimmed with small crystals of fresh, untwinned plagioclase. In many areas this recrystallization process is complete, and phenocrysts are pseudomorphed by a mosaic of small plagioclase crystals, each less than 0.1 millimetre in diameter. The fine-grained matrix comprises mainly plagioclase, random to subaligned flakes of biotite, and minor to trace amounts of quartz, hornblende, chlorite, and sulphides. Country rocks immediately adjacent to feldspar porphyry sills are often weakly hornfelsed.

The diorite sills predate the large, massive, granotoid stocks of Jurassic age (Hyndman, 1968; Parrish, 1981), however, the precise age of their intrusion and the skarn mineralization is not known.

GEOLOGY AND MINERALIZATION AT THE HEINO-MONEY ZONE AND SILVER QUEEN MINE

At numerous localities throughout the Tillicum and Grey Wolf Mountains area, the margins of some diorite sills and country rock immediately adjacent to them are overprinted with skarn alteration that often carries geochemically anomalous quantities of gold and/or silver. These skarns are generally separable into gold-rich and silver-rich types, as represented respectively by the Heino-Money zone, and the Silver Queen mine mineralization.

At the Heino-Money zone gold-bearing, siliceous, calc-silicate skarn alteration is stratabound. It is mainly hosted in a thin, wedge-shaped package of basaltic tuff and tuffaceous sedimentary rocks which is bounded to the west by metabasalts and to the east by a large, altered, feldspar porphyritic diorite body (Fig. 3-1). The skarn is characterized by a pinkish green colour; it is generally well layered with subparallel thin quartz veins and variable amounts of sulphides. The skarn assemblage includes quartz, tremolite-actinolite, clinozoisite, plagioclase, diopside, biotite, garnet, and microcline, with minor amounts of sericite and carbonate. Free gold occurs as fine to coarse disseminations and fracture fillings within and along walls of the quartz sulphide veins; gold is generally associated with pyrrhotite, pyrite, galena, and sphalerite (Roberts and McClintock, 1984).

A polished section study of the Heino-Money mineralization (Northcote, 1983) showed that individual gold grains range from less than 2 microns to more than 3 millimetres in diameter. The gold occurs as plates and anhedral grains; they are generally free, but may also be intimately associated with pyrrhotite, arsenopyrite, sphalerite, and pyrite-marcasite. Some pyrrhotite grains are rimmed with colloform pyrite-marcasite, while others contain small masses of hematite and graphitic material. Northcote (1983) also reports minor to trace amounts of tetrahedrite, chalcopyrite, and possibly electrum.

British Columbia Ministry of Energy, Mines and Petroleum Resources, Geological Fieldwork, 1985, Paper 1986-1.

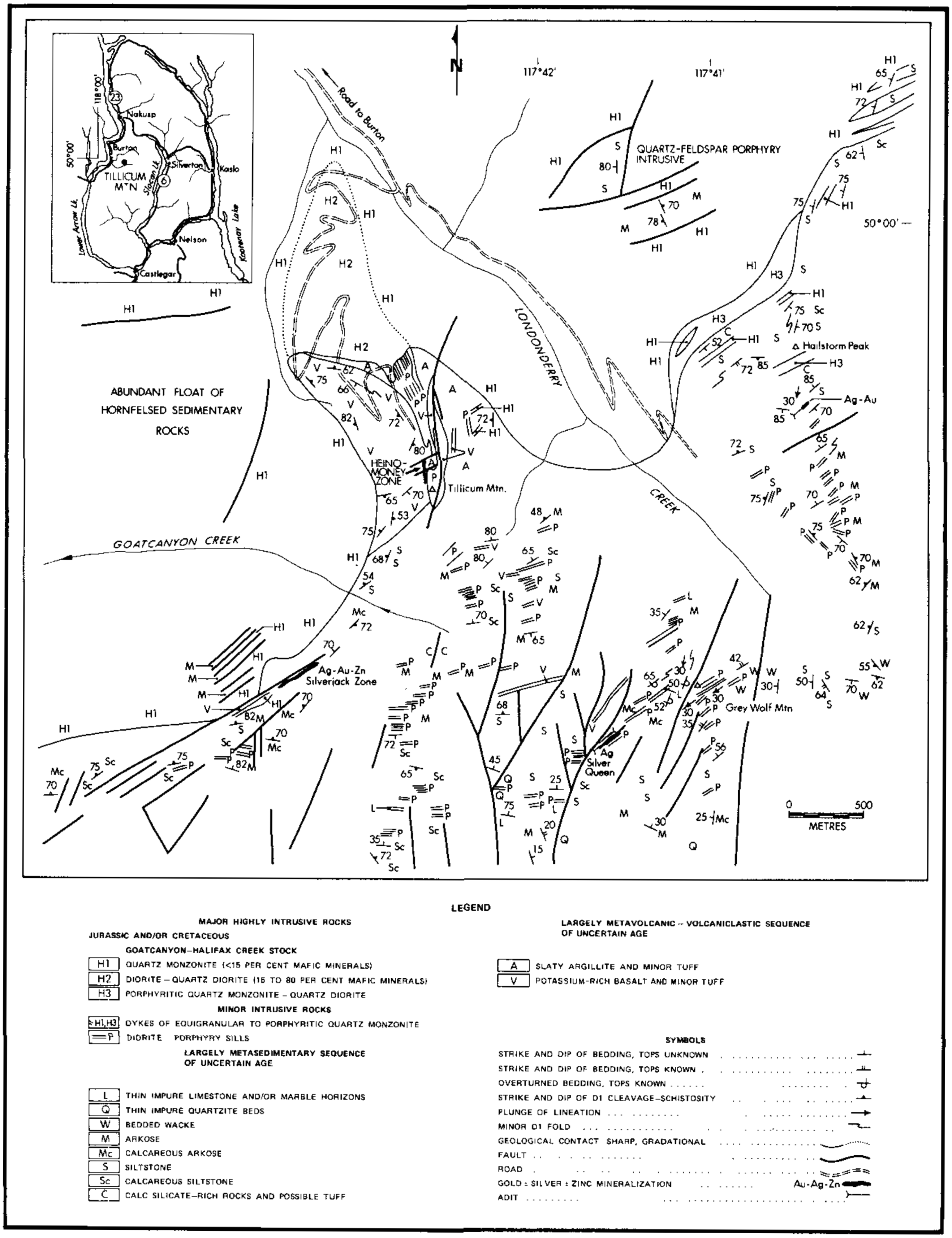

Figure 3-1. Simplified geology of the Tillicum-Grey Wolf Mountains area, showing the location of the Heino-Money zone and the Silver Queen mine. (Modified after Ray, *et al.*, 1985).

The Silver Queen mine property was active in the 1930's, but reportedly work terminated after a spring avalanche killed several miners. Intrusion of feldspar porphyritic diorite sills into a 30-metre-wide zone of impure calcareous quartzites, siltstones, and thin marble beds was accompanied by stratabound skarn development. Several mineralized horizons, each up to 20 metres thick are recognized; sulphide mineralization and skarn alteration are found in both the calcareous metasedimentary rocks and the adjacent feldspar porphyry sills. In contrast to the Heino-Money zone, mineralization is silver rich; gold is rare.

The skarn assemblage includes quartz, tremolite-actinolite, clinozoisite, garnet, biotite, and carbonate, with minor amounts of epidote and sphene. Anhedral garnet crystals up to 1 millimetre in diameter have clear margins but abundant inclusions in their cores. Some cores have overgrown and preserve a biotite schistosity that developed during the regional metamorphism. Mineralization extends for 300 metres along strike and grades from 3 to 240 grams silver per tonne. Associated sulphides include pyrite, pyrrhotite, tetrahedrite, sphalerite, galena, and pyrargyrite.

SAMPLING AND ANALYTICAL METHODS IN HOLES TM 82-16 AND SQ 84-10

Twenty-four samples were collected from hole TM 82-16 which is 48 metres long, and 35 samples were taken from hole SQ 84-10 which is 79 metres long. The location of each sample in the holes is shown on Figures 3-2 to 3-5, and in Tables 3-1 and 3-3. Each sample was split; one part being submitted for thin section, the other for geochemical analysis. These were analysed for their major element contents, as well as for Au, Ag, Cu, Pb, Zn, Co, Ni, Mo, Cr, Hg, As, Sb, Ba, Sr, Bi, and CO_2. Analytical results are presented in Tables 3-1 to 3-4. The analytical methods for all samples are as follows: major elements by Flame AAS with a precision of 0.75 per cent RSD; Au by Fire Assay; Ag, Cu, Pb, Zn, Co, Ni, Cr, As, Ba, Sr, Mo, and Bi by Flame AAS; Sb by Hydride AAS; Hg by Cold Vapour AAS; CO_2 by Induction Furnace.

The major and trace element analytical results are plotted on Figures 3-2 to 3-5; these illustrate the relative changes in elemental weight per cent throughout each drill hole. Correlation coefficients have not yet been calculated for these data.

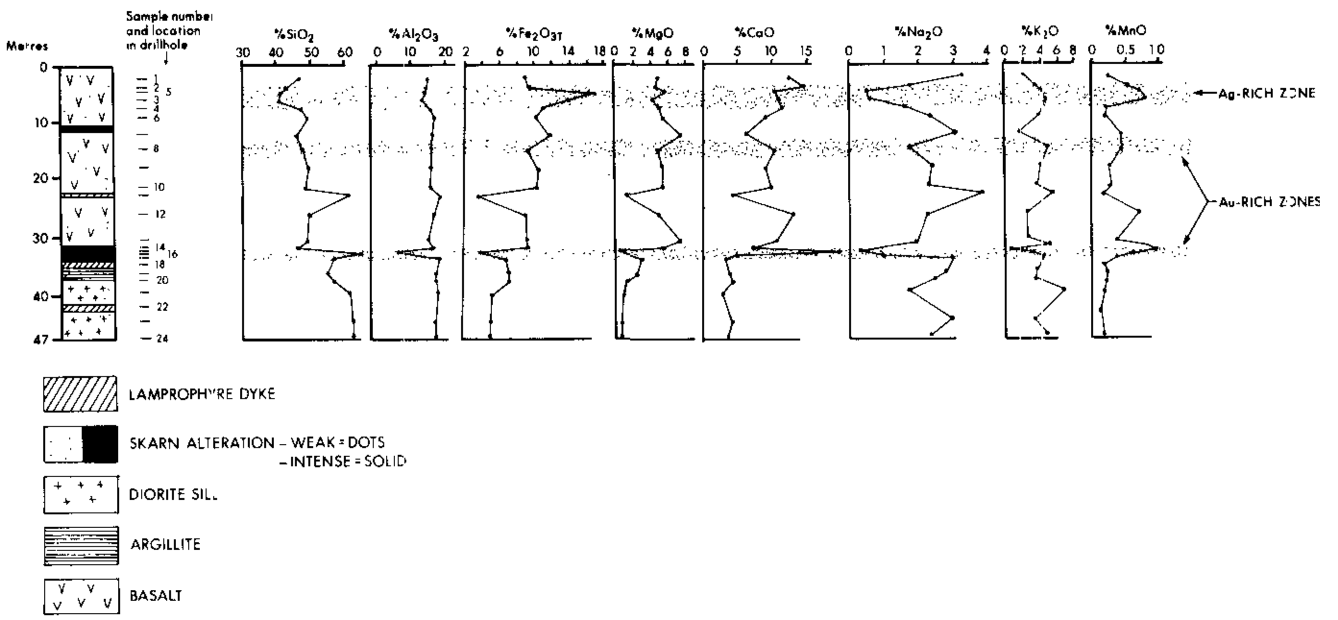

Figure 3-2. Geology and major element geochemistry of hole TM 82-16, Heino-Money zone, Tillicum Mountain.

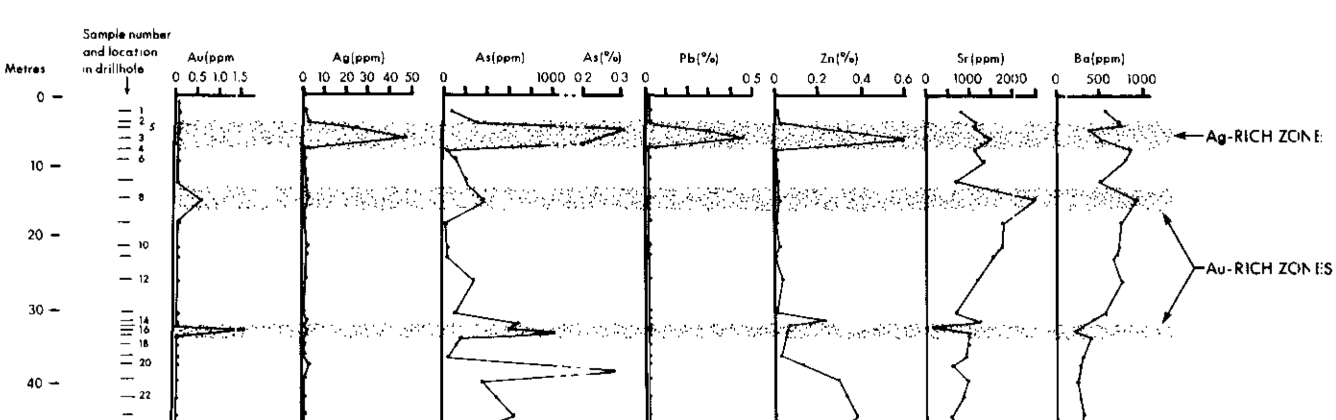

Figure 3-3. Trace element geochemistry of hole TM 82-16, Heino-Money zone, Tillicum Mountain.

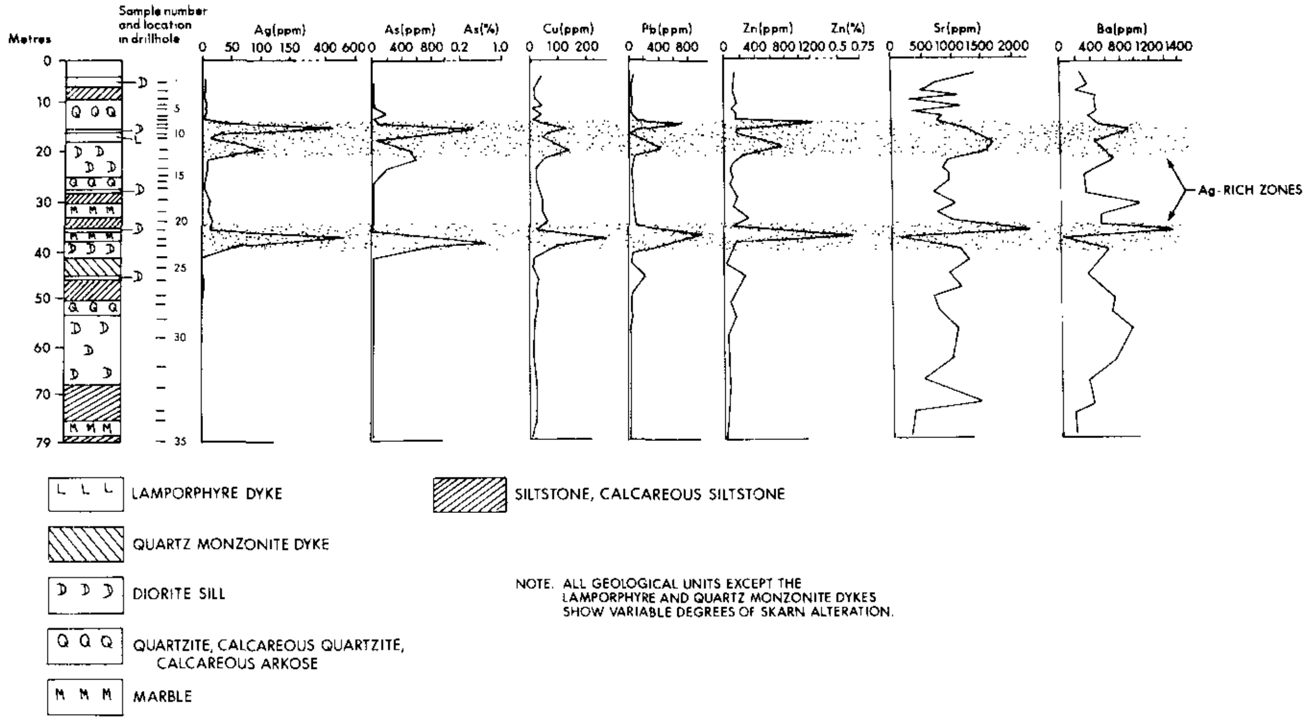

Figure 3-4. Geology and trace element geochemistry of hole SQ 84-10, Silver Queen mine.

TABLE 3-1
MAJOR ELEMENT ANALYSES OF SAMPLES TAKEN FROM HOLE TM 82-16 (HEINO-MONEY ZONE)
(Analytical values in per cent)

Sample No.	Depth of Sample (metres)	SiO_2	Al_2O_3	Fe_2O_{3T}*	FeO	MgO	CaO	Na_2O	K_2O	TiO_2	MnO	CO_2	Total**
TM 82-16-1	2.4	46.59	14.87	8.99	7.39	5.01	12.53	3.30	2.16	0.78	0.27	4.50	90.0
TM 82-16-2	4.0	43.32	14.57	9.59	7.87	4.73	14.82	1.81	3.45	0.79	0.54	4.54	98.1
TM 82-16-3	6.0	41.83	13.28	14.06	11.08	4.25	11.15	0.61	4.44	0.77	0.81	3.97	97.8
TM 82-16-4	7.6	47.43	15.27	11.10	8.73	5.13	11.53	1.60	4.29	0.99	0.23	2.46	100.8
TM 82-16-5	4.5	41.49	14.06	17.18	12.50	5.91	10.52	0.54	4.19	0.83	0.71	1.47	100.8
TM 82-16-6	9.1	49.25	16.39	10.39	8.62	5.71	9.24	2.36	3.89	0.90	0.20	1.01	99.8
TM 82-16-7	12.1	46.05	15.98	11.84	9.51	7.49	6.72	3.13	1.44	0.98	0.44	2.37	99.7
TM 82-16-8	14.6	48.48	15.60	9.69	7.74	4.98	10.50	1.73	4.85	0.92	0.44	1.04	99.7
TM 82-16-9	17.9	49.43	15.52	10.41	8.32	5.68	9.25	2.41	4.12	0.89	0.25	0.21	100.5
TM 82-16-10	21.3	48.41	15.35	10.20	7.25	5.51	10.07	2.32	3.77	0.89	0.30	1.18	99.6
TM 82-16-11	22.5	60.78	17.77	3.75	2.78	1.39	4.51	3.83	5.23	0.57	0.19	0.35	99.4
TM 82-16-12	25.9	48.75	15.70	9.04	6.99	5.15	13.56	2.27	2.47	0.94	0.72	0.69	101.1
TM 82-16-13	30.4	48.44	14.76	9.88	7.93	7.45	10.95	1.97	2.61	0.80	0.38	1.38	100.1
TM 82-16-14	31.6	45.99	15.92	9.72	6.38	4.66	7.50	0.90	5.12	0.89	0.80	4.28	98.6
TM 82-16-15	32.3	56.02	5.90	3.39	2.07	0.96	19.06	0.28	0.65	0.21	0.93	11.10	98.2
TM 82-16-16	32.9	66.00	11.68	5.27	3.57	2.10	4.99	0.80	3.37	0.59	0.58	1.49	99.0
TM 82-16-17	33.5	55.79	17.81	6.75	5.04	3.20	3.59	3.05	4.60	0.71	0.35	1.37	99.6
TM 82-16-18***	34.7	44.82	11.66	9.49	6.49	11.64	9.65	2.31	1.69	0.94	0.19	3.13	99.9
TM 82-16-19	36.2	54.00	16.62	7.16	5.76	2.69	4.38	2.75	3.79	0.76	0.24	2.32	96.2
TM 82-16-20	37.4	55.96	16.24	7.19	4.76	1.72	4.47	2.44	3.88	0.67	0.23	1.27	96.7
TM 82-16-21	39.6	60.75	16.91	4.92	3.99	1.24	3.12	1.70	6.92	0.52	0.20	0.48	99.3
TM 82-16-22***	42.0	50.06	14.05	8.07	5.78	7.22	6.48	2.17	2.91	1.03	0.14	3.75	99.8
TM 82-16-23	44.5	60.58	16.37	4.96	4.74	1.17	4.65	2.94	3.85	0.48	0.16	1.36	98.8
TM 82-16-24	47.5	61.17	16.69	5.09	3.99	1.27	3.76	2.24	5.09	0.51	0.18	0.24	98.3

* Total iron expressed as Fe_2O_3
** Total = major oxides and LOI
*** Post-ore lamprophyre dyke

GEOLOGY AND GEOCHEMISTRY OF HOLE TM 82-16 (HEINO-MONEY ZONE)

The geology of hole TM 82-16 is shown on Figure 3-2; it totals 47 metres in length and was drilled vertically to intersect part of the Heino-Money zone. With the exception of some late lamprophyre dykes, the entire hole shows varying degrees of skarn development, marked by garnetiferous calc-silicate alteration. The first 30 metres of the hole comprise massive to schistose metabasalts that are locally amygdaloidal. The lower portion of the hole, from 37 to 47 metres (Fig. 3-2) is a skarn-altered porphyritic diorite sill. Between the metabasalt and the diorite unit (30 to 37 metres) is a zone of intense skarn development and sulphide mineralization which contains some highly altered, sheared, and schistose remnants of argillite. This prominent altered zone and the diorite sill are cut by lamprophyre dykes that postdate both the skarn development and the sulphide mineralization. Minor amounts of disseminated pyrite and pyrrhotite, which occur throughout the hole, are more abundant at a depth of 6 metres in the metabasalts and again at a depth of 32 metres, close to the intensely altered contact between the argillite and the metabasalt. In addition to pyrite and pyrrhotite, these two sulphide-rich zones contain minor amounts of arsenopyrite, chalcopyrite, and sphalerite; the upper zone also carries traces of galena. Disseminated arsenopyrite is common throughout the hole, but is noticeably more abundant as veins and stringers at depths of 6, 32, and 38 metres.

The whole rock and trace element analytical results for the 24 samples analysed from hole TM 82-16 are listed in Tables 3-1 and 3-2, and plotted on Figures 3-2 and 3-3. These show that gold is confined mainly to the narrow, intensely skarn-altered contact zone between the metabasalt and the sheared argillites. This zone had been previously sampled and entirely removed by Esperanza Exploration Ltd. and returned assay values up to of 90 ppm gold; remnant chips collected during this study assayed 1.7 ppm gold. Silver, which shows no spatial association with the gold, appears to be related to disseminated galena mineralization at the 6-metre depth. The element plots on Figures 3-2 and 3-3 suggest that gold has a positive but sporadic correlation with As, SiO_2, CaO, and MnO, and a negative but sporadic correlation with Al_2O_3, MgO, Na_2O, K_2O, total iron, Sr, and Ba. Gold appears to have no significant correlation with Ag, Pb, and Zn. Silver has a positive but sporadic correlation with total iron, K_2O, MnO, As, Pb, and Zn, and a weak to moderate negative correlation with MgO, CaO, and Sr. It appears to be unrelated to Al_2O_3, SiO_2, Na_2O, and Ba.

GEOLOGY AND GEOCHEMISTRY OF HOLE SQ 84-10 (SILVER QUEEN MINE)

The geology of hole SQ 84-10 is shown on Figure 3-4. It was drilled to intersect silver-bearing skarn mineralization at the defunct Silver Queen mine (Fig. 3-1). The hole cuts a thinly interbedded sequence of calcareous metasedimentary rocks that includes quartzite, siltstone, arkose, and marble; some beds are graphitic. Schistosity increases toward the bottom of the hole; this makes it difficult to identify the original nature of the metasedimentary rocks. The sedimentary sequence is intruded by six diorite sills that vary from fine grained and equigranular to coarsely porphyritic and weakly schistose. All the sedimentary and dioritic rocks in the hole are variably skarn altered; however, skarn development is most intense close to the margins of the diorite sills. Sporadic pyrite, pyrrhotite, sphalerite, galena, tetrahedrite, and pyrargyrite occur as disseminations and blebs between 9 and 45 metres depth. The skarn-sulphide mineralization is postdated by a dyke of fresh quartz monzonite at 44 metres depth, and by several late lamprophyre

TABLE 3-2
TRACE ELEMENT ANALYSES OF SAMPLES TAKEN FROM HOLE TM 82-16 (HEINO-MONEY ZONE)
(Analytical values in ppm)

Sample No.	Au	Ag	Cu	Pb	Zn	Co	Ni	Cr	As	Ba	Sr
TM 82-16-1	<0.3	1.5	101	51	145	31	32	90	75	580	810
TM 82-16-2	<0.3	3.0	162	110	190	43	36	110	342	720	1 160
TM 82-16-3	0.3	49.0	650	4 600	6 200	37	27	50	2 000	510	1 480
TM 82-16-4	0.3	1.0	164	24	100	43	37	60	22	850	1 150
TM 82-16-5	<0.3	26.0	600	2 500	3 100	58	31	80	2 900	370	1 170
TM 82-16-6	<0.3	1.3	158	60	127	42	26	70	138	770	1 370
TM 82-16-7	<0.3	1.8	212	73	203	43	39	140	221	500	670
TM 82-16-8	0.7	2.6	164	173	290	43	28	70	395	930	2 530
TM 82-16-9	<0.3	0.9	162	58	148	35	29	90	25	750	1 810
TM 82-16-10	<0.3	2.2	140	67	274	39	32	100	22	700	1 740
TM 82-16-11	<0.3	1.6	65	87	102	22	10	10	56	660	1 550
TM 82-16-12	<0.3	1.9	124	77	418	58	63	350	310	740	1 170
TM 82-16-13	<0.3	0.8	87	41	150	42	45	180	131	550	700
TM 82-16-14	<0.3	2.7	145	95	2 300	31	34	130	733	320	1 230
TM 82-16-15	<0.3	1.1	56	61	590	15	7	10	606	310	190
TM 82-16-16	1.7	2.0	56	112	501	26	17	30	1 100	200	930
TM 82-16-17	<0.3	1.0	51	25	540	24	17	40	194	390	1 020
TM 82-16-18*	<0.3	<0.3	36	8	90	43	168	910	<10	910	780
TM 82-16-19	<0.3	0.5	53	20	250	23	17	40	43	320	890
TM 82-16-20	<0.3	2.7	68	41	1 200	34	18	10	2 800	250	600
TM 82-16-21	<0.3	1.3	64	98	3 000	23	9	<10	369	230	970
TM 82-16-22*	<0.3	<0.3	23	18	129	31	72	360	<10	620	850
TM 82-16-23	<0.3	0.8	60	84	3 800	22	5	10	690	320	580
TM 82-16-24	<0.3	0.5	68	86	2 500	22	6	<10	38	260	820

* Post-ore lamprophyre dykes
All samples recorded <4 ppm Mo, <10 ppm Sb, <10 ppb Hg, and <5 ppm Bi

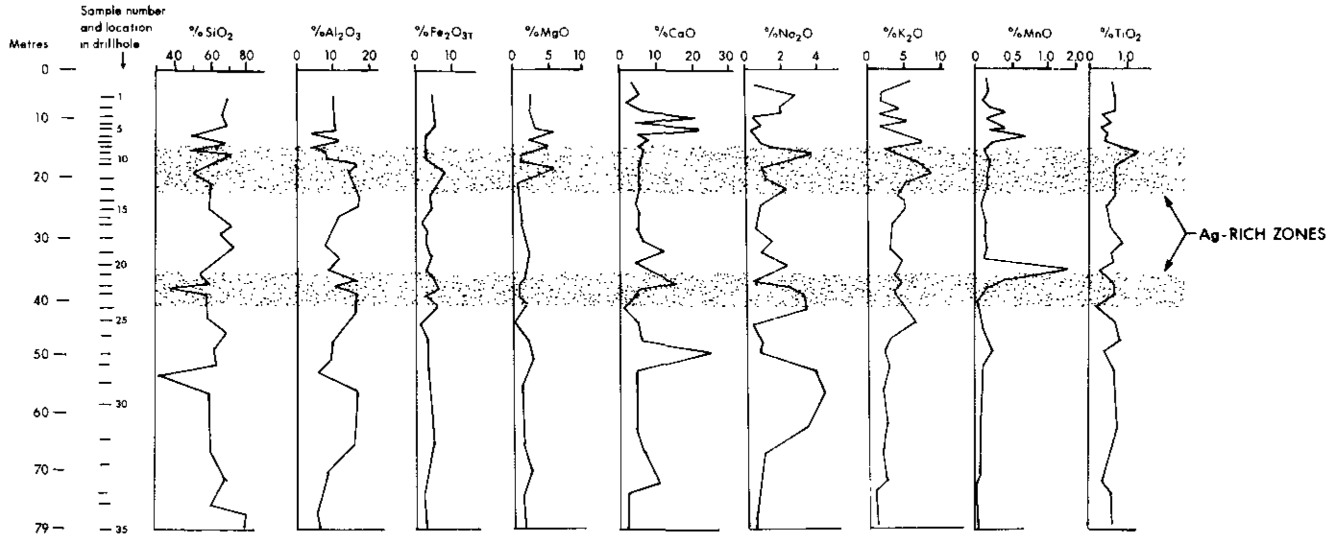

Figure 3-5. Major element geochemistry of hole SQ 84-10. Silver Queen mine.

TABLE 3-3
MAJOR ELEMENT ANALYSES OF SAMPLES TAKEN FROM HOLE SQ 84-10 (SILVER QUEEN MINE)
(Analytical values in per cent)

Sample No.	Depth of Sample (metres)	SiO_2	Al_2O_3	Fe_2O_{3T}*	FeO	MgO	CaO	Na_2O	K_2O	TiO_2	MnO	CO_2	Total**
SQ 84-10-1	5.4	68.91	10.49	3.39	1.89	2.54	3.28	0.51	5.74	0.60	0.41	1.69	99.3
SQ 84-10-2	7.0	67.05	11.89	4.26	2.88	2.32	5.35	2.63	1.89	0.70	0.18	1.68	99.3
SQ 84-10-3	8.8	70.00	11.41	4.98	4.00	3.11	1.86	1.79	1.47	0.73	0.09	0.83	99.6
SQ 84-10-4	10.0	62.02	12.19	4.20	3.08	3.24	5.92	1.92	3.83	0.65	0.18	3.21	99.6
SQ 84-10-5	10.6	49.72	3.94	2.00	1.55	5.92	22.19	0.31	1.28	0.25	0.42	11.50	99.6
SQ 84-10-6	12.1	69.42	10.75	2.31	1.65	2.24	3.84	0.94	5.24	0.58	0.13	2.53	99.7
SQ 84-10-7	12.9	49.16	4.42	2.34	1.82	5.27	22.46	0.33	1.58	0.29	0.41	12.20	99.8
SQ 84-10-8	14.0	71.43	8.63	2.51	1.69	2.62	4.91	0.62	4.35	0.49	0.18	2.82	99.3
SQ 84-10-9	14.9	66.68	8.35	2.63	1.90	1.34	7.98	0.66	4.60	0.42	0.70	5.53	99.7
SQ 84-10-10	15.8	60.10	16.65	4.40	3.15	1.26	4.83	1.29	7.49	0.61	0.23	1.13	99.9
SQ 84-10-11***	16.7	49.17	14.78	7.64	5.35	6.25	6.90	3.69	2.30	1.43	0.14	3.24	99.4
SQ 84-10-12	19.5	61.15	16.12	5.56	4.58	0.97	4.87	0.93	7.16	0.66	0.22	0.88	99.7
SQ 84-10-13	21.3	59.02	17.74	3.48	2.69	1.03	5.15	1.06	8.51	0.74	0.17	1.23	99.6
SQ 84-10-14	23.1	59.45	17.14	4.59	3.52	1.25	5.08	2.28	5.32	0.71	0.21	0.89	99.1
SQ 84-10-15	24.6	68.31	12.82	3.27	3.03	1.55	4.69	1.73	4.45	0.65	0.13	1.58	99.7
SQ 84-10-16	25.9	72.11	10.86	1.68	1.46	1.56	4.45	0.91	5.43	0.47	0.09	1.53	99.9
SQ 84-10-17	27.4	68.28	10.52	3.12	2.47	1.87	5.46	0.70	5.16	0.47	0.10	2.82	99.7
SQ 84-10-18	29.8	74.04	8.85	3.01	2.00	2.39	4.42	0.49	3.71	0.58	0.14	2.63	100.2
SQ 84-10-19	32.0	64.17	12.11	4.09	3.29	2.40	7.14	1.55	3.36	0.86	0.14	2.86	99.6
SQ 84-10-20	34.1	56.32	8.93	3.20	2.05	2.08	12.38	0.87	3.24	0.55	0.20	12.60	96.8
SQ 84-10-21	35.9	59.05	17.28	5.31	3.42	1.72	4.51	2.39	5.12	0.68	0.11	1.62	100.1
SQ 84-10-22	37.8	38.01	9.21	8.67	4.25	1.04	17.41	0.40	4.05	0.30	2.17	12.90	94.2
SQ 84-10-23	39.0	59.19	17.44	3.74	2.96	1.22	5.26	2.23	5.35	0.60	0.43	1.22	98.0
SQ 84-10-24	41.4	59.95	17.33	4.75	3.61	1.56	5.11	3.38	3.96	0.70	0.15	1.09	99.5
SQ 84-10-25	43.5	69.93	14.79	1.77	1.26	0.41	1.50	3.51	5.27	0.24	0.04	0.37	99.3
SQ 84-10-26	46.3	63.29	11.28	3.40	2.15	2.49	5.81	0.52	7.02	0.69	0.10	3.51	99.1
SQ 84-10-27	49.3	65.74	10.22	3.79	2.90	3.23	6.52	0.96	3.43	0.79	0.19	1.74	99.8
SQ 84-10-28	51.2	28.35	7.07	3.40	2.65	2.51	26.04	0.94	2.76	0.37	0.29	21.50	93.2
SQ 84-10-29	54.2	60.66	17.48	4.81	3.73	1.53	5.05	4.12	3.31	0.72	0.15	1.22	100.0
SQ 84-10-30	57.9	60.57	17.37	4.88	3.98	1.54	4.86	4.56	2.21	0.76	0.16	0.95	99.5
SQ 84-10-31	64.0	61.36	17.11	5.14	4.61	1.76	5.07	3.64	3.11	0.75	0.14	0.68	99.9
SQ 84-10-32	68.2	69.77	9.48	3.72	2.72	3.16	7.56	1.22	2.58	0.60	0.12	0.95	100.0
SQ 84-10-33	73.1	61.55	7.97	2.92	2.20	1.75	12.03	0.98	3.24	0.44	0.12	7.85	99.9
SQ 84-10-34	74.9	81.37	7.43	2.33	1.86	1.84	2.39	1.05	1.59	0.73	0.05	1.78	100.4
SQ 84-10-35	79.2	79.34	7.91	3.53	2.73	2.57	2.82	0.76	1.72	0.66	0.07	0.45	100.9

* Total iron expressed as Fe_2O_3
** Total = major oxides and LOI
*** Post-ore lamprophyre dyke

dykes. The quartz monzonite dyke is cut by thin fractures that carry pyrite, pyrrhotite, and sphalerite, but the lamprophyre dykes are barren.

Plots of the major and trace element geochemistry in hole SQ 84-10 are shown on Figures 3-4 and 3-5. No gold mineralization was encountered, but silver enrichment occurs between 4 and 24 metres depth. The plots demonstrate that silver has a positive correlation with MnO, Cu, Pb, As, and Zn, and a negative correlation with Na_2O, Al_2O_3, and total iron. Sharp fluctuations in Sr, Ba, MgO, SiO_2, and K_2O values occur within the silver-rich zones; enhanced CaO values are recorded at the margins of the silver-bearing horizons.

CONCLUSIONS

These preliminary results indicate that geochemical differences and similarities exist between the silver-rich and the gold-rich skarns in the Tillicum Mountain-Grey Wolf Mountain area. Gold and silver-bearing horizons are present in the skarns at the Heino-Money zone but they do not occur together. Gold mineralization is marked by an increase in SiO_2, CaO, MnO, and As, and a decrease in Al_2O_3, MgO, Na_2O, K_2O, total iron, Sr, and Ba. The horizons of highest arsenic enrichment, however, do not carry gold. Silver in the Heino-Money zone skarn is probably carried in galena; its presence is marked by increases in total iron, K_2O, MnO, As, Pb, and Zn, and a decrease in MgO, CaO, and Sr.

Polished section studies (Northcote, 1983) and this geochemical study suggest that the mineralizing process at the Heino-Money zone involved two phases of precious metal deposition. The first phase included the introduction of gold, arsenopyrite, and possibly sphalerite, accompanied by the crystallization of quartz, carbonate, and calc-silicate minerals. This was followed by the deposition of argentiferous galena and the continued introduction of arsenopyrite and sphalerite.

At the Silver Queen mine, the skarn contains a 20-metre-wide silver-rich zone which is associated with enhanced values of K_2O, MnO, Cu, Pb, As, and Zn, and a depletion in Na_2O, Al_2O_3, and total iron. Mineralization is associated with sporadic Sb enrichment, which probably reflects the relative abundance of tetrahedrite at the Silver Queen mine. Neither the Heino-Money zone nor the Silver

TABLE 3-4
TRACE ELEMENT ANALYSES OF SAMPLES TAKEN FROM HOLE SQ 84-10 (SILVER QUEEN MINE)
(Analytical values in ppm)

Sample No.	Ag	Cu	Pb	Zn	Co	Ni	Cr	As	Sb	Ba	Sr
SQ 84-10-1	1.0	35	41	140	21	22	30	10	<10	270	1 280
SQ 84-10-2	1.1	17	26	110	19	8	20	<10	<10	370	710
SQ 84-10-3	0.5	20	20	107	19	13	<10	<10	<10	180	460
SQ 84-10-4	7.6	44	40	148	20	21	30	<10	<10	480	1 120
SQ 84-10-5	3.3	5	44	182	9	16	<10	<10	<10	460	270
SQ 84-10-6	4.8	44	26	95	22	26	70	201	<10	450	1 150
SQ 84-10-7	1.4	12	39	150	11	15	30	<10	10	460	300
SQ 84-10-8	35	48	77	138	22	29	40	95	12	380	360
SQ 84-10-9	455	132	740	1 200	22	25	<10	1 000	168	420	760
SQ 84-10-10	35	59	110	167	24	13	20	2 600	<10	510	1 070
SQ 84-10-11*	11	42	25	123	34	129	410	<10	<10	930	1 310
SQ 84-10-12	112	143	456	780	24	8	20	568	45	450	1 710
SQ 84-10-13	11	50	60	250	19	8	40	608	<10	550	1 530
SQ 84-10-14	12	20	39	83	17	7	20	199	<10	700	940
SQ 84-10-15	7	18	36	76	10	11	40	110	<10	470	870
SQ 84-10-16	6	16	54	91	15	13	40	<10	<10	310	970
SQ 84-10-17	4	28	57	73	16	10	40	<10	<10	310	940
SQ 84-10-18	15	44	62	167	23	54	100	<10	<10	350	700
SQ 84-10-19	10	39	68	110	25	24	50	17	<10	1 070	1 070
SQ 84-10-20	18	58	97	297	18	64	160	11	<10	540	780
SQ 84-10-21	16	23	104	100	22	11	20	30	<10	540	1 000
SQ 84-10-22	603	271	1 000	7 500	10	2	30	7 000	171	1 500	2 370
SQ 84-10-23	68	94	617	143	24	5	<10	1 700	12	<20	80
SQ 84-10-24	1	15	47	103	22	5	10	<10	<10	670	1 130
SQ 84-10-25	0.8	10	34	36	19	4	<10	<10	<10	500	1 310
SQ 84-10-26	4	33	206	259	16	48	90	<10	<10	370	940
SQ 84-10-27	2.5	24	50	140	18	12	30	<10	<10	530	1 160
SQ 84-10-28	2.6	27	35	85	7	7	20	<10	<10	700	720
SQ 84-10-29	1.4	19	49	189	17	10	10	<10	<10	660	770
SQ 84-10-30	1.1	15	19	70	19	8	30	<10	<10	920	1 110
SQ 84-10-31	1.3	15	26	86	20	5	30	<10	<10	750	980
SQ 84-10-32	1.1	28	20	109	21	30	80	<10	<10	390	490
SQ 84-10-33	1.2	24	21	51	17	21	30	<10	<10	460	1 510
SQ 84-10-34	0.3	26	5	45	29	29	50	<10	<10	280	350
SQ 84-10-35	1.3	11	22	40	31	21	30	<10	<10	200	280

* Post-ore lamprophyre dyke
All samples recorded <4 ppm Mo and <5 ppm Bi
All samples recorded <10 ppb Hg except sample Nos. SQ 84-10-22 and SQ 84-10-29 which recorded 25 ppb Hg

Queen mine skarns contain Hg, Mo, or Bi enhancement, but the silver and gold-bearing zones at both properties are marked by an increase in MnO. Since silver and gold-rich horizons in the Heino-Money zone show notable geochemical differences, and are not spatially related, the cause of the positive correlation between the precious metals and MnO in the district is puzzling. It may reflect the presence of manganese-rich garnet (spessartine), carbonate (rhodochrosite), or pyroxene [Johannsenite, Ca(Mn, Fe)(Si_2O_6)]. While calcareous-rich rocks are apparently important to skarn development, the presence of organic carbon may also play a signficant role in localizing the precipitation of precious metals, since graphite occurs in the metasedimentary rocks at both the Heino-Money zone and the Silver Queen mine.

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THE POTASSIUM-RICH VOLCANIC ROCKS AT TILLICUM MOUNTAIN — THEIR GEOCHEMISTRY, ORIGIN, AND REGIONAL SIGNIFICANCE (82F/13, 82K/4)

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INTRODUCTION

This report presents some major and trace element analytical results from a suite of mafic metavolcanic rocks of uncertain age at Tillicum Mountain, situated approximately 30 kilometres south of Nakusp in southeastern British Columbia. The analyses indicate that the volcanic rocks represent arc-type, potassium-rich basalts belonging to the absarokite-shoshonite series (Iddings, 1895). Such lavas are of interest through their association with porphyry copper-gold and epithermal gold-type mineralization, and because they are believed to result from the termination of a subduction zone due to plate collision (Barberi, *et al.*, 1974; Kolios, *et al.*, 1980; Venturelli, *et al.*, 1984). Consequently, their presence at Tillicum Mountain is possibly significant with regard to both the tectonic environment of the volcanism and the source of the skarn-related precious metal mineralization in the district (Ray, *et al.*, this volume). The peculiar composition of the Tillicum Mountain volcanic rocks suggests that they correlate with either the Lower Jurassic Rossland Group, which is mainly shoshonitic (Beddoe-Stevens, 1982), or, less likely, with the central belt of the Upper Triassic Nicola Group, which is also shoshonitic (Spence, 1985).

GEOLOGY OF THE TILLICUM MOUNTAIN AREA

The metavolcanic rocks analysed in this study form part of a predominantly metasedimentary succession within the highly deformed, easterly trending Nemo Lakes belt (Parrish, 1981). This belt represents a 5-kilometre-wide roof pendant; to the north and west it is intruded by the Goatcanyon-Halifax Creeks stock of Jurassic and/or Cretaceous age (Hyndman, 1968), while to the south it is invaded by the Nemo Lakes quartz monzonite stock of Eocene age (Parrish, 1981).

Supracrustal rocks of the Nemo Lakes belt in the Tillicum Mountain area are dominated by metamorphosed siltstone, calcareous siltstone, arkose, and wacke, with lesser amounts of mafic volcanic rock, tuff, argillite, impure carbonate, and marble layers. No marker horizons are recognized in the supracrustal succession, which exhibits rapid lateral and vertical changes in lithology (Ray, *et al.*, 1985). Despite the deformation and metamorphism, some sedimentary structures, including grading and crossbedding, are locally preserved. The supracrustal rocks underwent a post-Early Jurassic phase of regional metamorphism and folding (Hyndman, 1968; Parrish, 1981) that predates the Middle to Late Jurassic intrusion of the granitoid stocks (Read and Wheeler, 1976). This resulted in sillimanite grade metamorphism throughout most of the Nemo Lakes belt (Parrish, 1981); however, the metamorphic grade was lower around Tillicum Mountain and resulted in the formation of biotite, muscovite, chlorite, and amphibole. In addition to the regional metamorphism, the rocks were locally subjected to two episodes of contact metamorphism. The first is associated with swarms of dioritic sills that probably accompanied the regional deformation; these sills are apparently related to some gold and silver-bearing skarns in the district (Roberts and McClintock, 1984; Ray, *et al.*, 1985). The second hornfelsing is related to intrusion of the large granitoid stocks and postdates the regional deformation.

The age, stratigraphy, and structure of the supracrustal rocks at Tillicum Mountain is uncertain. Little (1960) included them in the Triassic to Early Jurassic (?) Slocan and Lower Jurassic Rossland Groups, while Hyndman (1968) split the section, correlating the basic volcanic rocks on the northwestern slopes of Tillicum Mountain with the Triassic Kaslo Group, and the remaining metasedimentary rocks with the Pennsylvanian to Triassic Milford Group. Ray, *et al.* (1985) concluded from structural data and sedimentary tops that the volcanic and volcaniclastic sequence at Tillicum Mountain is older than the largely metasedimentary succession lying further south and southeast. However, no evidence of either a structural break or an unconformity was found between the two.

GEOLOGY OF THE TILLICUM MOUNTAIN VOLCANIC ROCKS

The mafic volcanic rocks sampled in this geochemical study are largely confined to an area north and west of Tillicum Mountain (*see* Fig. 3-1, Ray, *et al.*, this volume), where they are interlayered with mafic tuff, volcanic breccia, and some argillite. This volcanic-volcaniclastic-argillite sequence forms an arcuate, apparently folded unit over 500 metres in outcrop width. The volcanic rocks are massive to weakly layered to schistose; they comprise hornblende and calcic plagioclase, with lesser amounts of biotite, chlorite, tremolite-actinolite, and carbonate. Some flows are characterized by flow brecciated margins and deformed, feldspar-filled amygdales up to 0.5 centimetre in diameter. The tuffs and coarse volcaniclastic rocks locally contain coarse hornblende crystals up 1.5 centimetres in diameter and some stretched clasts.

GEOCHEMISTRY OF THE TILLICUM MOUNTAIN VOLCANIC ROCKS

Five analyses of basalts from a restricted area near the gold-rich Heino Money zone (Ray, *et al.*, 1985) were published by Kwong (1985); these are now interpreted to be shoshonites. For this study, whole rock analyses were completed on 12 samples of the Tillicum volcanic rocks (Table 4-1); these rocks were also analysed for Zr, Y, Cr, Sr, Rb, and Ba (Table 4-2). The samples were collected from volcanic flows over a wide area north and west of Tillicum Mountain, and care was taken to ensure they were not affected by skarn alteration. Various plots of this data, including the five analyses published by Kwong (1985), are illustrated on Figures 4-1 to 4-9.

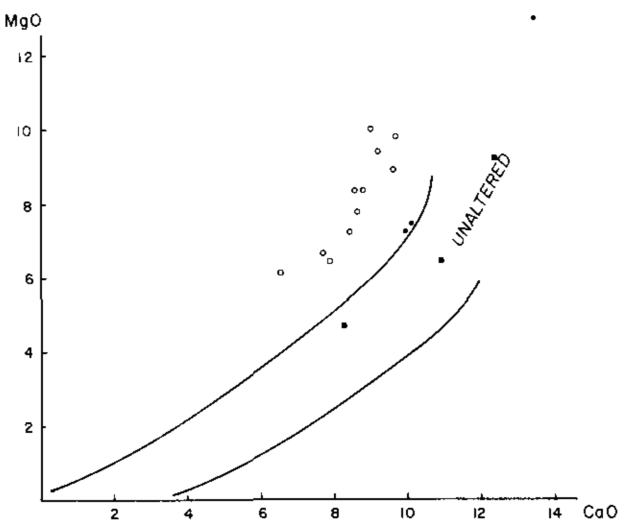

Figure 4-1. Weight percent MgO:CaO plot designed to screen 'unaltered' (filled symbols) and 'altered' (open symbols) samples. Circles: data from this study (least altered samples as filled circles), squares: data from Kwong (1985). Unaltered domain from de Rosen-Spence (1976).

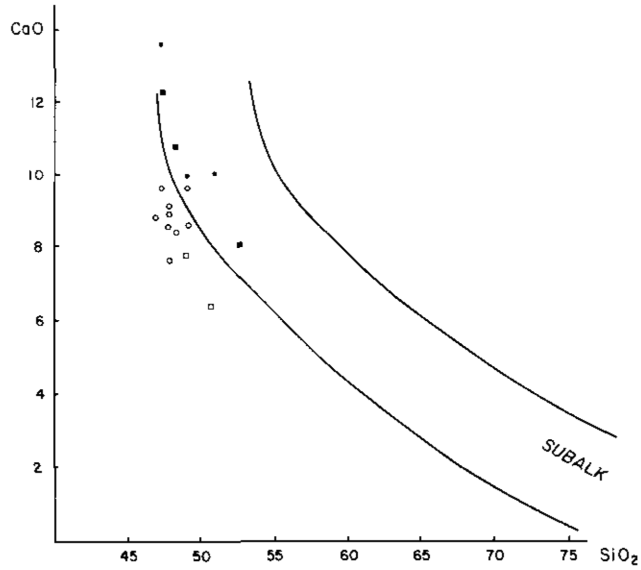

Figure 4-3. Weight per cent $CaO:SiO_2$ plot shows 'unaltered' and least altered samples in the subalkaline domain. Altered samples have lost CaO. Boundaries from de Rosen-Spence (1976).

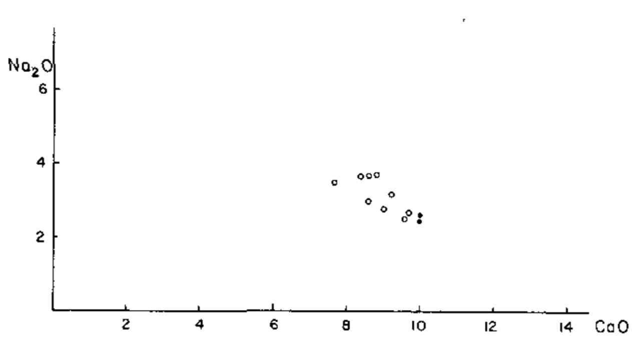

Figure 4-5. Weight per cent $Na_2O:CaO$ plot shows increase in Na_2O with decrease in CaO in altered samples, which indicates spilitization.

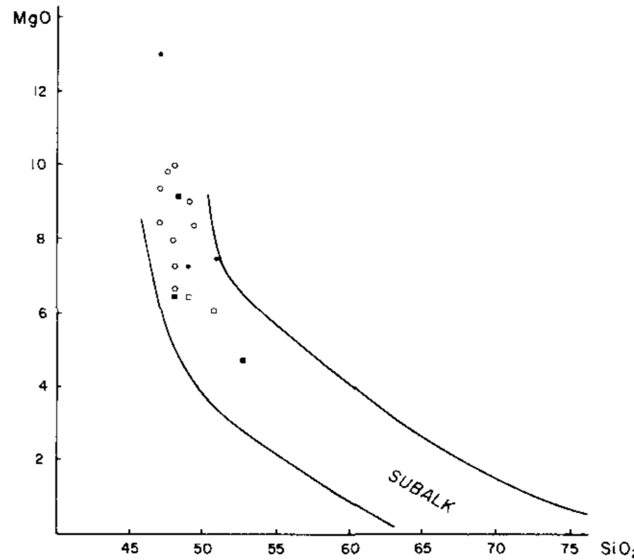

Figure 4-2. Weight per cent $MgO:SiO_2$ plot. All Tillicum Mountain basalts plot in the subalkaline domain. Sample with highest MgO is a pyroxenite. Boundaries from de Rosen-Spence (1976).

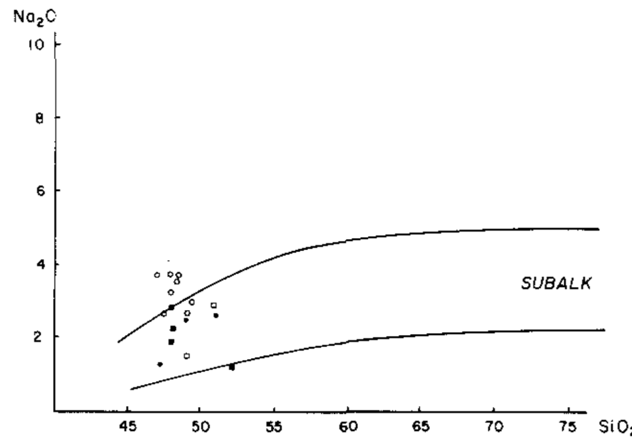

Figure 4-4. Weight per cent $Na_2O:SiO_2$ plot shows 'unaltered' and least altered samples in the subalkaline domain. Several altered samples have gained Na_2O. Boundaries from de Rosen-Spence (1976).

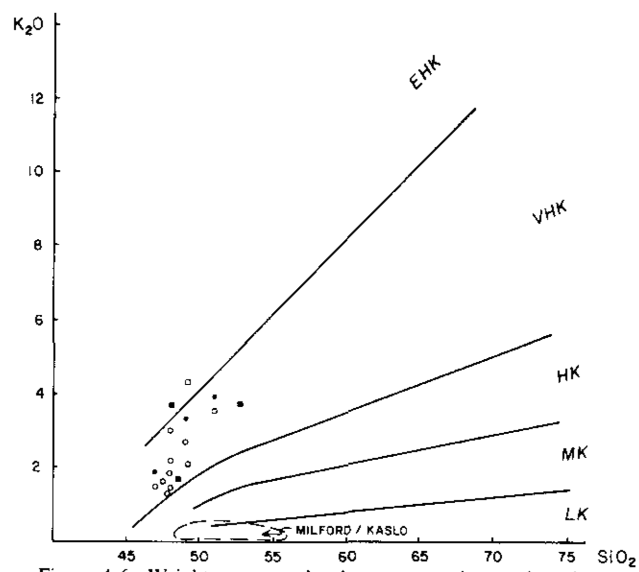

Figure 4-6. Weight per cent plot demonstrates the consistently very high K_2O content of the Tillicum Mountain basalts. Low (LK), medium (MK), and high (HK) K_2O domains from Gill (1981); very high (VHK) and extreme high (EHK) K_2O domains from Spence (1985). Note the Milford-Kaslo Groups volcanic rocks plot in the low K_2O (LK) field.

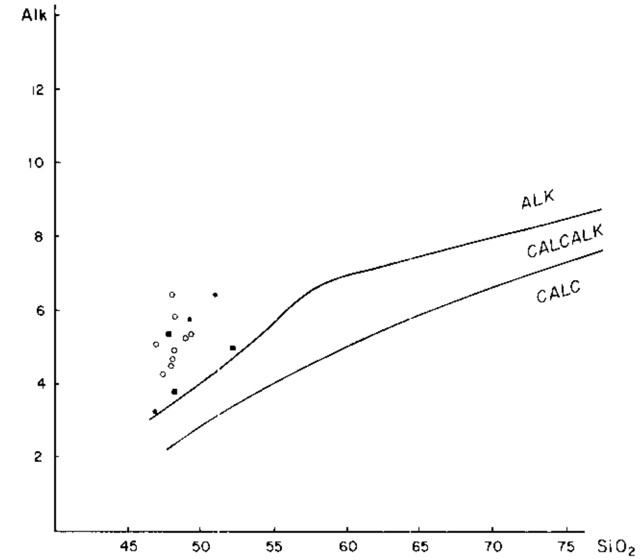

Figure 4-7. Weight per cent Alk:SiO_2 plot illustrates the alkaline nature of the Tillicum Mountain basalts. Boundaries from Kuno (1966), high-Al domain relabelled 'calc-alkaline' and tholeiitic domain 'calcic.'

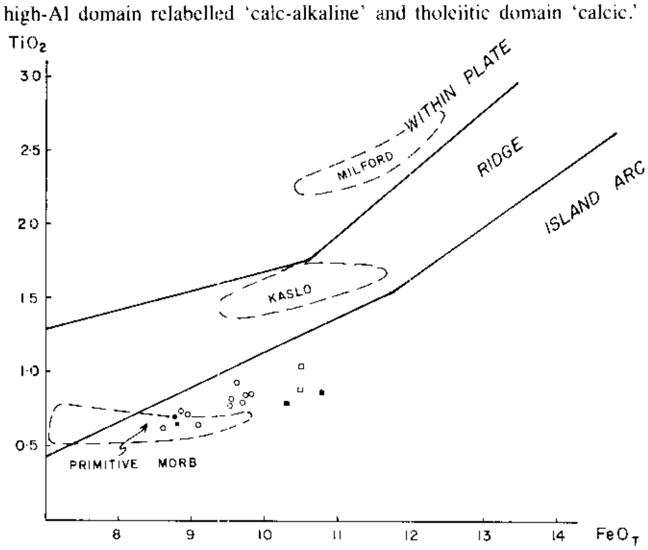

Figure 4-8. Weight per cent TiO_2:FeO_T plot designed for basalts with SiO_2 between 48 and 50.5 per cent. The Tillicum Mountain basalts are distinctly arc-type; Milford and Kaslo Group volcanic rocks plot in the within-plate and ridge domains in keeping with their setting in the Slide Mountain Terrane.

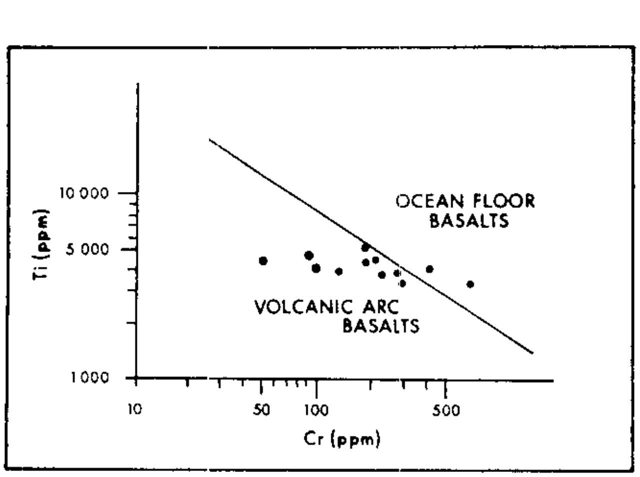

Figure 4-9. Log titanium-log chromium plot (after Pearce, 1975) of the Tillicum Mountain basalts listed in Table 4-2, showing their volcanic arc characteristics.

The MgO:CaO plot on Figure 4- . illustrates that the majority of the Tillicum Mountain basalts are 'altered' and/or may possess olivine cumulates in the more magnesium-rich samples. However, three samples presented by Kwong (1985) plot in the 'unaltered' field and may assist in confirming the magmatic trends. High values of MgO in several samples (Fig. 4-2) and generally low values of CaO for the altered samples (Fig. 4-3) account for the scatter of points on Figure 4-1.

The distribution of Na_2O values (Fig. 4-4) within the subalkaline domain, and the quasi-linear relationship between CaO and Na_2O (Fig. 4-5), suggest that spilitization is responsible for the low CaO and high Na_2O contents of some altered samples. However, the consistently very high K_2O (VHK) content of these rocks (Fig. 4-6) was not modified by spilitization. The subalkaline Na_2O and very high K_2O (VHK) content of these rocks results in an alkaline trend (Fig. 4-7) which is a major, diagnostic characteristic of shoshonitic suites (Spence, 1985). Despite weak spilitization, nine of the twelve samples analysed here have K_2O/Na_2O >0.6 for SiO_2 <50 per cent, which is characteristic for shoshonitic suites (Mackenzie and Chappell, 1972).

Contents of other elements are also in ranges that are characteristic of shoshonites (Tables 4-1 and 4-2): Al_2O_3 is variable and unrelated to the total iron, which is constant and low (<11 per cent); TiO_2 is also low (<1 per cent), while the Sr and Ba contents are high. Titanium plots are shown against total ferrous iron (Fig. 4-8), and chromium (Fig. 4-9); these demonstrate unequivocally that Tillicum Mountain volcanism took place in an arc environment.

These basaltic rocks are mafic and classify mainly (10 samples) as absarokite (SiO_2 <50 per cent); one sample is a shoshonite (SiO_2 >50 per cent) and one is an ultramafic pyroxenite with low Al_2O_3 (9 per cent) and high MgO and CaO (both 13 per cent). In conclusion, this geochemical study establishes the shoshonitic and arc character of the Tillicum Mountain basalts.

CORRELATIONS

The age of the Tillicum basalts and associated sedimentary rocks is controversial in the absence of radiometric and fossil data. The metasedimentary and metavolcanic rocks were placed in the Slocan (Triassic to Lower Jurassic) and Rossland (Lower Jurassic) Groups respectively by Little (1960). Hyndman (1968), however, correlated them respectively with the Milford Group (then considered to be Pennsylvanian to Triassic) and the Kaslo Group (then considered to be Triassic). Doubts were cast on Hyndman's correlations after the first analyses of basalts from Tillicum Mountain (Kwong, 1985) and the Milford and Kaslo Groups (Klepacki, pers. comm., 1985) became available. Indeed, basaltic rocks in the Milford Group (now Pennsylvanian) and Kaslo Group (now Permian; Klepacki and Wheeler, 1985) are tholeiites, being lower in K_2O (Fig. 4-6) and falling in the within-plate and ridge domains respectively (Fig. 4-8); shoshonites are absent in these settings.

Arc shoshonites, however, are present in both the Elise Formation of the Lower Jurassic Rossland Group (Beddoe-Stevens, 1982), situated 60 kilometres south of Tillicum Mountain, and in the central belt of the Upper Triassic Nicola Group (Spence, 1985), lying 200 kilometres to the west. Correlation with the Sinemur ian to Toarcian Elise Formation is favoured by the authors. The sedimentary rocks are apparently younger than the basalts (Ray, *et al.*, 1985) and may therefore correlate with the Lower and Middle Jurassic Archibald and Hall Formations of the Rossland Group.

The Rossland Group is not an isolated occurrence of Lower Jurassic shoshonitic volcanism. It lies at the southern end of a shoshonitic belt that includes high-K calc-alkaline and alkaline sodic rocks, and extends northward through the Horsefly area into the Toodoggone area (Spence, 1985). Triassic-Jurassic volcanic rocks of the Vernon area may provide the link between the Tillicum Mountain and Horsefly areas.

TABLE 4-1
MAJOR ELEMENT ANALYTICAL RESULTS FOR TILLICUM MOUNTAIN VOLCANIC ROCKS
(All values in per cent)

Lab No.	SiO_2	Al_2O_3	Fe_2O_{3T}*	FeO	MgO	CaO	Na_2O	K_2O	TiO_2	MnO	Total
29330	48.05	15.25	10.79	8.35	9.43	9.20	3.23	1.38	0.81	0.190	99.7
29331	48.17	16.53	10.90	8.44	7.76	8.61	3.70	1.30	0.84	0.191	99.5
29332	47.99	14.61	10.76	8.40	10.04	9.02	2.78	1.82	0.82	0.190	100.4
29333	47.53	15.09	10.52	7.73	9.91	9.67	2.71	1.63	0.78	0.164	99.8
29334	49.23	14.31	9.72	8.01	7.31	9.98	2.52	3.29	0.73	0.168	99.6
29335	48.13	16.84	10.60	8.50	6.68	7.73	3.47	3.05	0.82	0.183	100.0
29336	49.32	15.39	10.71	8.38	8.44	8.64	3.01	2.14	0.96	0.244	100.1
29337	51.13	13.01	9.78	7.07	7.47	10.09	2.59	3.92	0.69	0.189	100.7
29338	48.27	16.28	9.82	7.58	7.31	8.44	3.66	2.26	0.75	0.183	99.7
29339	47.18	9.10	9.47	7.57	13.07	13.37	1.32	1.87	0.65	0.189	99.3
29340	49.00	13.67	10.17	8.03	8.99	9.59	2.62	2.72	0.66	0.175	100.2
29341	46.97	15.83	9.74	6.39	8.55	8.84	3.66	1.46	0.73	0.162	99.8

* Total iron expressed as Fe_2O_3.
Major element analysis by Flame AAS with a precision of 0.75% RSD.

TABLE 4-2
TRACE ELEMENT ANALYTICAL RESULTS FOR TILLICUM MOUNTAIN VOLCANIC ROCKS
(All values in ppm)

Lab No.	Zr	Y	Cr	Sr	Rb	Ba
29330	72	6	210	980	27	410
29331	63	8	90	900	45	580
29332	78	3	220	530	69	410
29333	63	2	430	480	39	410
29334	61	1	140	2 420	75	580
29335	54	13	50	1 480	79	780
29336	59	7	200	1 260	70	680
29337	30	13	310	1 250	151	520
29338	51	7	110	1 200	50	610
29339	54	15	790	820	55	220
29340	53	15	320	1 270	88	620
29341	58	5	240	570	57	480

Zr, Y, and Rb analyses by XRF heavy absorber (Borate Fusion).
Cr, Sr, and Ba analyses by Flame AAS (Borate Fusion).

TECTONIC SIGNIFICANCE

Shoshonitic volcanism can be generated at a stage when plate collision results in the steepening and cessation of a subduction zone, which in turn leads to deep melting of mantle rocks in the presence of water enriched in incompatible elements. In recent arcs, two periods of shoshonitic activity have been documented (Kolios, *et al.*, 1980). One is related to an existing but dying subduction zone and is associated with calc-alkaline volcanism; the other is later, occurring after the termination of subduction, and is related to rifting and local extensional movements within areas of large plate convergence.

The Upper Triassic shoshonitic volcanism in central British Columbia occurred during docking of the Stikine, Cache Creek, and Quesnel Terranes in a subduction-related arc which produced tholeiitic, medium-K calc-alkaline, and alkaline sodic sequences. In contrast, the Lower Jurassic shoshonitic volcanism is associated only with high-K calc-alkaline and alkaline sodic volcanism, but was situated east of the contemporaneous calc-alkaline Hazelton (Howson facies) arc (Tipper and Richards, 1976). It is uncertain whether the Lower Jurassic shoshonites represent a late episode of the volcanism initiated in Upper Triassic time, or whether they are related to the destruction of the Hazelton subduction zone at depth.

CONCLUSIONS

This geochemical data establishes the arc shonshonitic (absarokite) character of the Tillicum Mountain basalts. Their composition is incompatible with oceanic-type tholeiites of the Upper Paleozoic Milford and Kaslo Groups to the east. They are best correlated with the shoshonitic Elise Formation of the Rossland Group to the south; they would thus form part of the Lower Jurassic shoshonitic belt which extends northward into the Toodoggone area. This work also suggests that the Rossland Group in general, and the Elise Formation in particular may represent favourable units for hosting other skarn-related precious metal deposits similar to those seen at Tillicum Mountain (Ray, *et al.*, this volume).

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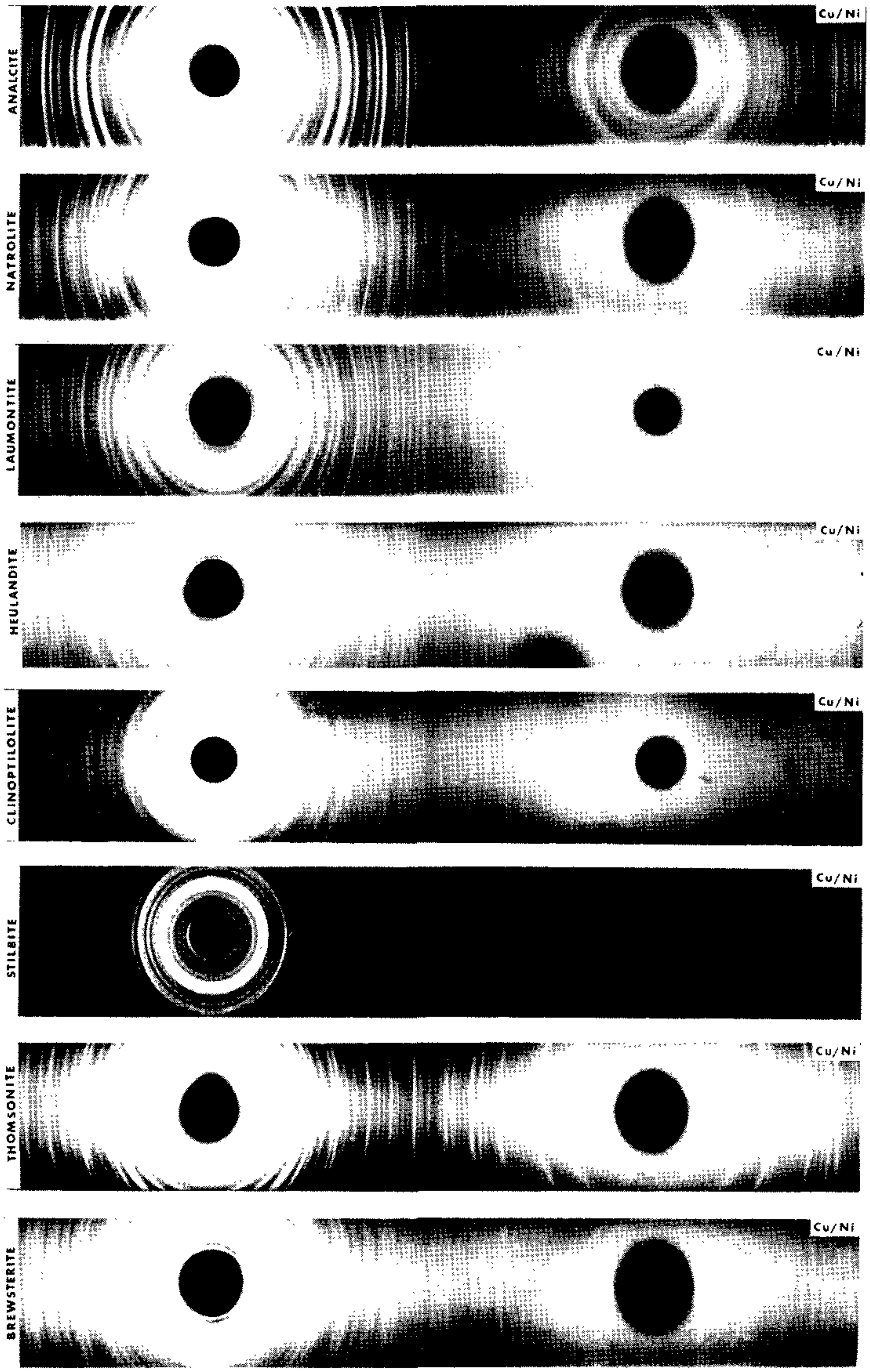

Plate 5-1. X-ray powder diffraction patterns for some common zeolites.

British Columbia Geological Survey
Geological Fieldwork 1985

ZEOLITES IN EOCENE ROCKS OF THE PENTICTON GROUP, OKANAGAN-BOUNDARY REGION SOUTH-CENTRAL BRITISH COLUMBIA (82E)

By Z. D. Hora and B. N. Church

INTRODUCTION

A survey of Early Tertiary rocks of the Okanagan and Boundary areas (Church, 1963, 1973) led to discovery of a large variety of zeolites in both volcanic and sedimentary formations of the Penticton Group. The most common of these are natrolite, laumontite, and heulandite (Plate 5-1). Subsequent re-examination of the original survey samples by Z. D. Hora indicated local abundance of clinoptilolite.

The importance of the clinoptilolite discovery stems from industrial use of this mineral. Clinoptilolite resembles heulandite and belongs to the same mineral-chemical series of hydrous calcium-sodium aluminum silicates. Unlike heulandite, however, clinoptilolite is stable at relatively high temperatures and displays remarkable base exchange and absorption properties. Clinoptilolite has the capacity to absorb ammonia and is well known as a cation sieve in removing cesium from solutions. The list of uses includes fillers and carriers, a component in some construction materials, waste water treatment, and petroleum refining.

The purpose of this report is to provide preliminary information on the occurrence of zeolites in Early Tertiary rocks, indicating their stratigraphic range and regional distribution.

GEOLOGICAL SETTING

The principal Early Tertiary rocks of the Okanagan-Boundary area are assigned to the Penticton Group which, in the type area near Penticton, consists of six formations having a total thickness of about 2 500 metres (Fig. 5-1). The age range for the group, according to K/Ar analyses, is 48.4 Ma (whole rock) to 53.1 Ma (biotite) ± 1.8 Ma. Structural control of these rocks appears to have been meridianally directed maximum stresses that produced rifting and many graben and half-graben structures.

ZEOLITE OCCURRENCES

Formations in the lower and middle part of the Penticton Group are locally enriched in zeolites. These include the basal Springbrook and coeval Kettle River sedimentary rocks as well as immediately overlying volcanic members of the Marron Formation. Clinoptilolite shows a preferential occurrence as a fine-grained matrix in volcaniclastic rocks such as commonly found in the White Lake Formation, which rests unconformably on the Marron rocks.

PENTICTON TERTIARY OUTLIER

The type section of the Marron Formation is displayed near the west margin of the Penticton Tertiary outlier (Fig. 5-1, section A-B), where the tiered lava units of this sequence overlook Yellow Lake. The Yellow Lake volcanics, lowest member of the Marron Formation, are visibly enriched in zeolites in fresh outcrops along Highway 3. These rocks are typically grey mafic phonolite lavas with dark pyroxene phenocrysts and light-coloured natrolite-filled amygdales. Calcite and analcite commonly accompany natrolite lining the gas cavities: thomsonite and mordenite are less common. Pink laumontite-leonhardite occurs with calcite in veinlets along the main and satellitic fractures.

The occurrence of primary analcite as phenocrysts and in the groundmass of the Yellow Lake lavas (Daly, 1912) is indicative of silica undersaturation (Church, 1978). This characteristic is believed to have been an important factor favouring the development of zeolites in these host rocks.

The trachytes of the Kitley Lake and Nimpit Lake members, near the middle of the Marron section, host several small zeolite localities. These consist of heulandite and, less commonly, brewsterite on small fissures. North of section A-B, a brownish tuffaceous grit and siltstone unit at the base of the Nimpit lava was found to contain clinoptilolite and analcite in the 10 to 20 per cent range (Table 5-1, Nos. 2 and 3).

Elsewhere in the Penticton Tertiary outlier, clinoptilolite was found interstitially in sedimentary rocks in the Springbrook Formation (Table 5-1, No. 1) and in tuffaceous sandstones at the base of the Kearns Creek member in the middle of the Marron Formation (Table 5-1, Nos. 4, 5, and 6).

SUMMERLAND TERTIARY OUTLIER

The Summerland Tertiary outlier is a remnant of a caldera structure with only a fragmentary representation of the middle sequence of the Penticton Group (Church, 1979). The single observed zeolite occurrence in the Nimpit trachyte lavas and ash flows, which underlie most of the basin, is a veinlet of heulandite found midway on the summit ridge of Mount Conkle, 3 kilometres southwest of Summerland. In contrast, a broad apron of sandstones and conglomerates assigned to the White Lake Formation, flanking Giants Head dacite dome on the west and north, shows a wide distribution of clinoptilolite, laumontite, and stilbite (Table 5-1, Nos. 7 to 15).

KELOWNA TERTIARY OUTLIER

The Kelowna Tertiary outlier is a larger copy of the Summerland caldera (Church, 1980b). Again, the White Lake Formation, consisting of a mixture of volcanic breccias, tuff, sandstones, and conglomerates, hosts numerous occurrences of authigenic clinoptilolite and laumontite (Table 5-1, Nos. 16 to 23).

ROCK CREEK TERTIARY OUTLIER

The Rock Creek Tertiary outlier consists of a series of down-faulted panels of mainly Kettle River sedimentary rocks and Yellow Lake volcanics (Church, 1980c). The area includes two of six known localities of analcite-bearing shackanite lava (Fig. 5-2). Red shale from the Storm Hill member and tuffaceous arkose from the Ed James Lake member of the Kettle River Formation contain significant amounts of analcite (wairakite ?) and stilbite (Table 5-1, Nos. 24 and 25).

CONCLUSIONS

Zeolites in the Penticton Group appear to be most abundant in the lowest part of the section suggesting, at first, a low-grade regional metamorphic effect. However, the close association of natrolite and

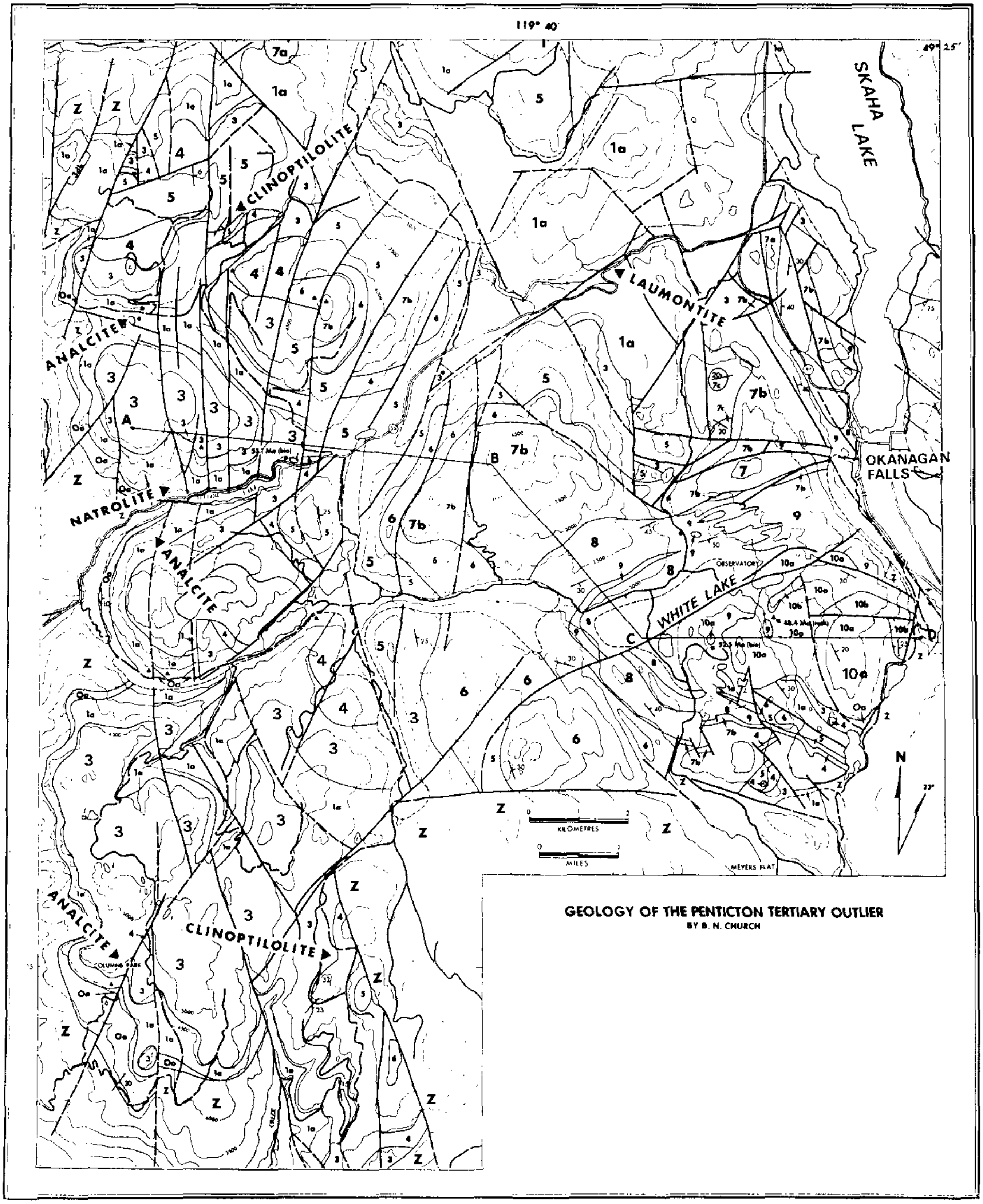

Figure 5-1. Geology of the Penticton Tertiary outlier.

LEGEND

MIOCENE

(OLALLA RHYOLITE)

| 11 | MOSTLY RHYOLITE BRECCIA, SOME MASSIVE OBSIDIAN, AND ASSOCIATED DYKES

EOCENE

PENTICTON GROUP

SKAHA FORMATION

| 10a | MOSTLY CHERT AND GREENSTONE SLIDE BRECCIA AND SOME TEPHRITE LAVA OVERLAIN BY POLYMICTIC FANGLOMERATE

| 10b | CHANNEL DEPOSIT OF GRANITE BOULDER CONGLOMERATE AND BRECCIA AND ARKOSIC SANDSTONES

WHITE LAKE FORMATION

| 9 | MOSTLY VOLCANIC BRECCIAS INCLUDING PYROCLASTIC ROCKS AND LAHARS, MINOR TRACHYTIC AND ANDESITIC LAVAS

| 8 | VOLCANIC CONGLOMERATE, SANDSTONES, AND SHALES

MARAMA FORMATION

| 7a | AENEAS BUTTE FELDSPATHIC DACITE

| 7b | MASSIVE APHANITIC DACITE LAVA AND SOME BRECCIA FORMING MOSTLY REMNANTS OF VOLCANIC DOMES

| 7c | VOLCANIC CONGLOMERATE WITH CLASTS FROM THE MARRON FORMATION

MARRON FORMATION

| 6 | PARK HILL MEMBER: MEROCRYSTALLINE ANDESITE LAVA AND MINOR BRECCIA

| 5 | NIMPIT LAKE MEMBER: TAN TRACHYTE AND TRACHYANDESITE LAVA AND MINOR BRECCIA

| 4 | KEARNS CREEK MEMBER: VESICULAR PYROXENE-RICH BASALTIC ANDESITE LAVA

EOCENE *(CONTINUED)*

MARRON FORMATION *(CONTINUED)*

| 3 | KITLEY LAKE MEMBER: TRACHYANDESITE LAVA WITH CONSPICUOUS GLOMEROPHENOCRYSTIC CLOTS OF FELDSPAR

| 2 | SHATFORD CREEK MEMBER: LOCAL DEPOSIT OF BROWN ANDESITE LAVA AND BRECCIA WITH SOME QUARTZ-FILLED AMYGDALES

YELLOW LAKE MEMBER

| 1a | MOSTLY PYROXENE-RICH MAFIC PHONOLITE LAVA WITH LOCAL WELL-DEVELOPED PHENOCRYSTS OF RHOMBANORTHOCLASE AND SOME PRIMARY ANALCITE, ABUNDANT ZEOLITE FILLINGS IN CRACKS AND AMYGDALES

| 1b | PURPLE AND GREY VOLCANIC WACKE FROM EROSION OF 1a AND PINK RADIOACTIVE FELDSPATHIC TRACHYTIC ASH FLOW, SANDSTONE, AND CONGLOMERATE

| 1c | CLARK CREEK PORPHYRY: A SILL-LIKE BODY RELATED TO 1a WITH LARGE FELDSPAR PHENOCRYSTS

SPRINGBROOK FORMATION

| Oa | POLYMICTIC CONGLOMERATE AND BRECCIA WITH CLASTS DERIVED MAINLY FROM PRE-TERTIARY BEDDED ROCKS

KETTLE RIVER FORMATION

| Ob | MAINLY GRANITE BOULDER CONGLOMERATES, ARKOSE, VOLCANIC WACKE, AND RHYOLITE BRECCIA

| Oc | SHINGLE CREEK PORPHYRY: A COARSE SANIDINE QUARTZ PORPHYRY INTRUSION FEEDER TO THE RHYOLITE VOLCANIC ROCKS OF Ob

PRE-TERTIARY ROCKS

| Y | MAINLY GRANITIC INTRUSIONS

| Z | MAINLY CHERTS, GREENSTONES, SCHISTOSE ROCKS, AND MINOR INTRUSIONS

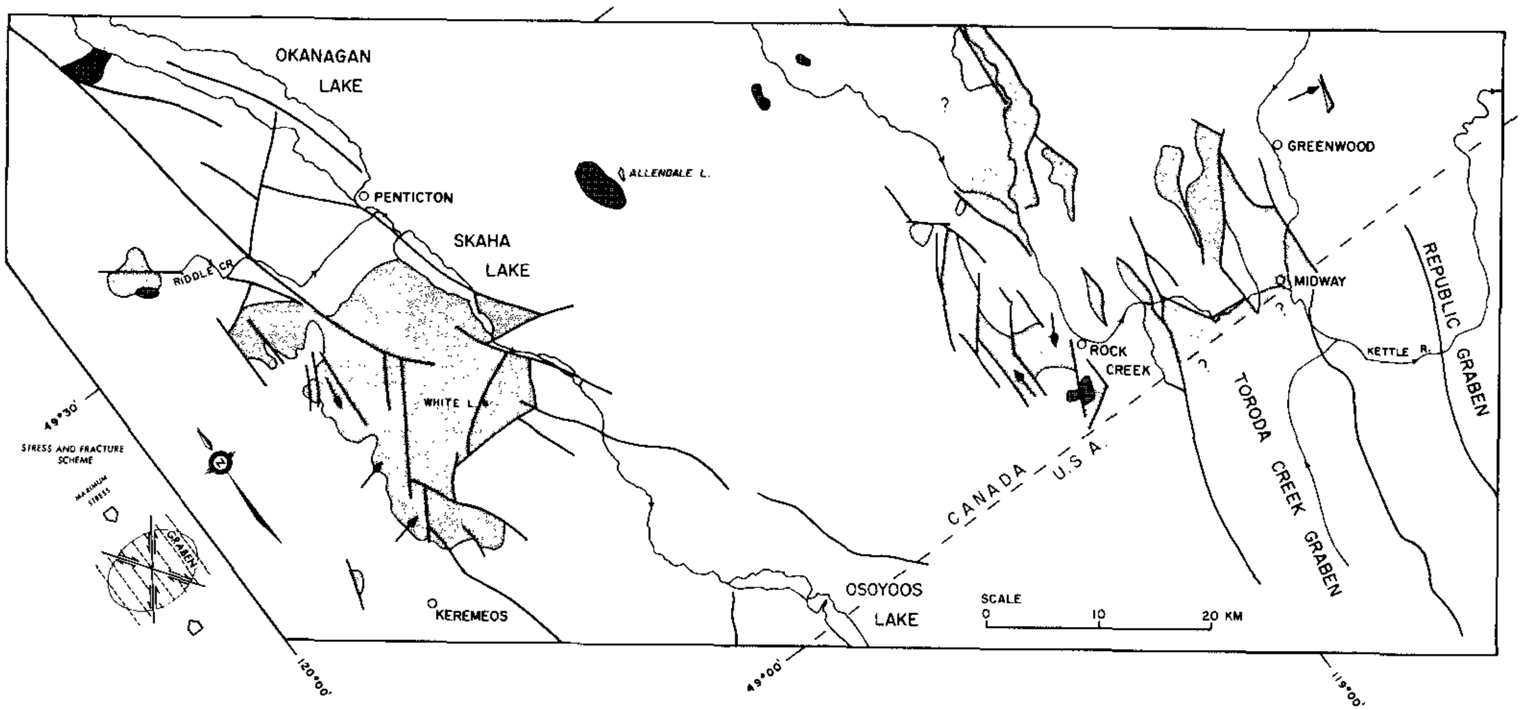

Figure 5-2. Distribution of analcite-bearing lavas in area of downfaulted Yellow Lake phonolite and mafic phonolite and Coryell source intrusions.

TABLE 5-1
ZEOLITES IN TERTIARY SEDIMENTARY ROCKS

No.	Coordinates (UTM) Easting	Northing	Description (X-ray Determinations)*
1	2967	54722	trace clinoptilolite
2	2998	54738	30% analcite, 10% clinoptilolite
3	2994	54748	20% clinoptilolite, trace analcite
4	3012	54579	20% clinoptilolite
5	3013	54571	5% clinoptilolite
6	3012	54585	8% clinoptilolite
7	3071	54950	10% clinoptilolite
8	3064	54946	5% sodium stilbite
9	3057	54958	5% sodium stilbite
10	3056	54945	8% clinoptilolite
11	3062	54957	8% clinoptilolite
12	3058	54964	8% clinoptilolite
13	3061	54964	10% clinoptilolite
14	3064	54996	10% laumontite, trace ferrierite
15	3065	54995	10% clinoptilolite
16	3044	55240	8% clinoptilolite
17	3048	55240	15% clinoptilolite
18	3078	55243	10% clinoptilolite
19	3071	55193	trace laumontite
20	3094	55219	10% laumontite
21	3093	55217	30% laumontite
22	3096	55256	10% clinoptilolite
23	3126	55254	8% laumontite
24	3635	54290	20% analcite (wairakite)
25	3485	54549	35% sodium stilbite

* Approximate values by XRD.

secondary analcite with undersaturated sodic volcanics of the Yellow Lake member may indicate that these minerals formed from deuteric solutions at the time of cooling of the lavas. Also, the occurrence of some laumontite and heulandite in fissures throughout wide sections of the Penticton Group indicates open hydrothermal plumbing systems. Indeed, the frequent association of clinoptilolite with tuffaceous sedimentary rocks high in the White Lake section suggests at least some is of authigenic or early diagenetic origin.

The discovery of clinoptilolite in Tertiary outliers of the Okanagan-Boundary region is of economic interest, however, none of the occurrences listed (Table 5-1) attains the present minimum commercial grade of 80 per cent. Nevertheless the wide distribution of clinoptilolite indicated by this preliminary work warrants additional study and careful prospecting.

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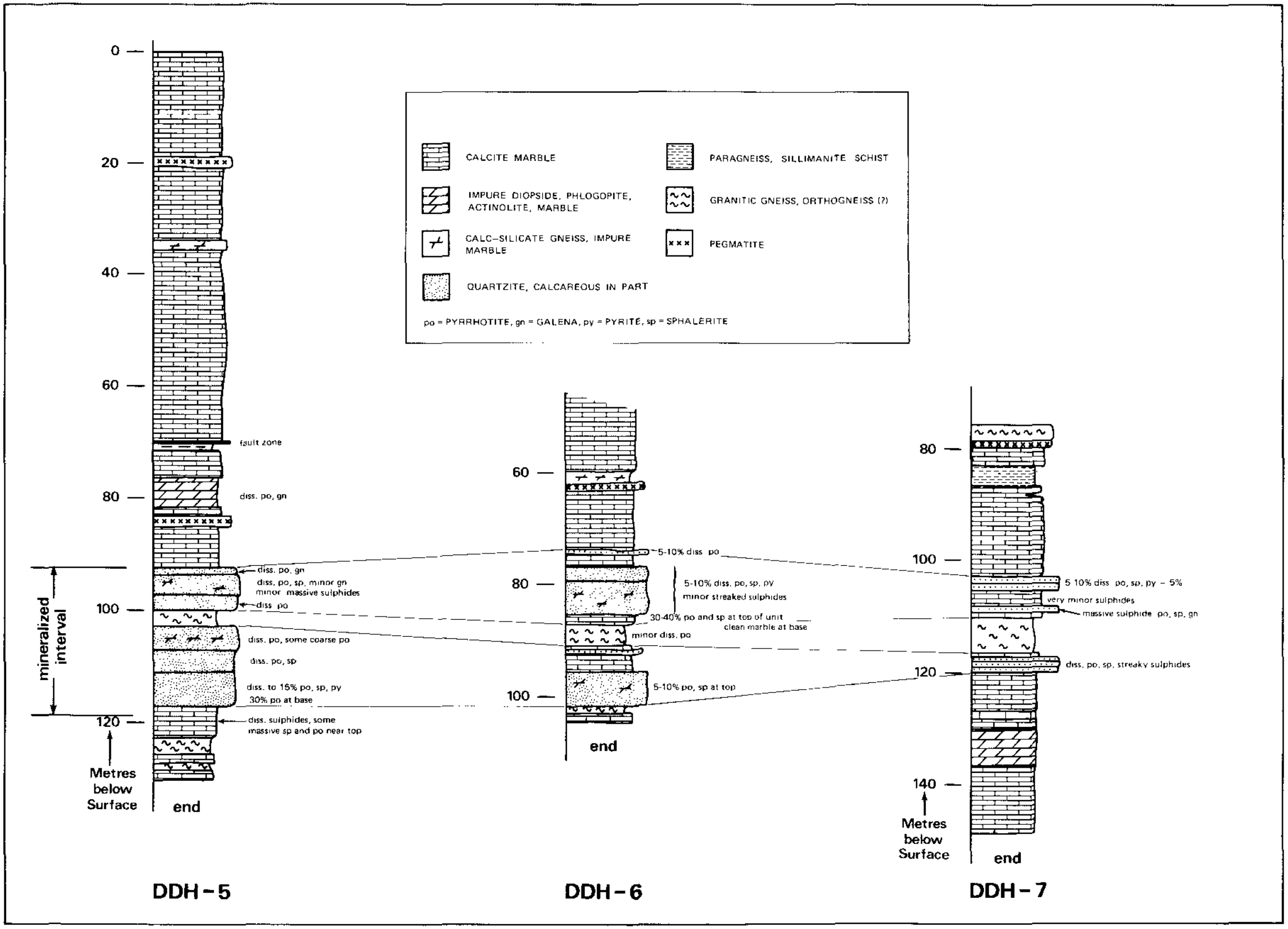

Figure 6-1. Diamond drill-hole sections through the mineralized interval of the Sherpa lead-zinc occurrence.

THE REBAR AND SHERPA LEAD-ZINC OCCURRENCES, SHUSWAP COMPLEX (82L/10)

By T. Höy

INTRODUCTION

The Rebar and Sherpa lead-zinc occurrences are both within the Monashee Mountains just east of Mabel Lake. Sherpa is a strata-bound zinc-(lead) occurrence located on the moderately west-dipping slopes above the east shore of Mabel Lake; Rebar includes a number of scattered boulders of rusty weathering massive sulphides located on the north slope of Tsuius Creek 6 kilometres to the east-southeast. A third mineralized occurrence in the immediate area, the D.S.-Rebar, is an unusual lead-quartzite deposit located 2 kilometres northeast of Rebar.

The Rebar and Sherpa claims were staked in 1982 by J. M. Leask to cover an area where high-grade sphalerite-galena-pyrite boulders had been discovered. Noranda Exploration Co., Ltd. optioned the property in 1983, and conducted a soil geochemical survey on the Sherpa claims (Bryan, 1983). During the 1984 field season, the property was mapped by Jim McDonald of Noranda, a geophysical survey was conducted (Bradish, 1984), and seven holes were drilled — three on the Sherpa claims and four on the Rebar claims. The D.S.-Rebar showing was discovered in late 1983 by I. Saunders and mapped during the 1984 season by Noranda. Continued work during the latter part of the 1985 field season included primarily surface geological mapping.

REGIONAL GEOLOGY

The Rebar-Sherpa area is within the Monashee Complex (Read and Brown, 1981) near the eastern edge of the Shuswap Metamorphic Complex. The area is underlain by rocks of the Monashee Group, a heterogeneous assemblage of dominantly gneissic rocks of unknown, but probable Precambrian and Paleozoic age (Jones, 1959; Okulitch, 1979). The Thor-Odin nappe, a late structural culmination along the eastern margin of the Shuswap Complex, lies about 15 kilometres to the east.

The geology in the immediate property area is not well known. A sequence of quartzites, calc-silicate and pelitic gneisses, marbles, and amphibolites trends generally northward and dips at various angles to the east. A pronounced foliation, essentially parallel to layering, suggests that the apparently simple homoclinal sequence that hosts the mineral occurrences is, in fact, part of a complex, isoclinally folded metasedimentary package.

MINERAL OCCURRENCES

SHERPA

Mineralization on the Sherpa property includes disseminated to massive pyrrhotite and sphalerite with minor amounts of pyrite and galena in a generally impure calcareous quartzite unit within pure to siliceous marble. The unit trends northeastward and dips moderately steeply to the southeast into the hillside; its exposed length is in excess of 500 metres. Three diamond-drill holes, spaced approximately 100 metres apart, have allowed construction of several sections through the mineralized interval (Fig. 6-1).

Hangingwall rocks include in excess of 70 metres of dominantly white, coarsely crystalline calcite marble (*see* DDH 5, Fig. 6-1). Phlogopite is common throughout the marble and fine-grained graphite is disseminated in darker bands; in less pure intervals, diopside, muscovite, tremolite, and quartz occur in variable amounts. Green to grey-coloured diopside-bearing calc-silicate gneiss layers and rare sillimanite-garnet gneiss layers occur in the hangingwall. In outcrop, marbles weather to a grey colour.

Footwall rocks are generally less calcareous than hangingwall rocks but still comprise dominantly pure and impure marbles. Sillimanite gneiss, quartz-feldspar gneiss, and calc-silicate gneiss layers also occur within the upper 10 metres of footwall in drill holes 5 and 6 (Fig. 6-1). Scattered outcrops of footwall rocks, exposed in the slopes below the mineralized interval, comprise interlayered grey-weathering marble, green to grey calc-silicate gneiss, and somewhat graphitic quartz-feldspar gneiss. Further down slope, gneiss and impure quartzite predominate and calcareous rocks are less dominant. Concordant to crosscutting pegmatite bodies are common in both footwall and hangingwall rocks.

The mineralized interval ranges in thickness from 17 to 27 metres. It is dominated by calcareous to relatively pure quartzite with thin interlayers of unmineralized marble, quartzite, and gneiss. Mineralization consists dominantly of rounded, disseminated grains and irregular blebs of pyrrhotite and sphalerite in a medium-grained diopside-phlogopite quartzite and also of highly irregular, composite grains interstitial to the quartz grains. Locally, pyrite forms rounded, composite grains within massive pyrrhotite, and galena occurs in trace amounts. Other accessory minerals in the quartzite include tremolite, apatite, graphite, calcite, and minor amounts of plagioclase and sericitized K-feldspar. As well, pyrrhotite and sphalerite are disseminated in coarse, granular marble units that are within or along the edge of mineralized quartzite layers. Total sulphide content in both quartzite and marble ranges from trace amounts to 30 to 40 per cent.

At the top of the mineralized interval, drill holes 5 and 6 intersected a thin, very fine-grained granular quartzite that contains finely disseminated pyrrhotite and sphalerite and accessory phlogopite, calcite, albite, and partially sericitized K-feldspar. In drill holes 6 and 7 (Fig. 6-1), an unmineralized layer of granular, foliated biotite-quartz-feldspar gneiss underlain by relatively pure marble occurs within the mineralized section.

Zinc, lead, and silver values are generally low. One unusually high-grade surface grab sample contained 6.70 per cent zinc and 0.015 per cent lead (H84S-6, Table 6-1).

REBAR

Mineralization on the Rebar property consists of a number of very rusted sulphide boulders that are partially buried on a logging road and skid trails at an elevation of 1 100 to 1 200 metres on the north slope of Tsuius Creek, 7 to 8 kilometres east of Mabel Lake. The boulders are somewhat angular, in contrast to many rounded glacial boulders in the immediate vicinity, suggesting a local source. Overburden is deep, however, and a 4.2-metre-deep trench failed to uncover bedrock. The nearest outcrops are several hundred metres up slope. Four drill holes, the closest collared approximately 200 metres above and 400 metres to the west of the mineralized boulder trains, failed to intersect any significant mineralization. The boulders contain massive, coarse-grained, dark-coloured sphalerite and

TABLE 6-1
ASSAY DATA FOR SELECTED SAMPLES, REBAR AND SHERPA PROSPECTS

Sample No.	Occurrence	Pb %	Zn %	Cu %	Ag ppm	Ba* %	Pb/ Pb + Zn	Lithology
H84S-6	Sherpa	0.015	6.70	0.015	5	0.01	0.002	sulphide-rich quartzite
Rebar 1	Rebar	0.005	6.23	0.050	3	>2	<0.001	rusted 'massive' sulphide
Rebar 2	Rebar	5.57	27.50	0.016	7	0.15	0.17	rusted 'massive' sulphide
Rebar 3	Rebar	0.027	2.64	0.008	<2	0.05	0.01	sulphide-rich quartzite
Rebar 4A	D.S. Rebar	4.80	0.016	0.021	23	>2	>0.99	impure quartzite
Rebar 4B	D.S. Rebar	0.98	0.013	0.016	7	>2	0.99	impure quartzite

* Semiquantitative emission spectrographic analysis.

pyrrhotite with large quartz eyes in a strongly oxidized silicate (?) matrix (Rebar 1, Rebar 2, Table 6-1). Others include well-layered, coarse-grained quartzite with disseminated and irregular intergranular streaks and blebs of pyrrhotite, sphalerite, and lesser pyrite and galena (Rebar 3). Although these boulders have considerably higher metal values than mineralized samples from the Sherpa area, both the mineralization and the composition of the host rocks are similar.

D.S.-REBAR

The D.S.-Rebar is a rusty weathering layer of calcareous quartzite a few metres thick that is exposed in a logging road cut 2 kilometres northeast of Rebar. The layer trends east-west and dips north at 10 to 15 degrees. Subrounded grains of galena and sphalerite are disseminated through the layer and irregular grains are interstitial to a mosaic of angular quartz grains. Scattered grains of diopside, biotite partially altered to chlorite, and barite are common in the quartzite. The quartzite layer is underlain by interbedded feldspathic quartzites and calc-silicate gneiss layers, and overlain by a rusty, impure siliceous marble and calc-silicate gneiss sequence.

Two grab samples were assayed (Rebar 4A, 4B, Table 6-1) and show the variability of metal values. Pb/Pb + Zn ratios are extremely high, in contrast to those of the Sherpa and Rebar occurrences; silver is moderately high in one sample. Barite, recognized in thin section, is reflected by the high (>2 per cent) barium content.

DISCUSSION

The Rebar and Sherpa mineral occurrences are somewhat similar to other Shuswap lead-zinc deposits in the area including Colby on the west side of Mabel Lake and Big Ledge, 40 kilometres to the southeast. At Colby, pyrrhotite, sphalerite, and minor amounts of galena occur in a diopside-bearing quartzite as well as in adjacent calc-silicate gneiss and marble (Höy, 1977a). Massive sphalerite-pyrrhotite lenses at Big Ledge occur within dark graphitic schists that grade to biotite quartzite (Höy, 1977b).

The D.S.-Rebar is an unusual lead-quartzite occurrence, perhaps similar to the 'lead sandstone' deposits reviewed by Bjorlykke and Sangster (1981). These commonly contain accessory barite (and fluorite), have low silver content, and high Pb/Pb + Zn ratios. No other 'lead-quartzite' deposits in the Shuswap Complex are known to the author, but a number of these types have been recognized in Eocambrian Hamill Group quartzites in the Kootenay Arc (for example, 'Bannockburn,' Ronning, 1977).

In summary, these occurrences are interesting but not unique new discoveries in the Shuswap Complex. They are easily accessible and warrant further work.

ACKNOWLEDGMENTS

The author wishes to acknowledge the generous hospitality of Noranda Exploration Co., Ltd. while on a three-day visit to the property in June, 1984. Discussions with J. M. Leask, J. McDonald, I. Saunders, and D. Bent are gratefully acknowledged; their help and cooperation were much appreciated.

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REA GOLD (HILTON) AND HOMESTAKE VOLCANOGENIC SULPHIDE-BARITE DEPOSITS SOUTHEASTERN BRITISH COLUMBIA (82M/4W)

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INTRODUCTION

Rea Gold and Homestake are volcanogenic sulphide-barite deposits in Devono-Mississippian Eagle Bay Formation rocks of the Omineca Crystalline Belt in southeastern British Columbia. Homestake was discovered in 1893 and has had extensive development and intermittent production since then. Rea Gold is a recent discovery and development is confined to geological mapping, trenching, and drilling (Davidson, 1984). The deposits occur within the Shuswap Highlands, just west of Adams Lake (Fig. 7-1) and are readily accessible by gravel roads east from Louis Creek on Highway 5.

REGIONAL GEOLOGY

The Adams Plateau-Barriere area has been mapped recently by Schiarizza and Preto (1984) and the area in the immediate vicinity of Rea Gold by White (1985). The Rea Gold deposit is within a thick sequence of intermediate to felsic volcanic and volcaniclastic rocks (unit EBF, Fig. 7-1) of the Eagle Bay Formation (Schiarizza and Preto, 1984). It is underlain by predominantly sericitic phyllites, also derived from felsic to intermediate volcanic rocks (unit EBA), that host the Homestake deposit. These units are overlain by metasedimentary rocks that include mainly argillites, siltstones, and grits; they are structurally overlain to the east by predominantly mafic volcanic rocks (unit EBG), host rocks for a Pb-Zn-Ag deposit called Twin Mountain (Fig. 7-1). This succession has been regionally metamorphosed to greenschist facies and intensely deformed. A penetrative mineral foliation obscures many primary structures, and tight to isoclinal folds which often have sheared-out fold limbs makes stratigraphic correlations and construction of a composite stratigraphic succession difficult.

The regional structure is dominated by a northwest-trending tight overturned syncline (Fig. 7-1). Rea Gold is on its inverted northern limb and Homestake on its southern limb. An east-dipping thrust fault is inferred (Schiarizza and Preto, 1984) to separate the Rea-Homestake package from the structurally overlying package of more mafic volcanic rocks that hosts the Twin Mountain deposit. More detailed mapping by Corporation Falconbridge and by White (1985) has not been able, however, to confirm the existence of this fault.

REA GOLD (HILTON)

INTRODUCTION

Rea Gold was discovered in October, 1983 by A. Hilton and R. Nicholl, and optioned to Rea Gold Corporation who in turn optioned it to Corporation Falconbridge. Published drill-indicated reserves include 120 000 tonnes containing 18.2 grams gold per tonne, 141.2 grams silver per tonne, 0.85 per cent copper, 4.11 per cent zinc, and 3.67 per cent lead.

The deposit includes two thin, laterally continuous sulphide lenses that lie stratigraphically above a highly altered sequence of dominantly mafic and minor felsic tuffs. Stratigraphically above these lenses is a thin mafic tuff sequence and a thicker sequence of argillite, siltstone, and grit. The succession is inverted; hence, the 'footwall alteration zone' or 'stockwork feeder zone' now forms the hangingwall of the lenses. The following description of Rea Gold is based on one week's fieldwork, mapping trenches and logging core. Although the diagrams and report are based on this work, they reflect in part the excellent detailed work of Corporation Falconbridge geologists whose maps and cross-sections were made available to us. The report is written without the support of chemical analyses, now in progress in the Ministry Laboratory, and conclusions regarding original nature of host rocks are tentative.

ROCK UNITS

The oldest unit within the deposit area comprises predominantly mafic tuffs (unit 1) that lie at the structural top of the succession. They include ash, crystal, and lapilli tuffs with variable amounts of disseminated pyrite. They are strongly foliated, producing green phyllites and schists; more massive 'greenstone' units may be derived from mafic flows. There are thin chert bands and a noticeable increase in sericite content toward the contact with unit 2. In general, this contact is gradational and reflects, in part, an increase in alteration in the stratigraphic footwall of the deposit.

Unit 2 is the 'footwall' alteration or stockwork feeder zone of the sulphide lenses. It is very extensive in the hangingwall of the more northerly of the two lenses, called L100 (Fig. 7-2), but only a few metres thick in the hangingwall of RG8, the southern lens (Figs. 7-3 and 7-4). It includes extensively altered mafic tuffs, otherwise similar to those in unit 1, chert layers, and thin more felsic (dacite?) ash tuff layers. These units now appear as pale tan to pale green siliceous phyllites and schists interbedded with pure to sericitic chert. Alteration increases dramatically toward the contact with the sulphide lenses. It includes:

(a) silicification through introduction of silica in the form of quartz veins, and of thin to relatively thick chert layers, discontinuous chert lamellae, and 'fragmental chert;'
(b) pyrite, which is disseminated, in veins, and in discontinuous streaks; it increases from 1 to 2 per cent in unit 1 to commonly 10 to 20 per cent near the stratigraphic top of unit 2; and
(c) sericite which becomes ubiquitous within unit 2.

White (1985) also notes both local soda enrichment (as massive albite and paragonite) and carbonatization (as dolomite, iron-rich magnesite, and calcite).

British Columbia Ministry of Energy, Mines and Petroleum Resources, Geological Fieldwork, 1985, Paper 1986-1.

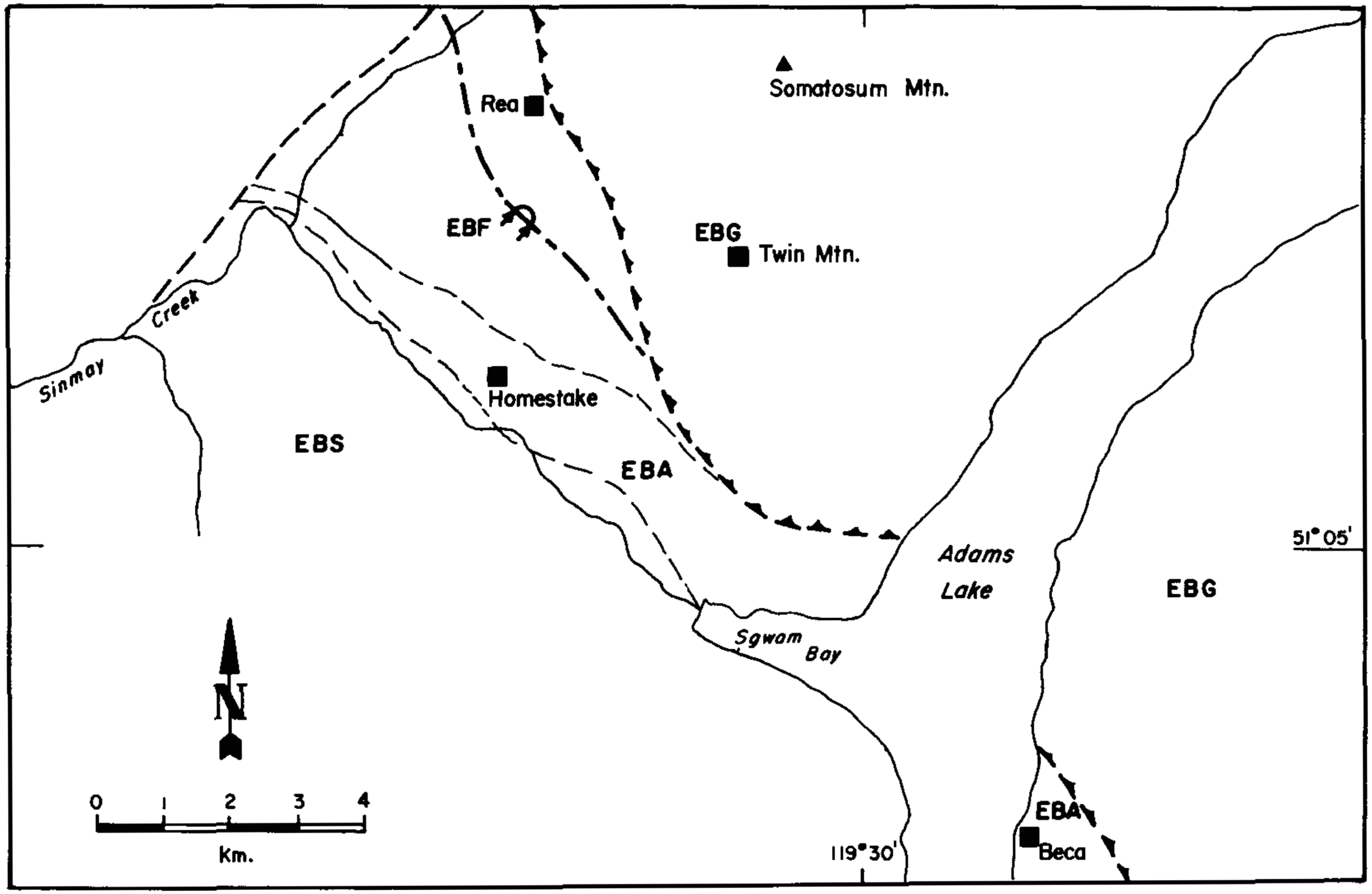

Figure 7-1. Map showing locations of Rea Gold and Homestake; geology from Schiarizza and Preto (1984).

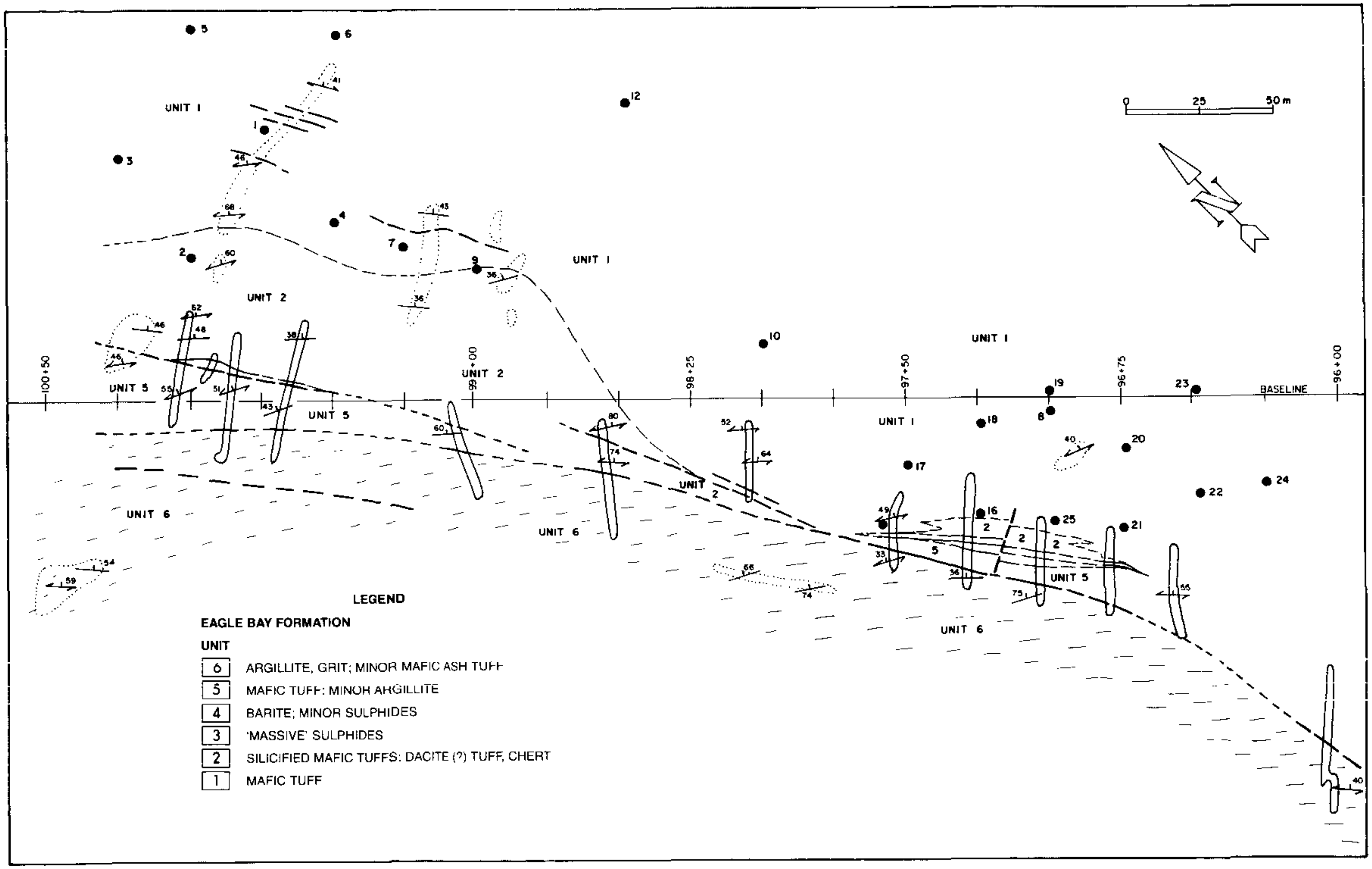

Figure 7-2. Geological map of Rea Gold property showing trenches and drill hole locations; modified from Corporation Falconbridge maps.

Stratigraphically overlying the sulphide or sulphide-barite lenses is a thin sequence of predominantly mafic tuffs (unit 5) that grades up into argillite. The tuffs are pale grey to brown-weathering thin-bedded chlorite phyllites. Silicified zones occur only locally (Fig. 7-5) and pyrite content is generally low. A dark grey tuffaceous 'argillite' (unit 5c, Figs. 7-3 and 7-4) with high Ba content (I. Pirie, pers. comm., 1985) occurs in the immediate footwall of the RG8 lens, at the stratigraphic base of unit 5. Unit 5 is generally in fault contact with unit 6, but in some drill intersections it grades through an interval of interbedded green phyllite and argillite (Fig. 7-5).

A sequence of metaclastic rocks (unit 6) at the structural base of the succession are the youngest rocks in the deposit area. They comprise grey laminated argillite, siltstone, wacke, and local pebble conglomerate with both volcanic and sedimentary clasts. Bedding and graded beds are well preserved. Thin mafic ash tuff layers occur in the basal part of unit 6.

SULPHIDE LENSES

Two main lenses are recognized. The more southern, the RG8 lens, appears to be at a slightly higher stratigraphic level than the

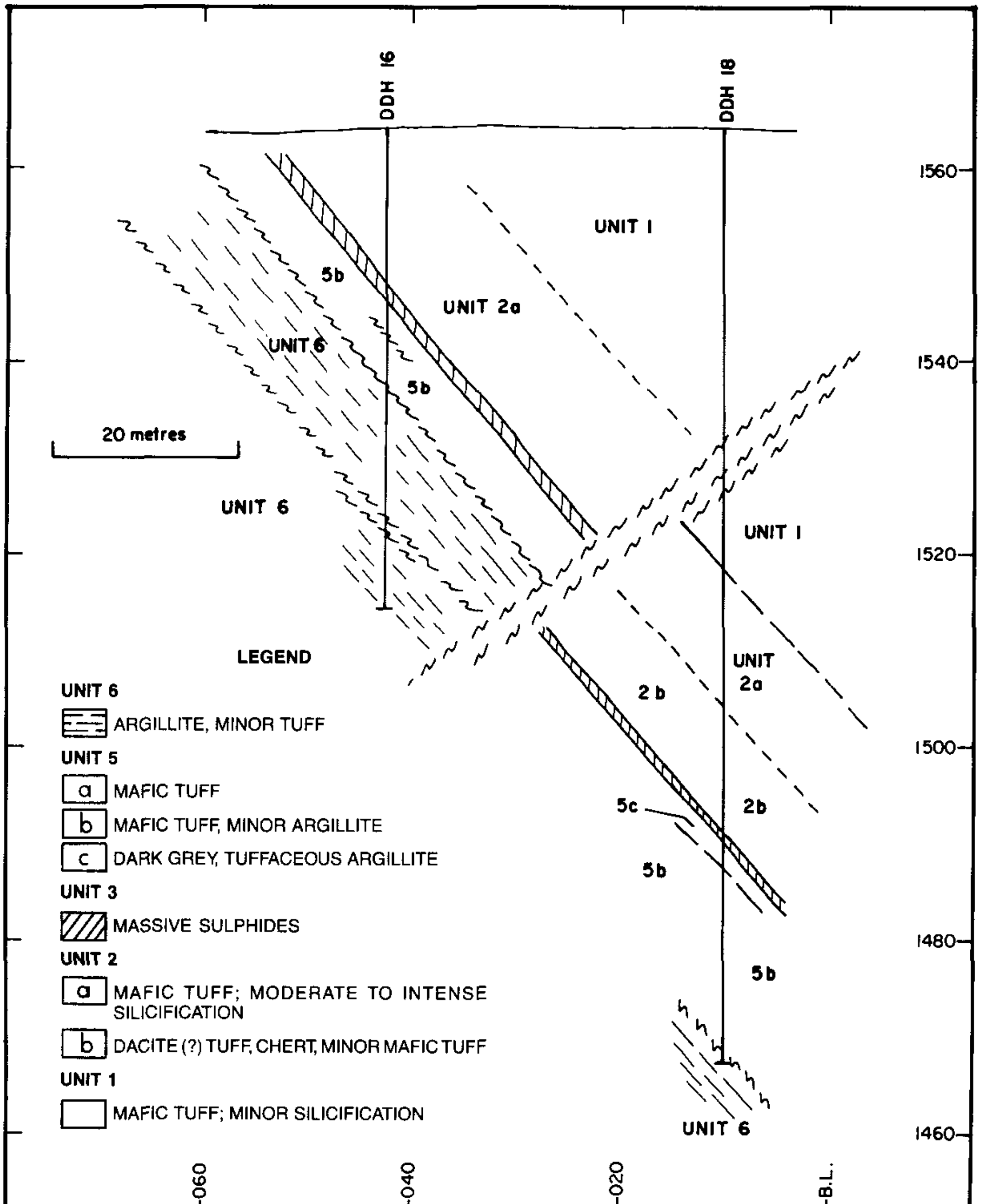

Figure 7-3. A vertical section (97 + 25) through the RG8 sulphide-barite lens, Rea Gold.

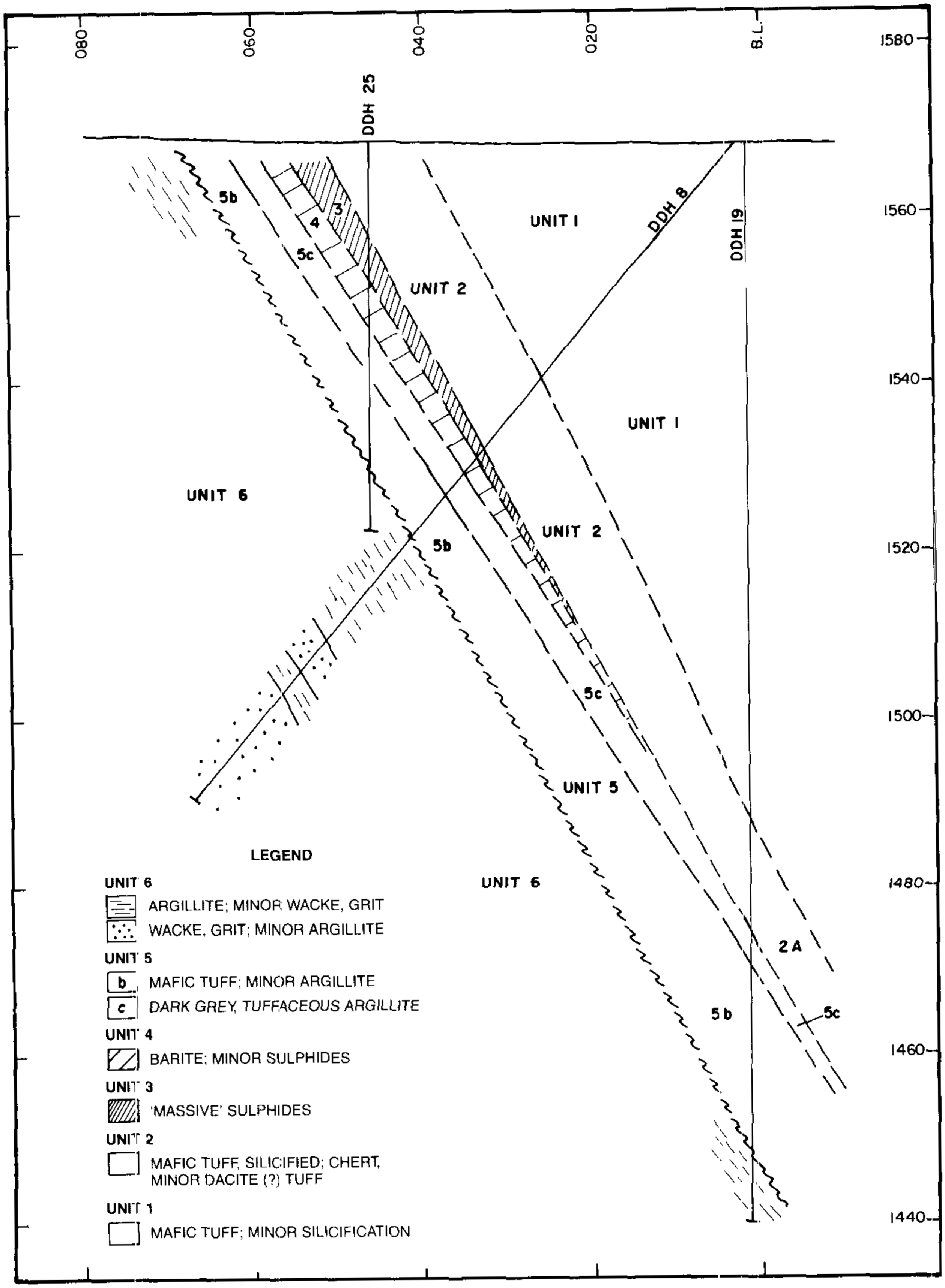

Figure 7-4. A vertical section (97+00) through the RG8 sulphide-barite lens, Rea Gold.

L100 lens (Fig. 7-2). It has a less extensive footwall alteration zone, and is 'capped' by massive barite. Descriptions of these sulphide lenses are based on visual examination of drill core and mapping of trenches.

The RG8 lens is well exposed in two trenches, 97 + 00 and 97 + 25, and its fringes in trenches 96 + 75 and 97 + 50 for a surface strike length of approximately 75 metres. It extends down dip at least 80 metres (Fig. 7-3). It has a relatively sharp contact with altered 'footwall' rocks of unit 2 and grades stratigraphically 'up' into massive barite of unit 4. However, it is in sharp contact with tuffaceous muds or mafic tuffs of unit 5 at its fringes. The barite 'cap' consists of grey to white, massive or faintly banded barite with variable amounts of disseminated sulphides. The sulphide content of the barite generally decreases away from the underlying massive sulphide.

The L100 lens has a surface strike length of approximately 50 metres and a down dip projection of at least 120 metres (Fig. 7-5). As described previously, it has a thick zone of intense silica alteration stratigraphically below, and is abruptly overlain by mafic tuffs of unit 5a. It does not have a barite 'cap.'

Sulphide mineralogy in both lenses includes pyrite, arsenopyrite, sphalerite, galena, chalcopyrite, and tetrahedrite-tennantite (White, 1985). Sulphides are fine grained and massive, crudely banded or brecciated. Gold occurs mainly in the massive sulphides but is also found in barite, in the footwall stockwork, and in fault gouge (I. Pirie, pers. comm., 1985). Silver is associated with both barite and massive sulphides, while zinc, lead, and copper occur primarily in massive sulphides.

STRUCTURE

The deposit and host rocks are essentially a northwest-trending, northeast-dipping homoclinal succession that has been structurally inverted. A pronounced mineral schistosity largely masks primary bedding except in structural footwall rocks where well-bedded and commonly graded metaclastic rocks occur. The observed bedding is commonly sub-parallel to the schistosity (Fig. 7-6) indicating tight to isoclinal folding. Changes in vergence of the bedding-schistosity intersections and the many small, rootless isoclinal folds indicate, however, that the succession is folded. Folding is asymmetrical in style and individual folds are confined to specific units since repetition of the major lithologic subdivisions is not apparent (Fig. 7-2). Within unit 2, cleavage-bedding intersections indicate a synformal

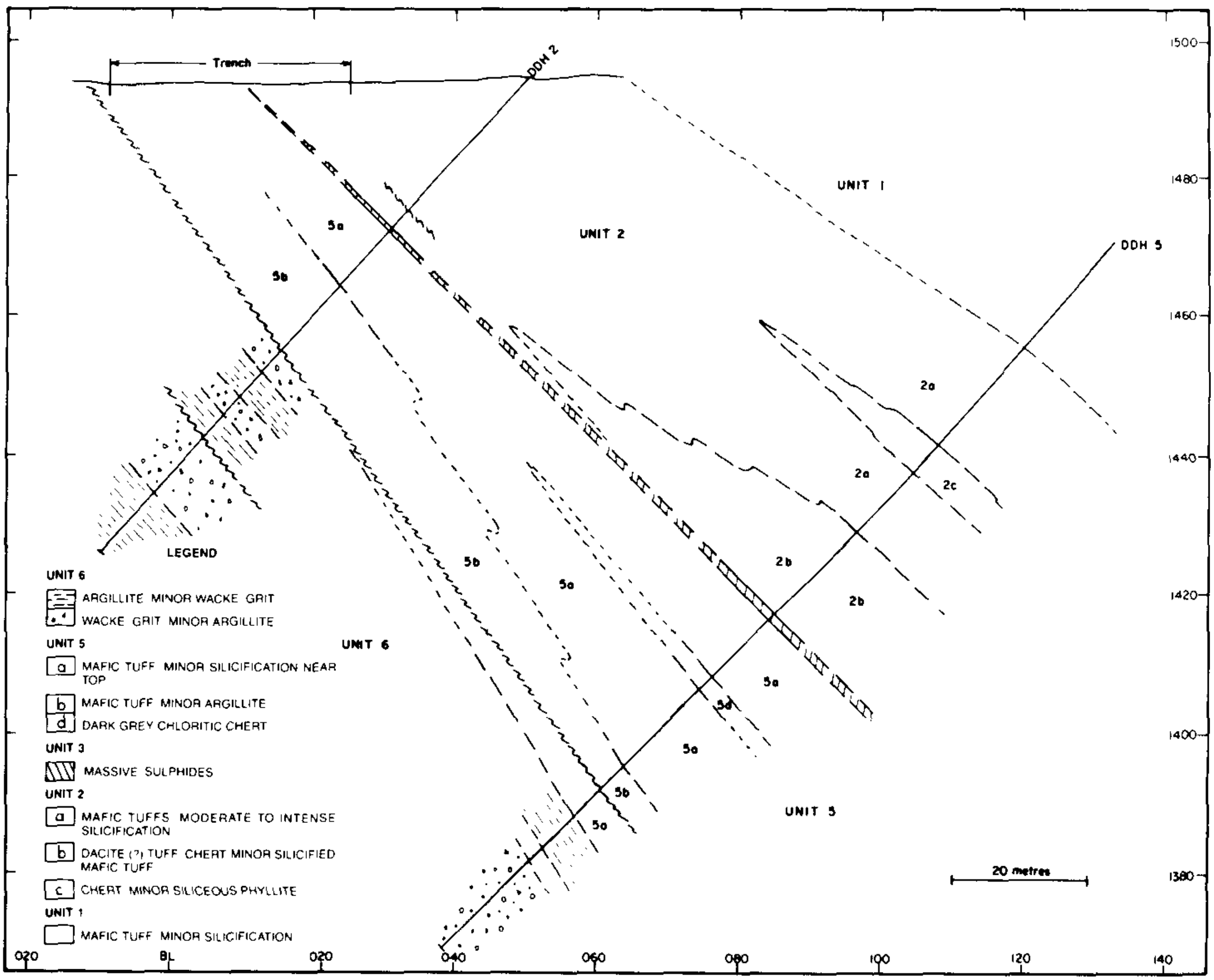

Figure 7-5. A vertical section (100 + 00) through the L100 sulphide lens, Rea Gold.

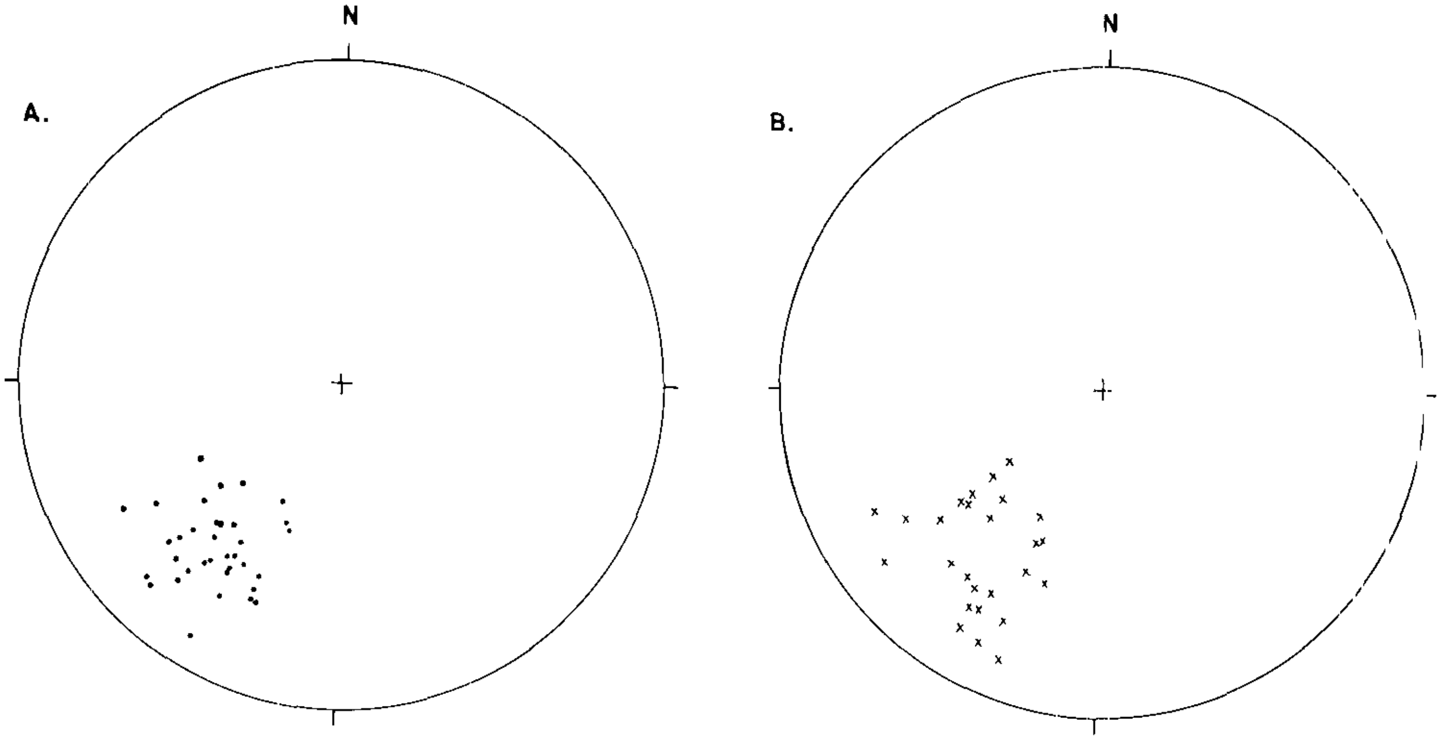

Figure 7-6. Equal area projections onto lower hemisphere of structural elements, Rea Gold. A — poles to foliation, B — poles to compositional layering.

axis located to the northeast. Yet relationships between the massive sulphides, barite, and alteration zone indicate the deposit is inverted; this suggests that the observed schistosity and associated folds are second generation structures superimposed on a previously inverted panel. Within more competent structural footwall rocks (unit 6), these folds are relatively open and the location of fold hinges can be defined. The most prominent is an overturned antiform located just southwest of the exposure at 100+50–060 (Fig. 7-2). A late southeast-trending crenulation cleavage, associated with minor open folds, is superimposed on the earlier schistosity.

Faults parallel to schistosity are common but only the largest are shown on the map. The most prominent fault strikes northwest, juxtaposing unit 5 against unit 6. The displacement on the fault is probably not large as there does not appear to be much loss of stratigraphy across it; the fault cuts locally up into unit 5 (for example, DDH 5, Fig. 7-5) leaving a normal stratigraphic contact between units 5 and 6.

SUMMARY AND CONCLUSIONS

Two massive sulphide lenses occur at the stratigraphic top of a thin felsic tuff and exhalative chert sequence that lies above a thicker sequence of mafic ash, crystal, and lapilli tuffs. Both lenses are underlain by a footwall feeder and alteration zone, characterized by intense silicification, pervasive pyrite, and sericite development, indicative of Si, Fe, and K metasomatism. The southern lens is 'capped' by a layer of massive barite. Both lenses are stratigraphically overlain by a thin sequence of mafic tuff which grades up into argillites, wackes, and grits. Deposition of sulphides and barite occurred near the end of a cycle of explosive volcanism. Intense regional deformation and greenschist facies regional metamorphism have altered the host rocks to produce a succession of sheared chlorite phyllites, quartz-sericite schists, and chert.

HOMESTAKE

INTRODUCTION

Homestake is a polymetallic base and precious metal deposit in intensely altered and sheared sericite schists of the Eagle Bay Formation (Schiarizza and Preto, 1984). Mineralization is generally contained in barite lenses or, locally, it is in quartz veins. Access to the property is provided by a switchback road that leaves the main road 5 kilometres northwest of Squaam Bay.

HISTORY

The property, as recorded in *Minister of Mines* Annual Reports (1927, 1936), was discovered in 1893 and first developed between 1893 and 1895. Work on the property was intermittent and shipments of ore occurred sporadically until 1927. The mine was reopened by Kamloops Homestake Mines Ltd. in 1935; workings at

TABLE 7-1
STRATIGRAPHIC SECTION OF THE EAGLE BAY FORMATION AT THE HOMESTAKE DEPOSIT

Map Unit	Description	Possible Primary Source Rock
	Greenstone	Basalt
5	Tuffaceous chlorite schist	Intermediate tuff
3/4	Chloritic schist/ankeritic phylite	Andesitic volcanic rocks/sedimentary rocks
2b	Sericite-quartz paper schist	Felsic tuff
2a	Sericite-quartz schist	Felsic volcanic rocks
1	Chlorite phyllite	Intermediate volcanic rocks

that time consisted of four adits and more than 455 metres of crosscuts, drifts, raises, and a winze. A 50-tonne per day flotation mill was installed on the site. Recorded production between 1935 and 1941 totalled approximately 6 965 tonnes from which 12 400 grams of gold, 9 565 900 grams of silver, 11 080 kilograms of copper, 171 325 kilograms of lead, and 246 520 kilograms of zinc were recovered. In the early 1970's, work on the property was resumed with geophysical and geochemical surveys, diamond drilling, and drifting to gain access to the old workings and to provide underground diamond-drill sites. Proven reserves were, at that time, estimated to be 1 010 800 tonnes with an average grade of about 240 grams silver per tonne, 2.5 per cent lead, 4.0 per cent zinc, 0.55 per cent copper, and 28 per cent barite (The Financial Post, Jan. 13, 1973). Since 1982 work by Kamad Silver Company Ltd. has confirmed and improved previous grade estimates but the deposit is considered difficult to mine, mainly because of the poor strength of the host rocks.

ROCK UNITS

The mineralized barite lenses are overlain by a siderite phyllite that contains interbedded argillite and by a tuffaceous chlorite schist unit. A wide zone of altered rock occurs below the mineralized lenses. Regional metamorphism and local hydrothermal alteration have obscured the primary composition of the host rocks; consequently, the following unit descriptions are based on mineral assemblages. Primary compositions are tentatively inferred from these assemblages (Table 7-1), and chemical analyses in progress will better characterize the original host rocks.

A poorly exposed chlorite phyllite (unit 1) occurs in the southern part of the map-area (Fig. 7-7). It is a thinly laminated brownish green chlorite phyllite that is noticeably less foliated than the overlying schists.

Unit 2 comprises dominantly sericite-quartz schist with abundant disseminated pyrite throughout. Unit 2a is a more massive phase of the 'paper' schist of unit 2b and contains lenticular, silica-rich segregations up to 6 centimetres in length. Unit 2b, referred to as a sericite-quartz 'paper' schist (Table 7-1, Fig. 7-7), is the most conspicuous unit in the map-area. In outcrop, the paper schist unit is easily discernible by its fissile appearance and by its weathered coating of yellow ferric sulphate. It is the host and the footwall to the barite-sulphide lenses and is interpreted to be a highly altered, predominantly felsic tuff unit. A number of quartz veins up to a

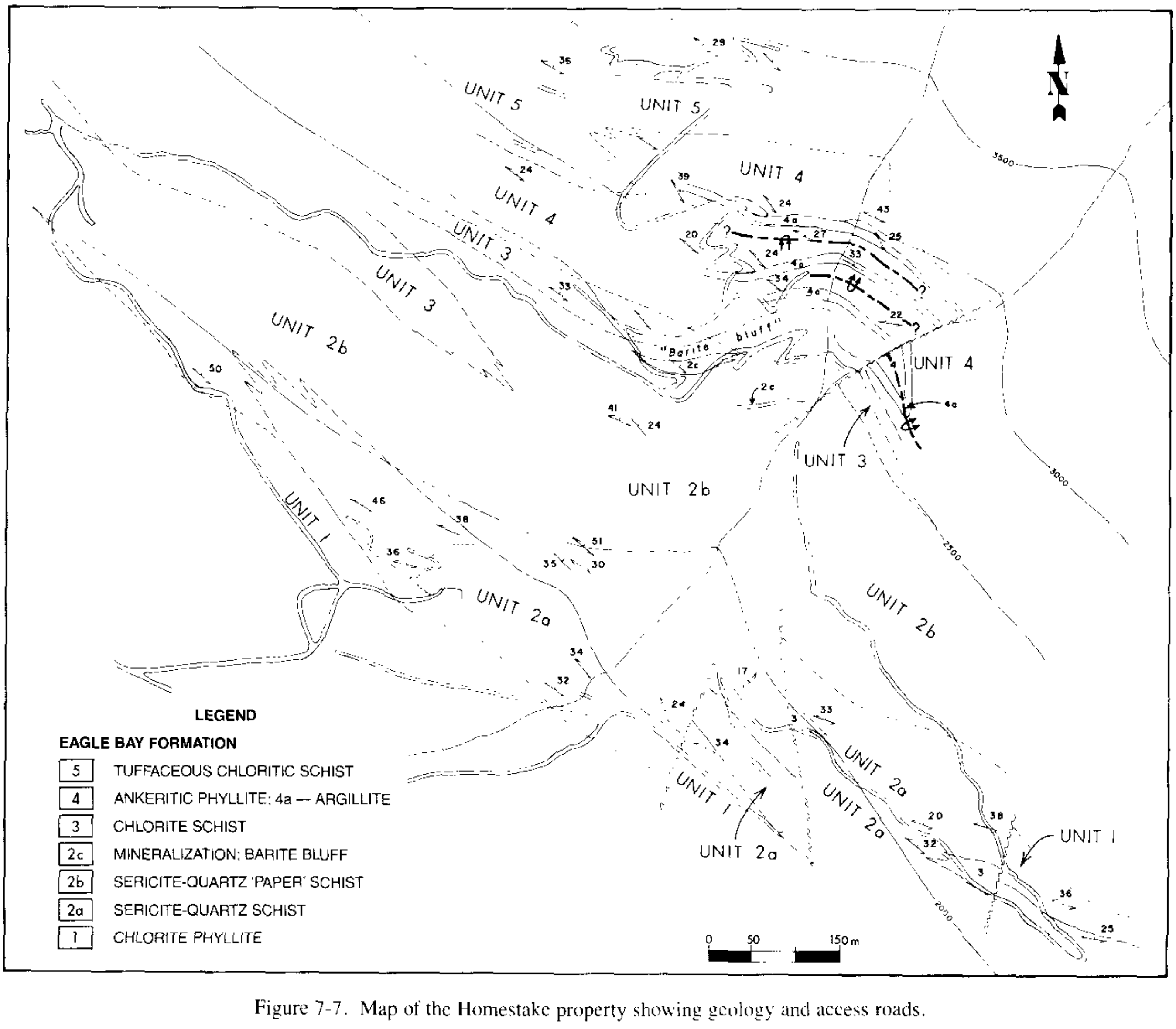

Figure 7-7. Map of the Homestake property showing geology and access roads.

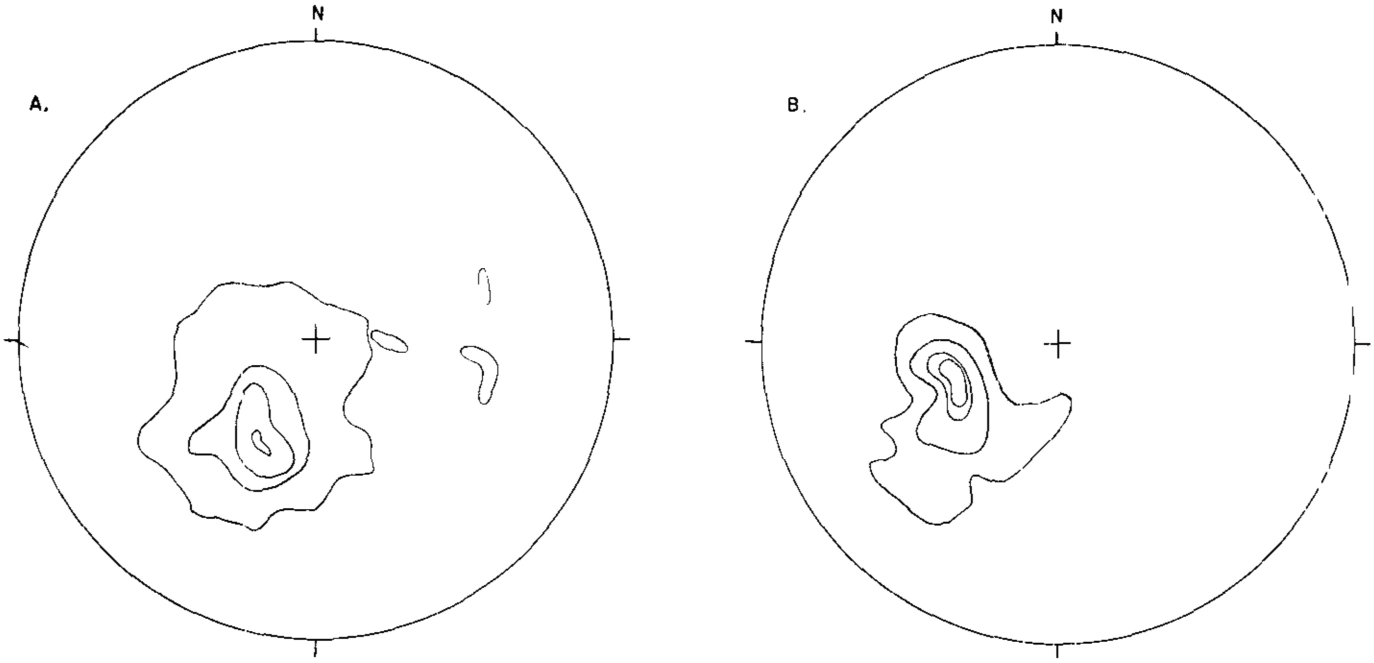

Figure 7-8. Lower hemisphere equal area projections of structural elements, Homestake deposit area. A — poles (92) to foliation, maximum concentration — 30%; B — poles (15) to compositional layering, maximum concentration — 33%; contour intervals — 1, 10, 20, 30%.

metre thick are found within the paper schist below the barite lenses; they contain pyrite but are generally barren of other sulphides.

A dark green laminated chlorite schist (unit 3, Table 7-1; Fig. 7-7) occurs stratigraphically above and laterally west of unit 2b. It consists of carbonate phenocrysts within a fine-grained chlorite-feldspar matrix. These phenocrysts, which may be pseudomorphic after plagioclase, are rimmed and partially replaced by chlorite. This unit is probably altered andesite tuff; its contact with unit 2b is in part an interfingering of felsic and intermediate tuffs but may also reflect an irregular pervasive potassic and silicic alteration boundary.

A fine-grained ankeritic phyllite (unit 4) composed of interbedded layers of ankerite-bearing chlorite phyllite occurs above units 2b and 3. In outcrop, limonite pseudomorphs after iron-rich carbonate give the rock a characteristic brown tinge. Some fine-grained pyritic argillites within the phyllite package are the most continuous and reliable marker units at Homestake. These argillite layers contain elongate quartz eyes or augen-shaped clasts up to 0.8 millimetre in diameter. The quartz eyes have cores of euhedral pyrite crystals and are set in a fine-grained pyritic and carbonaceous matrix of phyllosilicates, quartz, and feldspar. Unit 4 is interpreted to be largely a sedimentary clastic rock with interbedded chloritic tuff layers.

A tuffaceous chlorite schist (unit 5) occurs on the steep cliffs in the upper, northern portion of the Homestake area. The rock contains massive and tuffaceous zones composed of chlorite and carbonate, probably developed from regional metamorphism of rocks of intermediate composition such as andesite. Relict flattened felsic clasts imply a pyroclastic origin for at least part of this unit. Pyritic quartz veins and calcite stringers occur throughout the schist and, in several places, cut the foliation. Locally, cherty pods and argillite layers are interbedded with the schist. This unit is overlain by a thick greenstone sequence (V. A. Preto, pers. comm., 1985).

SULPHIDE-BARITE LENSES

A number of barite lenses with variable amounts of sulphides occur within the upper part of unit 2b. They are described in detail in early *Minister of Mines* Annual Reports (1927, 1936) and will be briefly reviewed here. At least three lenses, separated by sericite schist, are recognized. They range in thickness from less than a metre to at least 10 metres and underground some have been traced several hundred metres. Metallic minerals within these lenses include tetrahedrite, galena, sphalerite, pyrite, chalcopyrite, argentite, minor native silver, and trace ruby silver and native gold.

The lenses may consist either of massive to banded barite with only scattered metallic minerals throughout, or interlayered barite, schist, and sulphides. Two lenses are exposed on surface. The largest, referred to as the 'barite bluff' (unit 2c, Fig. 7-7), has an exposed thickness of 5 to 6 metres. It pinches out rapidly along strike, has a sharp hangingwall contact with sericite schist, and grades down into massive sericitic chert. A smaller lens, 1 to 2 metres thick, occurs below the 'barite bluff' unit (Fig. 7-7); it is banded but contains only minor sulphides.

STRUCTURE

A well-defined penetrative mineral foliation is ubiquitous throughout the Homestake area. The foliation is outlined by the preferred orientation of platy minerals such as sericite and chlorite, and lenticular silica-rich segregations in unit 2. Foliation, plotted on a stereonet (Fig. 7-8A), has a reasonably tight cluster around a maximum that strikes 120 degrees and dips 30 degrees northeast.

Original compositional layering is generally difficult to see. Except within argillite bands of unit 4, it has been largely obscured by either metamorphism or the intense deformation. In general, however, it strikes between 120 and 160 degrees with an average dip of 35 degrees northeast (Fig. 7-8B). The similarity between foliation and bedding attitudes indicates either tight to isoclinal folding or a constant facing direction.

No large folds have been identified in the chlorite or sericite phyllites beneath the barite lenses. Nearly all bedding-cleavage intersections in these phyllites have a common vergence. Therefore, the succession could be a homoclinal, non-folded sequence on the lower, upright limb of a tight syncline. However, rootless tight to isoclinal minor folds throughout the succession and the presence of large folds outlined by argillite beds in overlying rocks (unit 4) suggest that larger folds also occur within the phyllites. These folds would be asymmetric, essentially confined to a single unit, with shortened or sheared-out overturned fold limbs.

On a regional scale the Homestake property is located on the southern limb of a large overturned syncline (Schiarizza and Preto, 1984; Preto and Schiarizza, 1985). Evidence in the Homestake area, including fold closures and vergence obtained from bedding-cleavage intersections, supports a synclinal fold closure to the northeast.

SUMMARY

Sulphide-barite lenses at Homestake occur near the top of a thick sequence of pyritic quartz-sericite phyllites within a predominantly mafic to intermediate tuff succession. The quartz-sericite phyllites include both felsic tuffs and metasomatically altered footwall rocks in which potassium, silica, and iron have been introduced. Although macroscopic folds are not recognized within the footwall phyllites, their presence is inferred due primarily to recognition of folds in overlying units where bedding is more visible and to the presence of rootless minor folds within the phyllites.

CONCLUSIONS

Rea Gold and Homestake have many similarities. They are sulphide ± barite lenses within or near the top of a felsic (?) pyroclastic unit within a thicker pile of more mafic tuffs and minor mafic flows. Both have extensive footwall alteration zones characterized by silicification, sericitization, and pyrite development, and both are overlain by a mixed mafic pyroclastic and clastic sedimentary sequence. These deposits, as well as a number of other somewhat similar deposits in Eagle Bay Formation rocks such as Beca and Birk Creek (Goutier, *et al.*, 1985), are similar in many respects to the volcanogenic 'polymetallic' or Kuroko class of deposits.

ACKNOWLEDGMENTS

We wish to acknowledge the cooperation of Corporation Falconbridge while working on the Rea Gold property. Alex Davidson and Ian Pirie made available to us their maps and sections, and discussed freely many aspects of the geology of Rea Gold. Although the report on Rea Gold reflects many of their views, they do not necessarily agree with all the interpretations. Discussions with Colin Godwin, University of British Columbia, and P. Schiarizza, V. A. Preto, and G.P.E. White of the British Columbia Ministry of Energy, Mines and Petroleum Resources are appreciated. M. Fournier assisted with mapping at both Homestake and Rea, and in logging Rea core.

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CARBONATITES AND ASSOCIATED ALKALIC ROCKS PERRY RIVER AND MOUNT GRACE AREAS SHUSWAP COMPLEX SOUTHEASTERN BRITISH COLUMBIA (82M/7, 10)

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INTRODUCTION

Carbonatites are carbonate-dominated igneous rocks that occur most commonly as intrusive bodies, generally associated with alkaline igneous rocks (Pecora, 1956; Heinrich, 1980). Extrusive carbonatites are less common but have been described in western Uganda (von Knorring and du Bois, 1961), northern Tanzania (Dawson, 1962, 1964; Hay, 1983), central Kenya (Le Bas and Dixon, 1965), western Kenya (Le Bas, 1977; Deans and Roberts, 1984), and Germany (Keller, 1981).

Many carbonatite bodies are valuable sources of a number of commodities. Nb has been produced at Oka and St. Honoré, Quebec and Araxa, Brazil; the Mountain Pass carbonatite in California is the largest producer of rare earth elements in the western world; and copper and by-product apatite, magnetite, vermiculite, and ZrO_2 are produced in Palabora, South Africa (Currie, 1976; Heinrich, 1980). Carbonatite deposits in the eastern Canadian Cordillera (Pell, 1985; White, 1985) have recently received some interest due to their enriched pyrochlore and rare earth element content, but none have yet had any production.

Carbonatites in the Perry River area along the northwestern margin of Frenchman Cap dome on the eastern edge of the Shuswap Metamorphic Complex (Fig. 8-1) were originally described by McMillan (1970) and McMillan and Moore (1974). Two varieties were recognized: type I intrusive sills and dykes, and a type II extrusive layer. Detailed mapping in the Mount Grace area north of the Perry River (Höy, 1979) led to the discovery of new occurrences of the type II carbonatite layer, referred to as the Mount Grace carbonatite (Höy and Kwong, in press) and confirmed the suggestion (McMillan and Moore, 1974) that it is an extrusive layer.

Work during the 1985 field season included eight days of sampling, detailed mapping, and section measuring. Sampling of both the intrusive carbonatites in the Perry River area and of the Mount Grace carbonatite provided additional data on their geochemistry and petrography. Detailed mapping and section measurements resulted in a better understanding of the relationship between intrusive carbonatites and associated syenites, a knowledge of the internal stratigraphy of the Mount Grace carbonatite, and the discovery of thin carbonatite tuff layers adjacent to the main Mount Grace carbonatite layer. Observations of clast size distributions in the Mount Grace carbonatite allow speculation regarding source areas. Continued research includes oxygen and carbon isotope studies in progress at the University of Alberta, U/Pb dating of zircons collected from both the carbonatites and nepheline syenites, and field mapping tracing the Mount Grace carbonatite northward.

Initial exploration in the Mount Grace area was centred around the Cottonbelt deposit, a massive sulphide Pb-Zn layer discovered in 1905. Carbonatites in the area have been periodically sampled for their rare earth element content, most recently by Duval International Corporation (Pilcher, 1983). Work by Duval was restricted to carbonatites south of Ratchford Creek; it included prospecting, geochemical sampling, and mapping. Claims in this area have been acquired recently by Active Mineral Explorations Ltd. of Vancouver.

GEOLOGICAL SETTING

INTRODUCTION

The Mount Grace carbonatite, intrusive carbonatites, and syenite gneiss bodies occur within a mixed paragneiss succession along the northwestern margin of Frenchman Cap gneiss dome (Fig. 8-1), one of several late domal structures near the eastern margin of the Shuswap Metamorphic Complex in southeastern British Columbia (Wheeler, 1965). The dome is exposed as a window between the Columbia River fault to the east and the Monashee décollement to the west (Read and Brown, 1981).

The core of Frenchman Cap dome comprises a mixed paragneiss and orthogneiss succession of probable Aphebian age (R. L. Armstrong, pers. comm., 1980). It is basement to an unconformably overlying 'mantling gneiss' or autochthonous cover succession, comprising a basal quartzite and overlying pelitic and calcareous rocks. The autochthonous cover succession hosts the carbonatites and syenite gneisses, as well as the Cottonbelt Pb-Zn layer.

The ages of the mantling paragneiss succession and carbonatites are not known. Based on regional correlations with platformal rocks to the east, a number of authors (Wheeler, 1965; Fyles, 1970; Höy and McMillan, 1979) tentatively assigned Eocambrian to Early Paleozoic ages to these rocks. A preliminary U/Pb date of 773 Ma was obtained from zircon of a syenite gneiss at the southern margin of Frenchman Cap dome (Okulitch, *et al.*, 1981) which is presumably of similar age to the carbonatites (McMillan and Moore, 1974; Currie, 1976; Höy and McMillan, 1979). Zircons from carbonatites and syenites from this area are being analysed and will provide a better age for these alkalic rocks and the host succession.

STRUCTURE AND METAMORPHISM

The structure of the northwestern margin of Frenchman Cap dome is dominated by the tight, early Mount Grace syncline (Fig. 8-2). The Mount Grace carbonatite occurs on both of its limbs. The fold has been traced approximately 20 kilometres from north of Ratchford Creek to south of Kirbyville Creek (where it is referred to as the Kirbyville syncline; Brown, 1980) and has been projected southward to the Perry River area where it is correlated (Journeay

1982) with an early 'Phase 1' isoclinal fold described by McMillan (1970, 1973). Its axial surface is defined by a mineral foliation that generally parallels layering in the attenuated limbs of the fold. Later southwest-trending 'Phase 2' folds are prominent in the Perry River area (McMillan, *op cit.*). They are superimposed on large isoclinal Phase 1 folds, accounting for the relatively complex outcrop pattern in that area (Fig. 8-2). Both phases of folding deform the Mount Grace carbonatite, the intrusive carbonatites, and the syenite gneisses.

Amphibolite facies regional metamorphism along the western and northwestern margin of Frenchman Cap dome has produced sillimanite-kyanite, sillimanite, and sillimanite-potassic feldspar-bearing assemblages in pelitic rocks. Calc-silicate assemblages contain diopside, garnet, and actinolite. Carbonates and the carbonatites are recrystallized to medium to locally coarse-grained granoblastic marbles.

STRATIGRAPHIC SUCCESSION

The stratigraphy of the 'mantling gneiss' succession that hosts the alkalic rocks is summarized from McMillan (1973) and Höy (1979). A laterally extensive quartzite (unit 3, Fig. 8-3) of variable thickness and purity forms the base of the succession. Crossbeds and graded grit beds occur locally in the quartzite and provide some of the few reliable stratigraphic top indicators. The quartzite is overlain by a sequence of interfingering, dominantly calcareous and pelitic schists (unit 4). Amphibolite layers, thin impure quartzite layers,

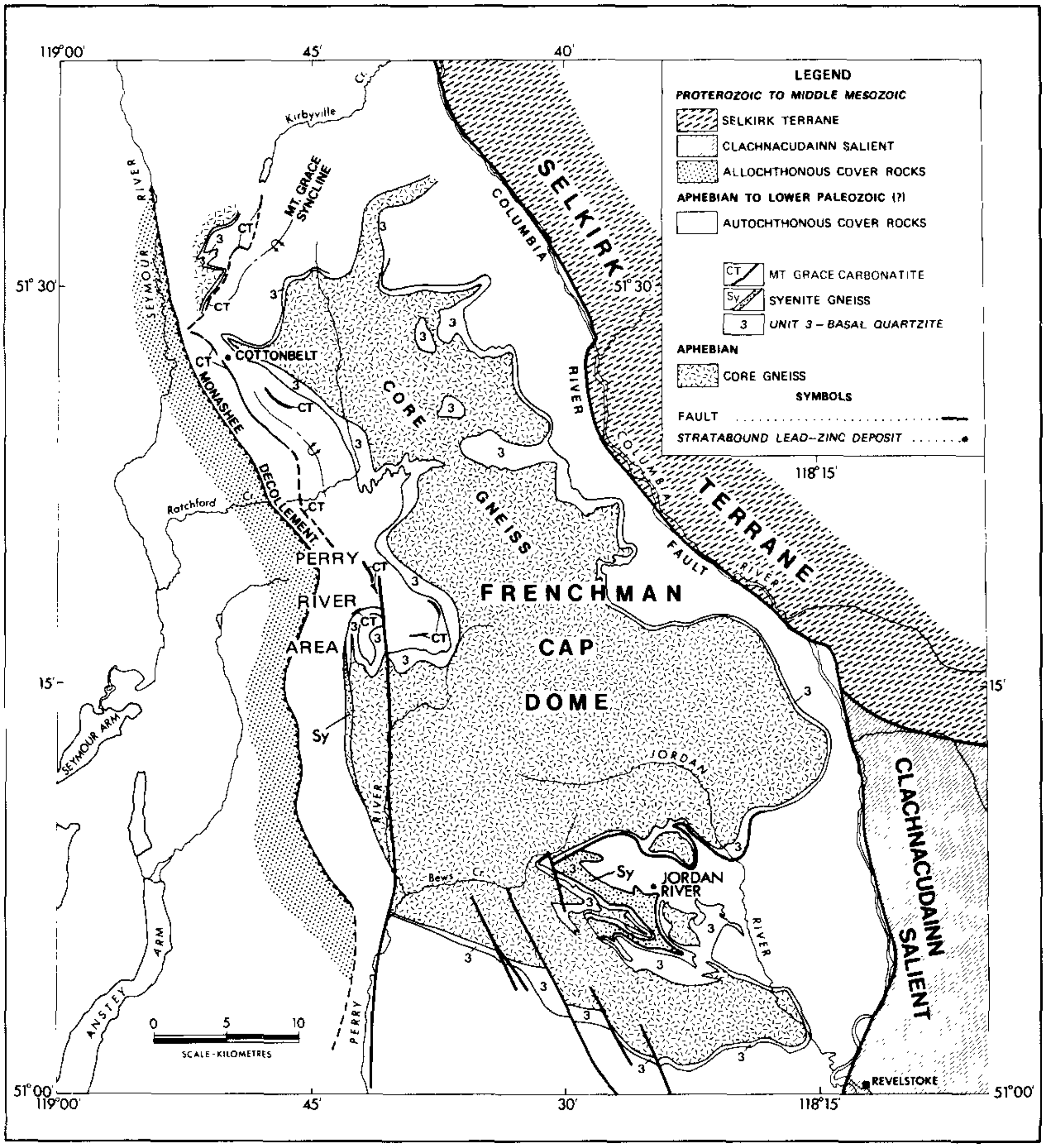


Figure 8-1. Regional geological map showing the distribution and tectonic setting of alkalic rocks in Frenchman Cap dome, Shuswap Metamorphic Complex (from Höy and Brown, 1980). The Perry River-Mount Grace area (Fig. 8-2) is outlined.

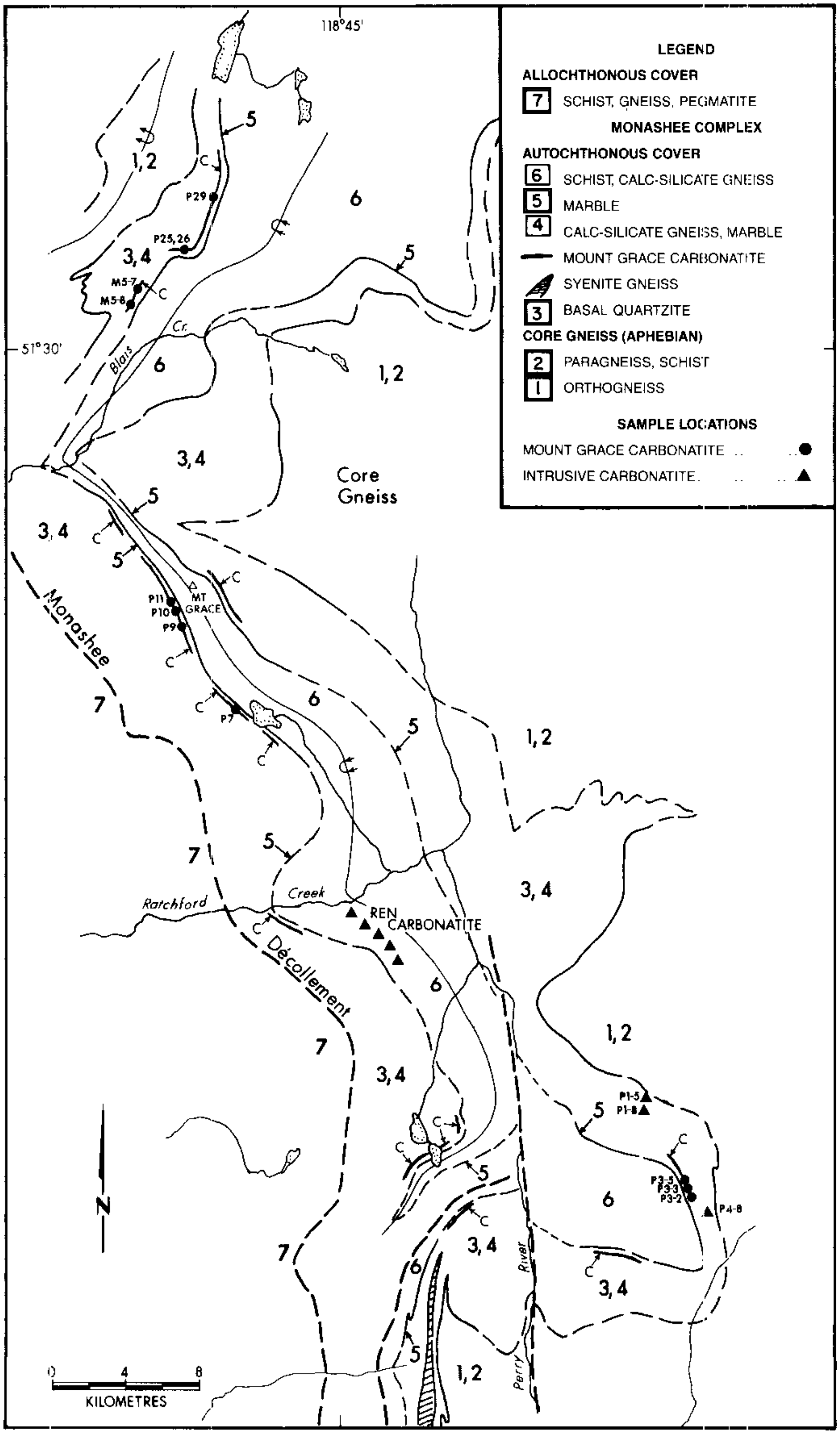


Figure 8-2. Location and structural setting of the Mount Grace carbonatite, intrusive carbonatites, and syenites in the Mount Grace-Perry River area (geology after McMillan, 1973; Höy, 1979; Journeay, 1982). Sample locations and sites referred to in text are shown.

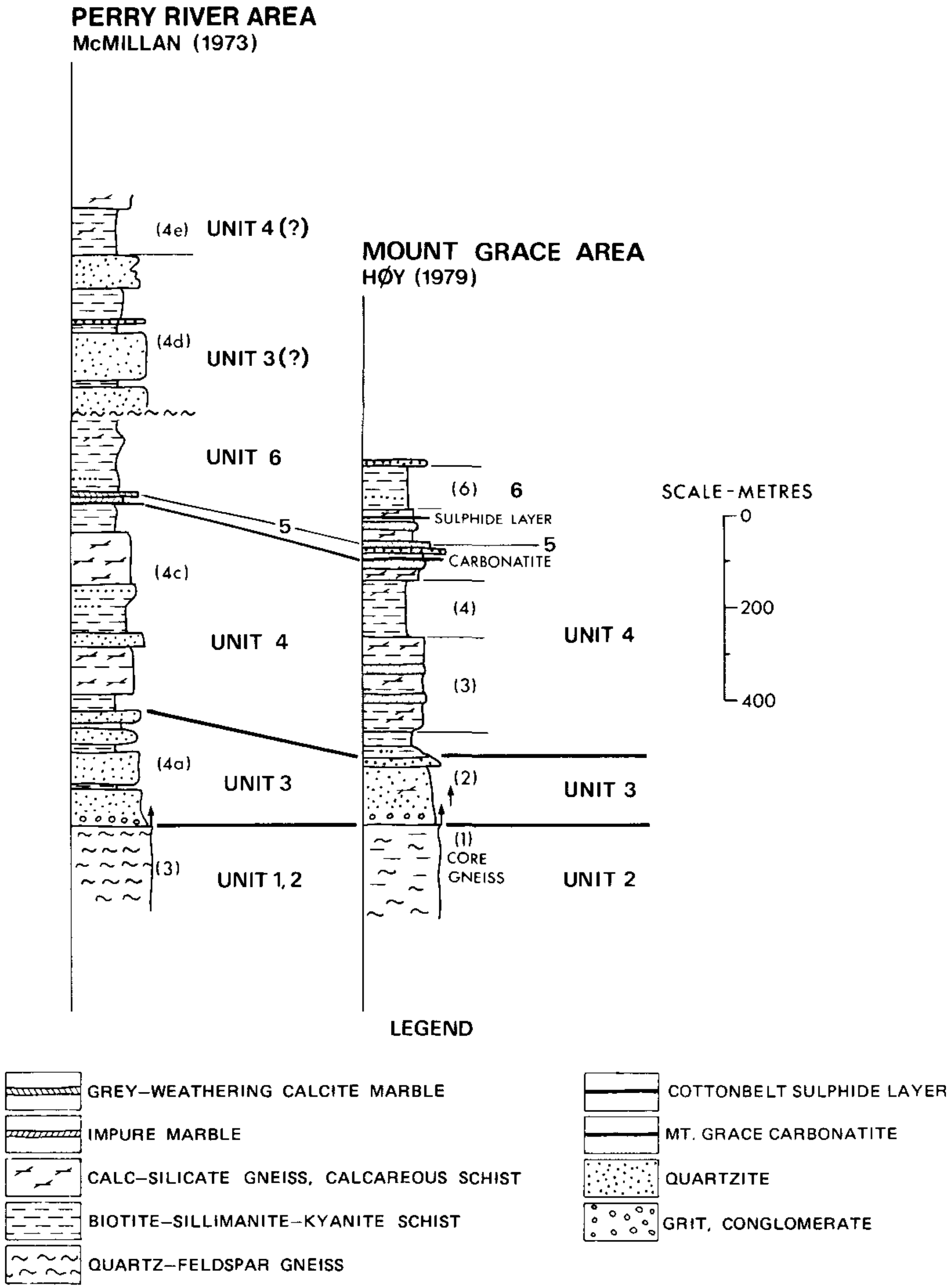


Figure 8-3. Correlations of units hosting carbonatites and syenites between the Mount Grace and Perry River areas. (Numbers in parentheses are unit designations of McMillan, 1973 and Höy, 1979).

TABLE 8-1
CHEMICAL ANALYSES OF TWO SAMPLES OF THE SYENITE GNEISS AT THE HEADWATERS OF ANSTEY RIVER (FIG. 8-2)

Sample No.	SiO_2	Al_2O_3	Fe_2O_{3T}	MgO	CaO	Na_2O	K_2O	TiO_2	MnO	$+H_2O$	$-H_2O$	CO_2	P_2O_5	S	FeO	Fe_2O_3
H78MC-1	53.57	19.76	5.54	0.37	2.79	6.037	10.9	0.597	0.154	0.45	0.05	0.62	<0.08	<0.01	1.30	4.10
H78MC-2	51.88	22.07	4.93	0.26	2.26	5.070	10.3	0.881	0.142	1.34	0.08	0.70	<0.08	<0.02	3.29	1.27

and swirled quartz-feldspar-biotite gneiss are common throughout this unit. The upper part of the unit is dominantly calcareous, comprising an interlayered succession of thin-bedded calc-silicate gneiss, kyanite and sillimanite schist and gneiss, calcitic and dolomitic marble, amphibolite, the Mount Grace carbonatite, and thin scapolite-rich calcareous layers. Overlying unit 4 is a grey-weathering crystalline calcite-dolomite marble layer (unit 5, Fig. 8-3). This marble is a valuable marker that can be traced around the margins of Frenchman Cap dome. It is overlain by a calcareous and pelitic succession (unit 6) that includes the Cottonbelt lead-zinc deposit.

In the Perry River area nepheline syenite gneiss bodies and associated discontinuous carbonatite lenses occur near the base of unit 3. They are overlain by the Mount Grace carbonatite (Plate 8-1a) which, in the core of the Mount Grace syncline just south of Ratchford Creek, is overlain by a lens (or lenses) of intrusive carbonatite (Pilcher, 1983), referred to as the 'Ren' carbonatite.

The succession in the Mount Grace and Perry River areas has been correlated (Höy and McMillan, 1979; Brown, 1980) with a similar succession in the Jordan River area at the south end of Frenchman Cap dome (Fyles, 1970). Here, syenite gneiss bodies, originally believed to occur stratigraphically above the level of the Mount Grace carbonatite (Currie, 1976), are now recognized to occur at a deeper stratigraphic level (Höy and McMillan, 1979).

The 'mantling gneiss' or autochthonous cover succession that unconformably overlies the core gneisses has been interpreted to be a shallow marine or platformal succession (McMillan, 1973; Höy

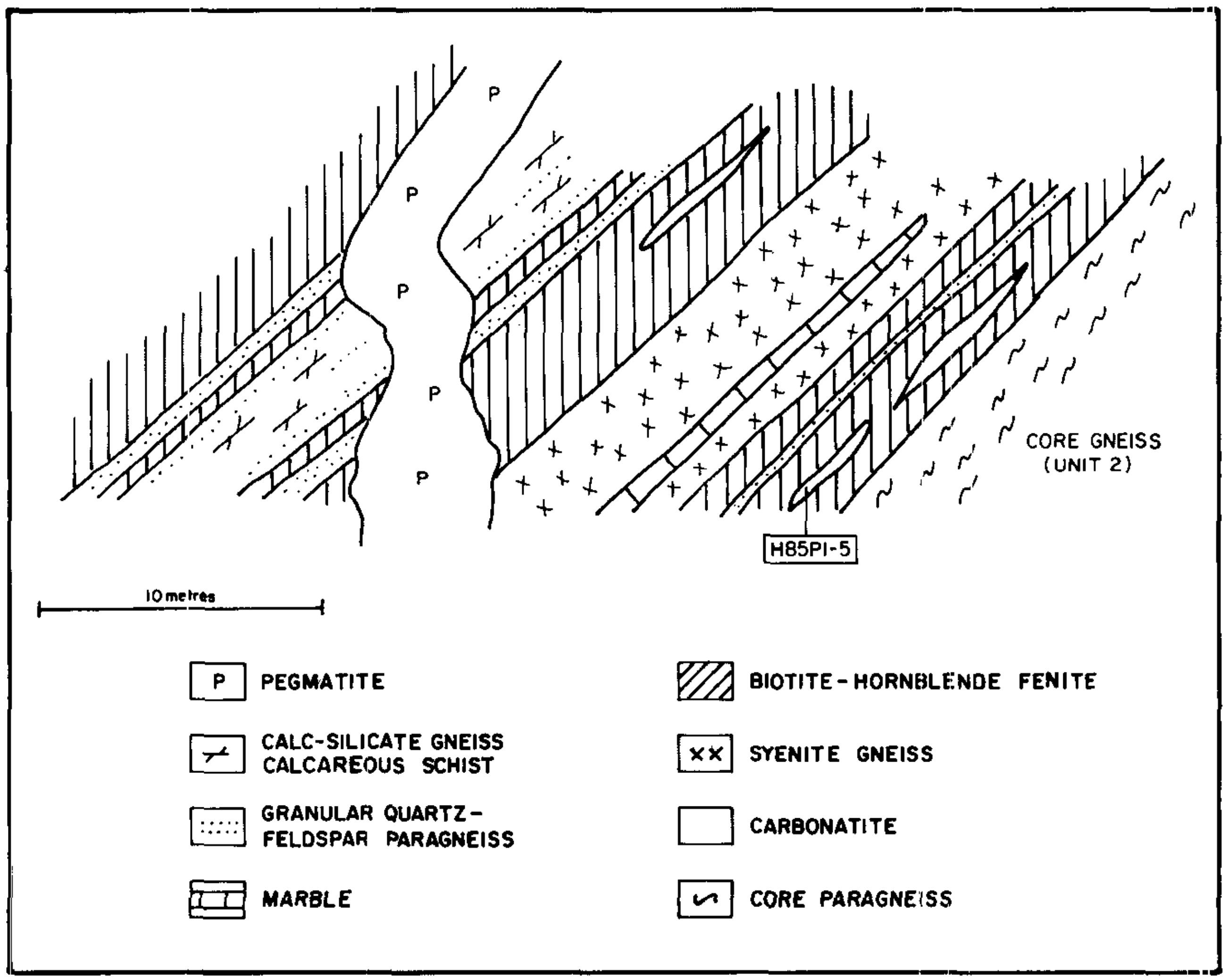


Figure 8-4. A schematic vertical section through the syenite-intrusive carbonatite-fenite zone at station H85P1 (Fig. 8-2).

and McMillan, 1979; Brown, 1980). It represents a transgressive marine sequence deposited on a low relief basement complex. Coarse fluvial sandstone, conglomerate, and perhaps a veneer of marine beach sands overlying a regional unconformity pass upward into fine-grained, calcareous muds and siltstones which probably were deposited on extensive tidal flats. The extrusive Mount Grace carbonatite was deposited near the top of this succession in a shallow marine environment.

ALKALIC ROCKS

INTRODUCTION

Alkalic rocks in the Perry River-Mount Grace area include:
(1) syenite, nepheline syenite gneiss;
(2) intrusive carbonatites, syenite;
(3) the intrusive 'Ren' carbonatite; and
(4) the extrusive Mount Grace carbonatite.

The syenites and intrusive carbonatites are restricted to the Perry River area, south of Ratchford Creek (Fig. 8-2). They are generally concordant with surrounding layering in metasedimentary rocks and are commonly intimately intermixed. Intrusive carbonatites are thin layers or lenses with well-defined metasomatic envelopes or 'fenite' margins. The Mount Grace carbonatite is essentially a thin layer that has been traced or projected at least 45 kilometres from the Perry River area to north of Blais Creek.

SYENITE, NEPHELINE SYENITE (UNIT 4b OF McMILLAN, 1973)

The largest syenite body in the Perry River area (*see* Fig. 8-2) is a concordant unit up to 300 metres thick and 12 kilometres long (McMillan, 1973). It is internally foliated and layered with alternating bands of syenitic and feldspathoidal rock. Country rocks along its margins are metasomatically altered with development of a rusty zone enriched in feldspar, pyroxene, muscovite, and/or pyrrhotite. Two analyses of the syenite are shown in Table 8-1; additional analyses are given by McMillan (*op cit.*). Semi-quantitative emission spectrographic analyses of these two samples indicate enrichment, relative to granites, of Ga, Be, Y, and Yb, as well as Nb, Zr, and sometimes Ba (McMillan, 1973).

INTRUSIVE CARBONATITES AND ASSOCIATED SYENITIC ROCKS

This unit includes a zone of intermixed syenitic rocks, fenite, carbonatite, and metasedimentary rocks near the base of the autochthonous cover succession. Two occurrences (sites H85P1, H85P4, Fig. 8-2) were studied in detail and extensively sampled for geochemistry and zircon separations. These occurrences appear to be part of a single continuous zone at least 4 kilometres in length (*see* Fig. 3 of McMillan and Moore, 1974). The zone is concordant with layering but on a regional scale may cut up section to the south.

TABLE 8-2a
MINOR AND TRACE ELEMENT DATA (SEMI-QUANTITATIVE EMISSION SPECTROSCOPY) OF CARBONATITES AND METASEDIMENTARY HOST ROCKS, PERRY RIVER AND MOUNT GRACE AREAS*

Sample No.	Rock Type	Mn	Sr	Ba	Nb
H85P1-5	intrusive carbonatite	3 000	>1 000	1 700	tr
H85P1-8	intrusive carbonatite	2 000	>2 000	1 100	tr
H85P3-2A	impure marble	100	1 500	400	—
H85P3-2B	impure marble	300	1 000	900	—
H85P3-2C	impure marble	200	700	200	—
H85P3-2E	Mt. Grace carbonatite	1 000	1 200	900	—
H85P3-3	Mt. Grace carbonatite	6 500	700	200	700
H85P3-5B	impure marble	2 500	tr	tr	tr
H85P4-3B	intrusive carbonatite	400	>2%	1 800	100
H85P4-3C	intrusive carbonatite	1 400	>1%	2 500	tr
H85P7	Mt. Grace carbonatite	2 800	400	2 200	200
H85P9	Mt. Grace carbonatite	6 000	5 000	1 800	500
H85P10	Mt. Grace carbonatite	4 000	>5 000	200	500
H85P11	Mt. Grace carbonatite	2 500	3 000	2 800	100
MG5-7	Mt. Grace carbonatite	3 000	1 500	1 600	100
MG5-8	Mt. Grace carbonatite	1 300	4 000	1 500	100
H85P25A	impure marble	1 500	600	900	—
H85P25B	carbonatite tuff	1 000	>1%	900	400
H85P25C	impure marble	1 200	600	1 200	—
H85P26A	Mt. Grace carbonatite	2 500	>1%	1 000	500
H85P26B	Mt. Grace carbonatite	2 500	>1%	3 000	1 000
H85P26Bi	mixed tuff-marble	800	700	300	—
H85P26C	mixed tuff-marble	1 500	1 000	1 000	—
H85P26D	Mt. Grace carbonatite	800	6 000	1 600	200
H85P26E	Mt. Grace carbonatite	400	4 000	900	—
H85P26F	Mt. Grace carbonatite	1 200	5 000	1 600	100
H85P26G	marble, minor tuff	1 200	1 000	3 500	100
H85P26H	impure marble	1 300	500	400	—
H85P29	Mt. Grace carbonatite	4 000	4 000	1 200	300

* All analyses in ppm.
Sample localities plotted on Figure 8-2.

Sections through the zone are illustrated on Figures 8-4 and 8-5. The syenitic rocks are most prominent near the base of the zone. In the northern section, they comprise essentially a single layer 5 to 6 metres thick, whereas at site H85P4 they form a number of layers. The syenitic rocks are foliated, compositionally banded, and contain rare thin metasedimentary layers and occasional small discontinuous carbonatite lenses. The syenitic rocks are composed primarly of 70 to 80 per cent plagioclase (andesine) and microcline in varying proportions. True syenites are less common than monzonites (microcline is generally less abundant than plagioclase). Principal mafic minerals are aegerine ± biotite. Sphene, magnetite, apatite, chalcopyrite, and allanite are common accessory minerals. A thin layer of predominantly albite within calc-silicate gneiss at site H84P1 contains abundant coarse molybdenite.

Dark grey to black, well-layered amphibole fenite occurs throughout both sections. It is comprised primarily of aegerine, sodic amphibole, biotite, and sphene. Calcite, apatite, plagioclase, magnetite, chalcopyrite, and ilmenite may also be present. In section H85P1, it forms a thin 2 to 3-metre-thick footwall contact zone between the syenitic rocks and core gneiss and a considerably thicker hangingwall zone where it is interbedded with metasedimentary layers (Fig. 8-4). It comprises greater than 50 per cent of the southern section where it contains abundant irregular zones, discontinuous lenses, and thin layers of carbonatite. The contacts between fenites and syenite gneiss, core gneiss, and thin granular quartz-feldspar layers within fenite are generally sharp, whereas contacts between fenites and calc-silicate layers are gradational. This, and the occurrence of thin remnant granular gneiss layers within fenite, suggest that calc-silicate layers are fenitized in preference to less calcareous layers.

Carbonatite lenses occur throughout the fenite and occasionally within the syenite and adjacent metasedimentary layers. Carbonate minerals comprise 70 to 80 per cent of the rock. Amphibole, apatite and phlogopite are the principal mafic components. Sphene, aegerine, plagioclase, magnetite, pyrrhotite, pyrochlore, chalcopyrite, pyrite, and ilmenite may be present. Within fenite, the carbonatites may occur as relatively thick buff-weathering foliated and laminated layers (Plate 8-1); as swirled, discontinuous lenses (Plate 8-2a); or as small coarse-grained irregular pods with typically calcite centres and biotite-amphibole margins. Large subhedral to euhedral amphibole, sphene, ilmenite, and apatite crystals occur throughout these pods. Thin continuous carbonatite layers also occur in syenite and in metasedimentary layers (Plate 8-2b). They are fine grained, include thin discontinuous fenite amphibolite lenses, and have only thin fenite margins. Analyses of two samples of intrusive carbonatite are shown in Tables 8-2a and 8-2b; H85P1-5 is a coarse-grained variety within fenite and H85P1-8 is a white crystalline marble in overlying schist.

TABLE 8-2b
RARE EARTH ELEMENT DATA (NEUTRON ACTIVATION) OF CARBONATITES AND METASEDIMENTARY HOST ROCKS, PERRY RIVER AND MOUNT GRACE AREAS*

Sample No.	Ce	Dy	Er	Eu	Gd	Ho	La	Lu	Nd	Pr	Sc	Sm	Tb	Th	Tm	Yb
H85P1-5	2 010	41	<100	18	<720	9	1 470.0	1.7	654	290	8.45	73.8	5.4	35.9	3.4	17.4
H85P1-8	927	18	<100	9	<430	5	704.0	1.3	271	<99	0.12	35.6	2.4	<0.5	2.0	10.0
H85P3-2A	10	<1	<100	<1	<200	<1	6.6	<0.1	<5	<50	1.37	0.8	<0.5	1.2	<0.5	<0.5
H85P3-2B	18	1	<100	<1	<200	<1	11.1	<0.1	8	<50	2.92	1.6	<0.5	3.1	<0.5	<0.5
H85P3-2C	7	<1	<100	<1	<200	<1	4.1	<0.1	<5	<50	1.17	0.7	<0.5	2.6	<0.5	<0.5
H85P3-2E	155	4	<100	2	<240	<1	93.9	0.3	65	<64	7.42	8.2	0.8	30.6	<0.5	1.6
H85P3-3	1 430	20	<130	13	<590	5	957.0	0.7	469	<130	3.78	56.0	3.3	3.2	1.6	6.5
H85P3-5B	19	<1	<100	<1	<200	<1	10.2	<0.1	8	<50	0.63	1.9	<0.5	1.8	<0.5	<0.5
H85P4-3B	7 630	55	<100	83	<2 800	<3	>2 000.0	0.5	3 540	<550	0.58	313.0	11.0	24.8	6.7	7.4
H85P4-3C	614	13	<100	11	400	8	317.0	0.2	279	<71	0.12	41.4	1.6	5.0	1.2	2.9
H85P7	1 170	8	<100	8	<540	2	736.0	0.2	380	<120	7.19	33.2	1.4	3.7	1.0	3.4
H85P9	1 190	15	<100	12	<530	3	722.0	0.5	424	170	6.89	42.7	2.2	15.2	1.6	4.9
H85P10	875	15	<100	12	<440	4	505.0	0.5	345	100	6.70	43.6	2.3	15.0	1.9	4.9
H85P11	1 410	10	<100	9	<580	2	937.0	0.4	433	<130	8.75	38.2	1.5	5.7	1.0	3.3
MG5-7	198	12	<100	5	<260	2	94.2	0.4	91	<65	5.37	16.[illegible]	1.5	0.7	0.8	3.3
MG5-8	235	11	<100	4	<280	2	131.0	0.4	88	<68	4.42	14.6	1.4	0.6	0.7	3.3
H85P25A	126	4	<100	2	<250	<1	79.1	0.2	43	<62	9.27	5.9	<0.5	22.9	<0.5	1.4
H85P25B	598	20	<100	9	390	8	320.0	1.2	236	<80	1.89	33.9	3.0	17.9	2.0	9.0
H85P25C	47	2	<100	<1	<220	<1	28.7	<0.1	12	<56	7.56	3.1	<0.5	11.1	<0.5	1.0
H85P26A	670	17	<100	8	620	8	400.0	1.0	247	110	2.35	34.4	2.4	7.1	1.5	8.7
H85P26B	605	14	<100	7	<440	5	362.0	0.9	224	<96	2.17	28.6	1.8	6.4	1.8	6.1
H85P26Bi	152	3	<100	2	<200	<1	83.7	0.2	57	<50	2.01	9.2	0.6	<0.5	<0.5	1.2
H85P26C	176	5	<100	3	<200	<1	110.0	<0.1	64	<50	1.51	10.4	0.5	<0.5	<0.5	1.2
H85P26D	611	7	<100	4	<440	<1	479.0	0.3	149	<100	4.67	13.4	0.8	3.1	0.5	2.6
H85P26E	289	7	<100	5	<250	1	151.0	0.1	123	<60	2.14	15.1	0.8	0.6	0.7	1.6
H85P26F	512	9	<100	6	<370	2	310.0	0.3	188	<89	5.51	23.2	1.3	1.3	0.6	2.5
H85P26G	311	6	<100	4	<320	1	184.0	0.2	114	<78	6.68	15.2	1.3	4.9	0.8	2.3
H85P26H	45	4	<100	<1	<200	<1	26.5	0.2	17	<50	7.42	3.5	<0.5	6.5	<0.5	1.4
H85P29	398	11	<100	5	<400	1	242.0	0.5	139	<100	5.22	17.8	1.1	0.5	0.8	4.1

* All analyses in ppm.
Sample localities plotted on Figure 8-2.

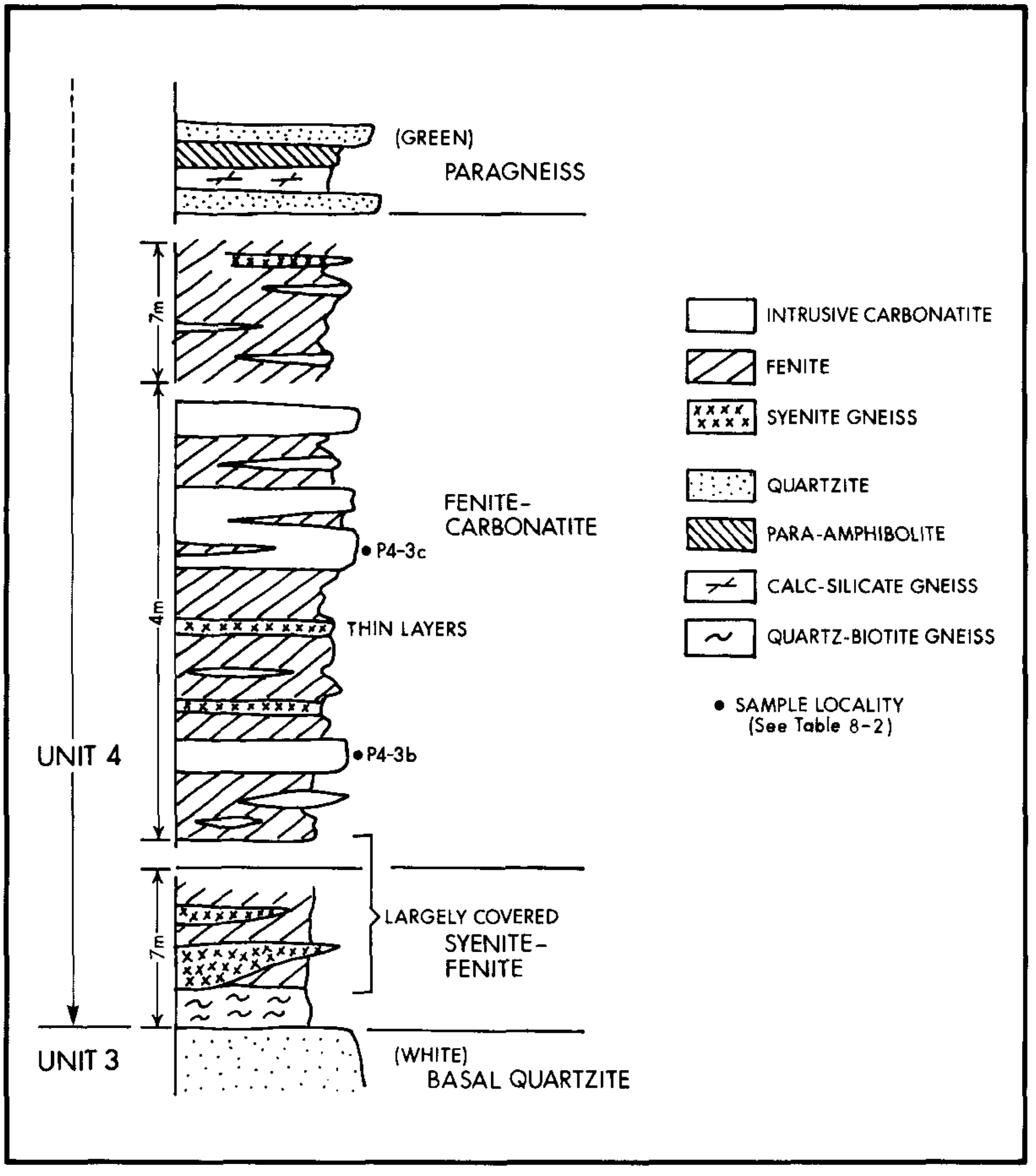
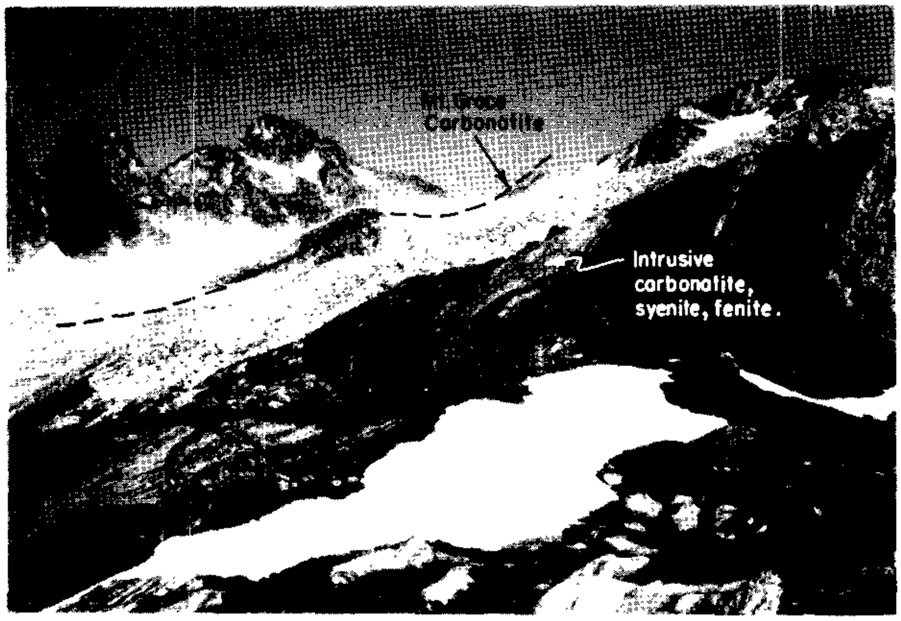
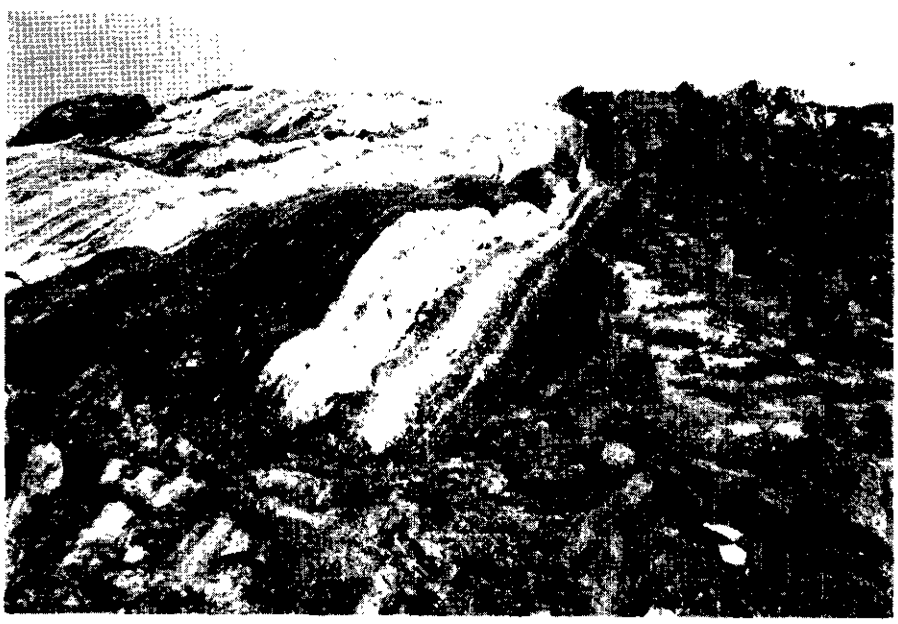


Figure 8-5. A measured section through the syenite-intrusive carbonatite-fenite zone at station H85P4 (Fig. 8-2).



(a)



(b)

Plate 8-1. Intrusive carbonatites-fenites, just south of station H85P4 (Fig. 8-2). (a) Overview showing position of carbonatite-fenite-syenite unit in foreground, and overlying Mount Grace carbonatite in distance. (b) Detail of interlayered intrusive carbonatite and dark grey to black amphibolitic fenite.

(a)

(b)

Plate 8-2. Intrusive carbonatites at station H85P1. (a) Swirled, discontinuous carbonatite lenses in fenite (sample H85P1-5). (b) Intermixed buff-weathering carbonatite and fenite, overlain by grey-weathering carbonatite (sample H85P1-8).

REN CARBONATITE

A new occurrence of a carbonatite in unit 6 in the core of the Mount Grace syncline (Fig. 8-2) is reported by Pilcher (1983). It is a concordant unit at least 3 kilometres in length and 20 to 200 metres in width that has fenitized margins and zones of fenite within it (Pilcher, pers. comm., 1985). It weathers to 'a mottled orange-brown colour, has a well-banded to salt-and-pepper texture, and averages 60 to 80 per cent calcite, 10 to 30 per cent apatite with accessory biotite, amphibole, sphene, and minor pyrrhotite, pyrite, sphalerite, chalcopyrite, pyrochlore (?), and monazite (?)' (Pilcher, *op cit.*, p. 8). It differs from the previously described intrusive carbonate-syenite complex; it is substantially thicker, occurs higher in the succession, and does not appear to be closely associated with syenite.

MOUNT GRACE CARBONATITE

GENERAL DESCRIPTION

Field descriptions, petrography, and geochemistry of the Mount Grace carbonatite are described by Höy and Kwong (in press). This paper reviews briefly that data and presents extensive additional trace and rare earth element data and some detailed sections through the carbonatite layer.

The Mount Grace carbonatite layer averages 3 to 5 metres in thickness. Locally it narrows to less than a metre, but near (?) its northern limit (H85P29, Fig. 8-2), it is estimated to be greater than 60 metres thick. Although in most places it is a single layer, it locally comprises a main layer plus a number of thinner layers separated by paragneiss and marble. It has been traced or projected beneath overburden for a strike length of approximately 60 kilometres. The contacts of the Mount Grace carbonatite with overlying and underlying calcareous gneisses are sharp, but in places they grade through approximately 1 metre into grey-weathering, massive to thin-bedded calcite marble. In contrast with intrusive carbonatites in the Perry River area, the Mount Grace carbonatite has no fenitized margins.

In the field, the carbonatite is recognized and characterized by an unusual pale to medium brown-weathering colour. Grains of dark brown phlogopite, colourless apatite, and needles of amphibole weather in relief. Pyrrhotite, pyrochlore, and zircon are locally developed accessory minerals. The Mount Grace carbonatite is commonly internally bedded, with a layer or several layers of 'blocky' tephra interbedded with finer grained, massive or laminated carbonatite. The blocky tephra layers contain three types of matrix-supported clasts: small granular albitite clasts up to 3 centimetres in diameter, consisting of pure albite or albite with variable amounts of phlogopite; syenite clasts, 1 to 10 centimetres in diameter, consisting of K-feldspar with variable amounts of plagioclase calcite, apatite, and rare feldspathoids; and larger rounded to subrounded biotite-plagioclase gneiss, schist, and quartzite clasts that *are commonly up to 20 centimetres in diameter. The lithic clasts* may be internally folded and have a pronounced layering or foliation that is randomly oriented with respect to the regional mineral foliation. The lithic and albitite clasts are generally randomly distributed.

(a) (b)

Plate 8-3. Mount Grace carbonatite (station H85P3). (a) Well-layered extrusive carbonatite containing small clasts of dominantly albitite (b) Large clast of mixed syenite-paragneiss (?) with relict fenite (?) along contact.

throughout a blocky tephra layer, but in some layers they are concentrated in the central portion or occasionally graded with clast size increasing up section.

The Mount Grace carbonatite was examined in detail and extensively sampled in the Perry River area (H85P3), in the Mount Grace area, and north of Blais Creek (H85P25).

PERRY RIVER AREA (H85P3)

The maximum thickness of the Mount Grace carbonatite in exposures at this site and north to the ridge (*see* Plate 8-1a) is approximately 1 metre. It consists of a single well-bedded layer that contains generally small (2 to 3-centimetre) albitite and lithic clasts (Plate 8-3a). Uncommon, larger clasts (to 15 centimetres maximum) include folded lithic fragments and a rare syenite clast with a preserved fenite margin (Plate 8-3b). The carbonatite layer is within a mixed impure marble, calc-silicate and pelitic gneiss sequence (Plate 8-4). The immediate footwall is a thin grey marble of sedimentary origin (*see* Tables 8-2a and 8-2b, sample H85P3-2C).

Rare earth element data and some trace element data for both the carbonatite and host rocks from this locality are listed in Tables 8-2a and 8-2b.

MOUNT GRACE AREA

The Mount Grace carbonatite occurs on the inverted west limb of the Mount Grace syncline. It structurally overlies the white crystalline marble of unit 5 and the Cottonbelt Pb-Zn layer near the base of unit 6. It has been traced discontinuously approximately 13 kilometres in the Mount Grace area, from limited exposures in trees near its south end to fairly continuous exposures west of Mount Grace, to two drill intersections at its north end. Its thickness varies from less than a metre at its north end to a maximum of approximately 3 metres just north of sample P11 (Fig. 8-2). It decreases in thickness southward but appears to increase again in the southern exposures. The size of included clasts appears to increase proportionately with thickness; 30 to 40-centimetre diameter clasts are common in the thicker sections, but only 5 to 10-centimetre maximum clast sizes occur in thinner sections.

Trace and rare earth element data of carbonatite samples from the Mount Grace area are given in Höy and Kwong (in press), and some additional data from this study (H85P7 to H85P11) are listed in Tables 8-2a and 8-2b.

BLAIS CREEK AREA

A measured section at site H85P25 (Fig. 8-2) illustrates the succession in the Blais Creek area and the position of the Mount Grace carbonatite near the top of unit 4 (Fig. 8-6). The carbonatite unit is 8.2 metres thick and includes a thick basal part of mixed coarse blocky tephra and fine-grained tuff and marble, overlain by interlayered impure metasedimentary marble and tuff (Fig. 8-7). Within the basal part are interbedded coarse tephra layers, fine-grained layers, and a number of coarsening upward cycles. Clasts are abundant (Plate 8-5), averaging 15 to 20 centimetres in diameter; the largest are 30 to 40 centimetres. In general, lithic clasts are larger than albitite clasts. The top of the Mount Grace carbonatite is dominated by impure siliceous marble that contains a few thin, brown-weathering, fine-grained tuff layers.

Analyses of the carbonatite layers and host rocks are listed in Tables 8-2a and 8-2b, and selected data plotted on Figure 8-7. The data confirms the existence of thin tuff layers within metasedimentary marble at the top of the carbonatite unit (sample H85P25B) and indicates that some of the fine-grained marble layers within the basal part of the carbonatite unit, those that have low REE concentrations (for example, H85P26B, H85P26D), may be largely of sedimentary origin with only a minor tuff component.

The thickness of the Mount Grace carbonatite increases dramatically northward to at least 20 metres at site H85P29 (Fig. 8-2). An associated increase in clast sizes here indicates close proximity to a source or vent area. The Mount Grace carbonatite has not been studied in detail at this locality and has only been traced a further 1 kilometre to the north.

TRACE ELEMENT AND RARE EARTH ELEMENT (REE) DATA

Analyses of selected samples of the intrusive carbonatites, the Mount Grace carbonatite, and host metasedimentary rocks are listed in Tables 8-2a and 8-2b. These samples are mainly from the Perry River and Blais creek areas as data from the Mount Grace area are given in Höy and Kwong (in press). Both types of carbonatite are characterized by relatively high Mn, Sr, and Ba values, and the extrusive Mount Grace carbonatite by Nb values that range up to 1 000 ppm (Table 8-2a).

Total REE concentrations (Table 8-2b) of both extrusive and intrusive carbonatites average between 0.1 and 0.2 per cent, with one sample of the Perry River intrusive carbonatite (H85P4-3B) containing greater than 1.5 per cent REE content. Chondrodite normalized REE plots of selected samples (Figs. 8-8, 8-9, and 8-10) illustrate the light rare earth element (La through Eu) enrichment that is typical of carbonatites worldwide. Comparison of plots for intrusive and extrusive carbonatites shows that although the slopes (enrichment) are similar, the intrusive carbonatites that are closely associated with syenite (Fig. 8-8) generally have higher absolute values of REE's than the Ren or the Mount Grace carbonatites. Overlap in REE values suggests that contamination of the Mount Grace carbonatite by simultaneous deposition of marine carbonate was minimal.

CONCLUSIONS

Initial alkalic magmatism included intrusion of syenites, nepheline syenites, and carbonatite lenses in a platformal metasedimentary succession that unconformably overlay a basement complex. Subsequent explosive volcanism from widely separated vent areas produced a number of interfingering pyroclastic ash flow or air fall layers, now preserved as the Mount Grace carbonatite. The extrusive episodes were separated by quiescent periods and locally deposition of marine carbonate. Intrusion of the Ren carbonatite in overlying metasedimentary rocks indicates that alkalic magmatism spanned a considerable time interval.

ACKNOWLEDGMENTS

Discussions with W. J. McMillan and Y.T.J. Kwong of the Ministry of Energy, Mines and Petroleum Resources and S. Pilcher of Duval International Corp. are gratefully acknowledged. Silicate and minor element analyses were done by the Ministry Laboratory and rare earth element analyses under contract by Bondar-Clegg.

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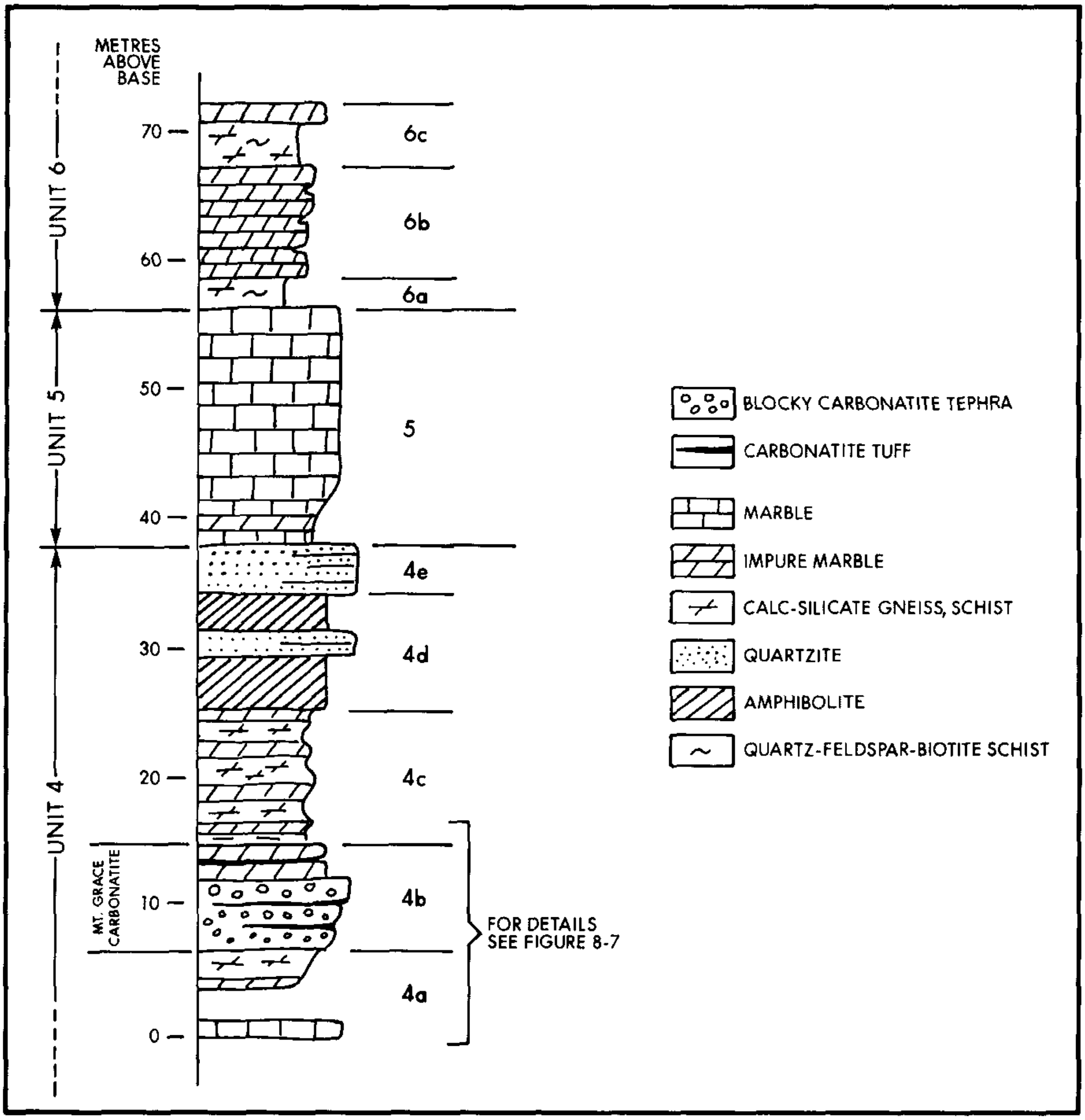


Figure 8-6. A measured section at stations H85P25, H85P26, Blais Creek area that includes the Mount Grace carbonatite and adjacent host rocks.

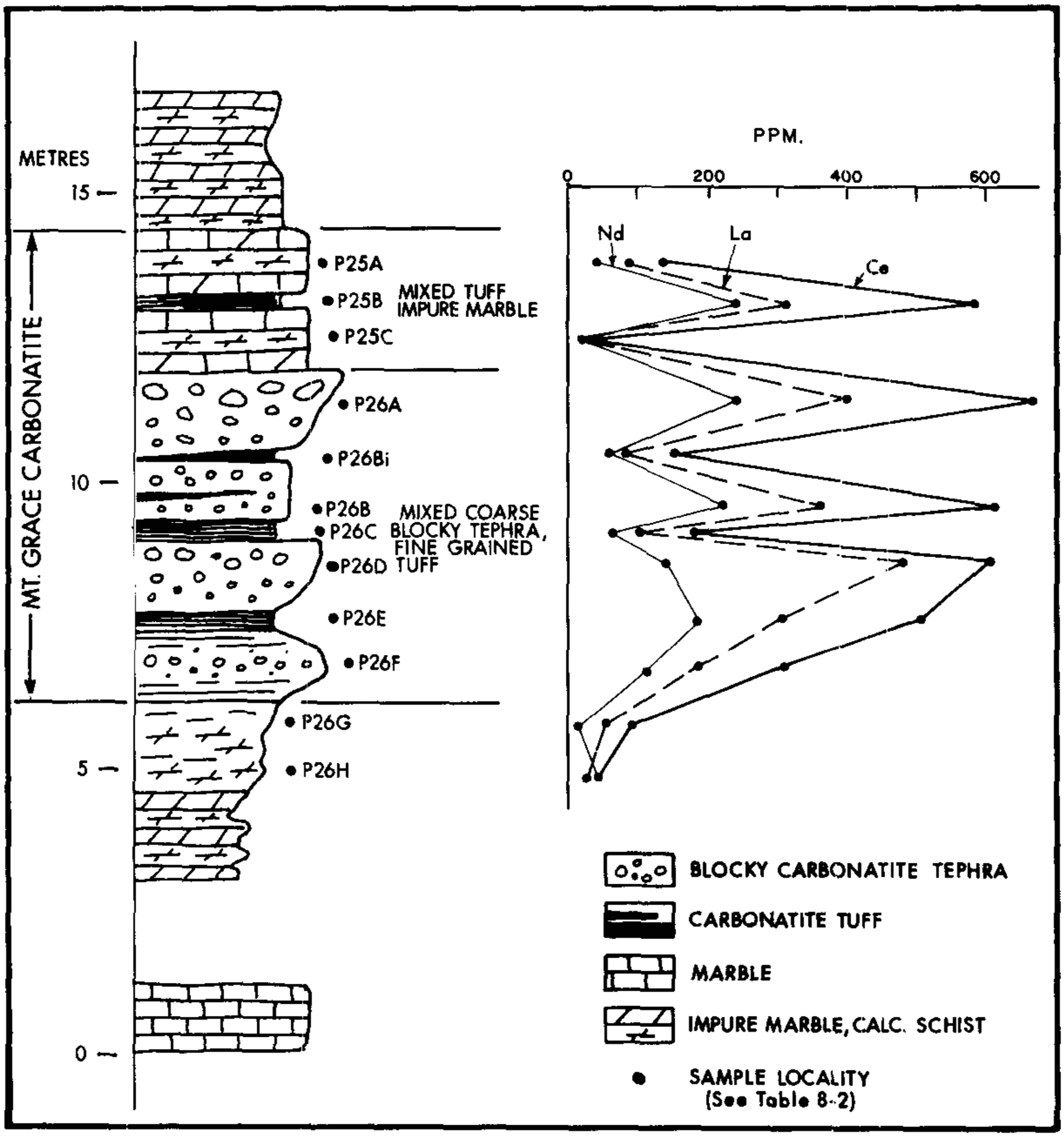


Figure 8-7. Detailed section of the Mount Grace carbonatite, Blais Creek (stations H85P25 and H85P26), showing La, Ce, and Nd values of selected samples.

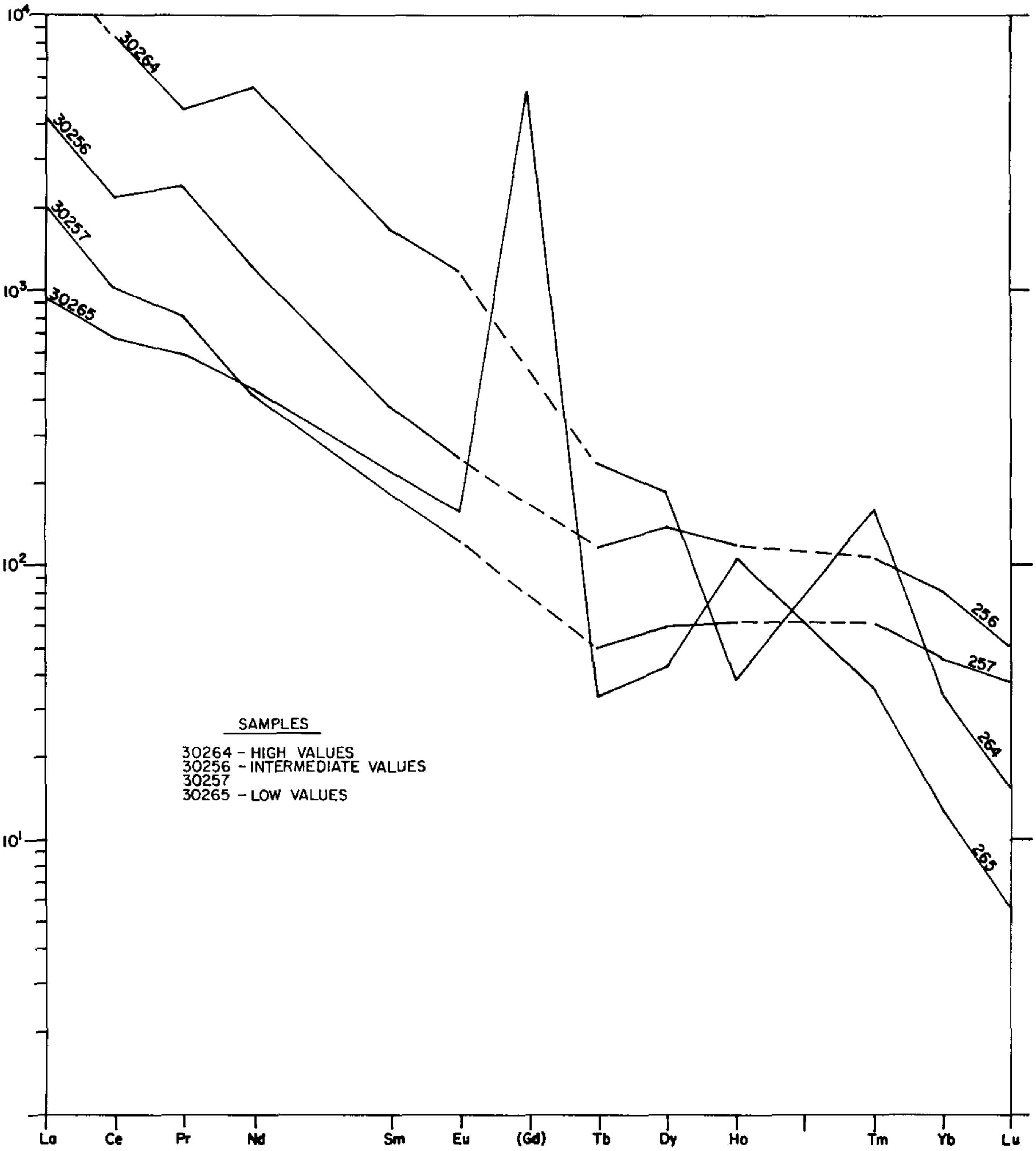


Figure 8-8. Chondrodite normalized rare earth element plots of intrusive carbonatites, Perry River area.

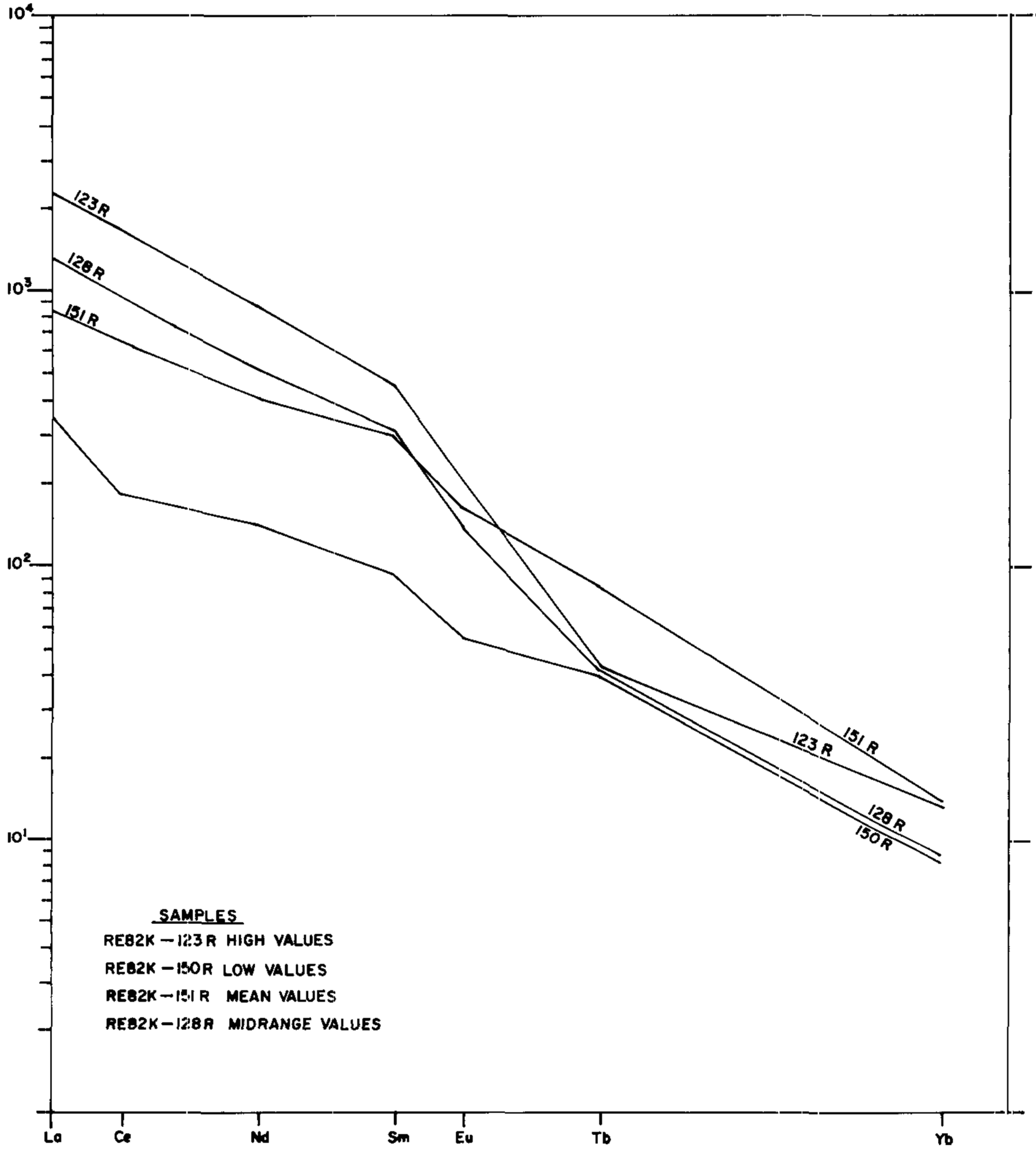


Figure 8-9. Chondrodite normalized rare earth element plots of the Ren intrusive carbonatite.

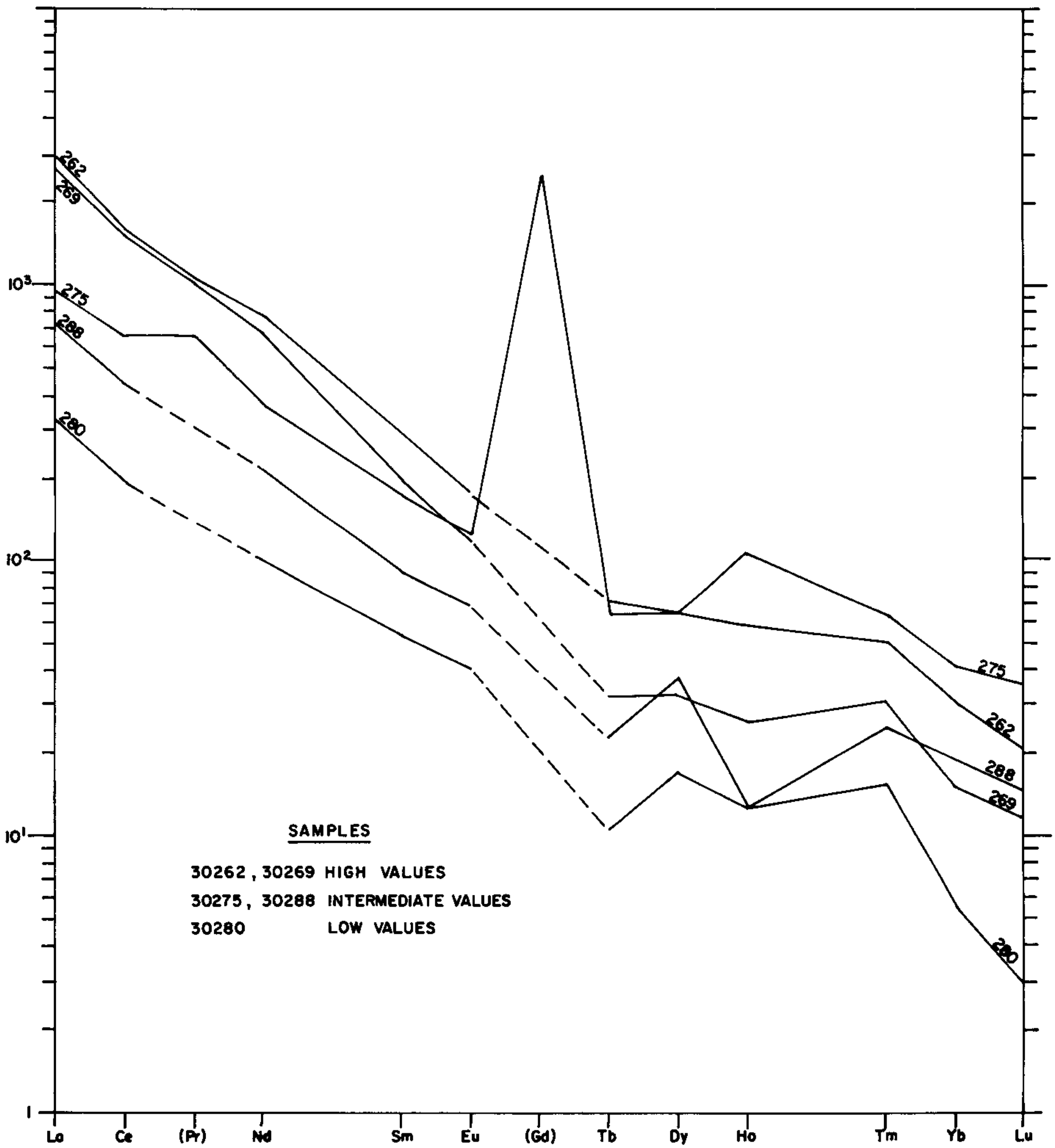
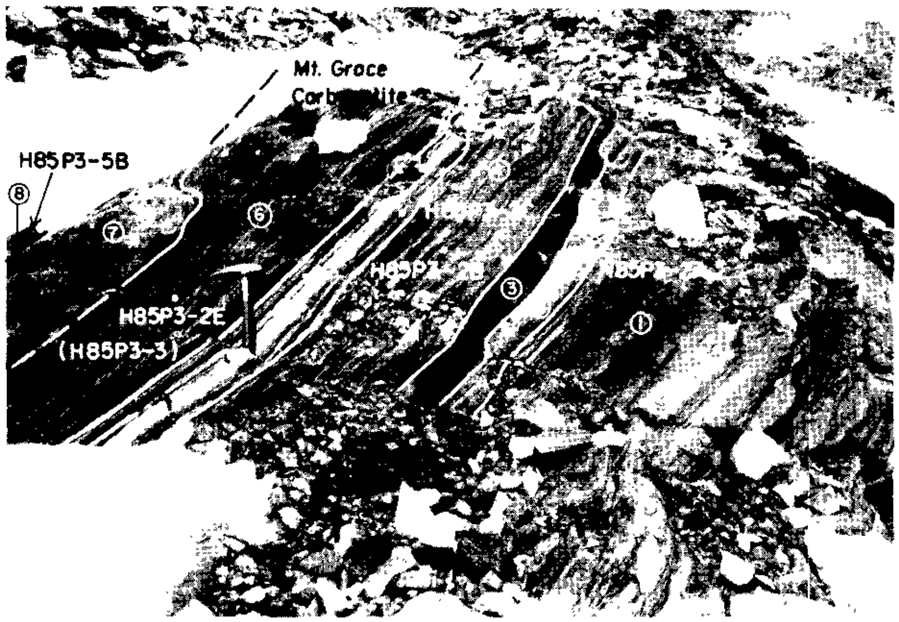


Figure 8-10. Chondrodite normalized rare earth element plots of the Mount Grace intrusive carbonatite.



LEGEND

8 IMPURE MARBLE
7 CALC-SILICATE GNEISS
6 MOUNT GRACE CARBONATITE
5 GREY MARBLE
4 IMPURE MARBLE, CALC-SILICATE GNEISS
3 RUSTY SCHIST
2 IMPURE MARBLE
1 CALC-SILICATE GNEISS, IMPURE MARBLE, PELITIC SCHIST

Plate 8-4. The Mount Grace carbonatite and host succession at site H85P3, showing locations of analysed samples (Tables 8-2a and 8-2b).

Plate 8-5. Subrounded paragneiss clasts in the Mount Grace carbonatite at the Blais Creek section (station H85P25).

British Columbia Geological Survey
Geological Fieldwork 1985

GEOLOGY OF THE EAGLE BAY FORMATION BETWEEN THE RAFT AND BALDY BATHOLITHS* (82M/5, 11, 12)

By Paul Schiarizza

INTRODUCTION

A 600-square-kilometre area centred near the town of Vavenby was mapped between mid-July and mid-October. This work extends the mapping of the Eagle Bay Formation and adjacent rocks carried out by the Ministry of Energy, Mines and Petroleum Resources under the direction of V. A. Preto from 1978 to 1981. The results of this year's work will be released in early 1986 as an Open File map at a scale of 1:50 000.

ROCK UNITS

EAGLE BAY FORMATION (UNITS 1 to 8)

The Eagle Bay Formation within the map-area has been subdivided into eight units. At the base of the formation is a quartzite-dominated succession (unit 1) of unknown age. This is overlain by a succession of felsic to intermediate metavolcanic rocks (units 2 and 3) and fine to coarse-grained clastic metasedimentary rocks (units 4 and 5) which are inferred to be mainly of Devono-Mississippian age based on correlations with dated Eagle Bay rocks to the south. Structurally above these rocks is a mafic metavolacanic-limestone division (unit 6) locally overlain by intermediate metavolcanics (unit 7). Fossil *archaeocyathids* from the Tshinakin limestone member of unit 6 indicate that it is Early Cambrian in age, and therefore must be in thrust contact with the underlying portion of the Eagle Bay package of Devono-Mississippian age. The structurally highest division of the Eagle Bay Formation comprises clastic metasedimentary rocks of unit 8, which sit above unit 6 in the eastern part of the map-area. This panel of rocks is overturned, however, and unit 8 may be the oldest unit within the Eagle Bay succession.

UNIT 1

Unit 1 is dominated by light to medium grey quartzite, platy chorite-muscovite quartzite, and chlorite-muscovite-quartz schist. Biotite and garnet are commonly present in the vicinity of Reg Christie Creek, where the rocks are of higher metamorphic grade (Fig. 9-1). Locally, unit 1 contains significant proportions of limestone, calc-silicate schist, dark grey phyllite, silvery sericite-quartz phyllite, and green chloritic schist. Unit 1 is the structurally lowest rock unit exposed within the map-area. It occurs in a discontinuous belt which extends along the southern margin of the Raft batholith from Mount McClennan westward to the western edge of the map-area, and from just east of Vavenby on the east side of the North Thompson River eastward along Reg Christie Creek. A thin horizon of mainly platy quartzites, siltites, and chlorite-muscovite-quartz schists, which occurs between unit 6 and orthogneiss of unit 9 north of Gollen Creek, is also included within unit 1. Rocks correlative with unit 1 along the northern margin of the Baldy batholith in the vicinity of Harper Creek (unit 1a) are intruded by large volumes of granitic orthogneiss, and are intercalated with thin horizons of 'quartz-eye' sericite schist. These horizons are probably derived from quartz porphyry sills related to overlying felsic volcanics of unit 2.

Unit 1 is lithologically similar to unit SDQ of Schiarizza and Preto (1984) in the Adams Lake-Barriere Lakes area. It also appears to correspond closely to descriptions by Campbell and Tipper (1971) of their unit 1 which consists largely of quartzite and quartz-mica schist and outcrops on the north side of the Raft batholith about 20 kilometres northwest of the map-area. The age of unit 1 is unknown, but it may be considerably older than the overlying Devono-Mississippian portion of the Eagle Bay succession.

UNIT 2

Unit 2 consists mainly of light silvery grey sericite-quartz phyllite and chlorite-sericite-quartz phyllite derived largely from felsic to intermediate volcanic and volcaniclastic rocks. The phyllite commonly contains eyes of glassy quartz to several millimetres in size, and locally includes fragmental members containing felsic clasts that are highly flattened within the plane of the schistosity. Also present within unit 2 is green chloritic phyllite derived from more mafic volcanic rock, dark grey phyllite and siltstone, light grey sericitic quartzite, and thin horizons of pyritic cherty rock that may be of exhalative origin.

Unit 2 outcrops most extensively along a much faulted belt south of the North Thompson River which extends from the western boundary of the map-area as far east as Chuck Creek. It sits above unit 1a in the western part of this belt and above orthogneiss of unit 9 to the east. Unit 2 is absent, or very thin, along the faulted extension of this belt in the vicinity of Gollen Creek, but occurs locally above unit 1 south of Reg Christie Creek where this stratigraphic level is repeated as a south-dipping panel on the north limb of the Graffunder Lakes synform (Fig. 9-2, section A-A'). Unit 2 is also exposed above unit 1 on the north side of the North Thompson River, west of Crossing Creek, but is absent just to the east, where unit 1 is directly overlain by unit 4.

Unit 2 is inferred to be Devonian in age based on correlation with felsic to intermediate metavolcanic rocks of that age in the Adams Lake area (unit EBA of Schiarizza and Preto, 1984).

UNIT 3

Unit 3a comprises pale to medium green, strongly to weakly foliated chlorite-sericite schists which commonly contain crystals of feldspar, hornblende, and quartz, as well as lithic clasts to several centimetres in size. This unit was derived largely from intermediate crystal-lithic tuffs, but may also include some porphyritic flows. These rocks overlie unit 2 between Lute and Baker Creeks as well as on the slopes west of Foghorn Creek (unit EBF of Schiarizza and Preto, 1984). This unit also outcrops between Jones and Avery Creeks where it apparently underlies unit 5.

Unit 3b comprises feldspar porphyry, feldspathic schist, sericite-feldspar-quartz schist, and metavolcanic breccia that are derived from trachytic, dacitic, and rhyolitic intrusive and extrusive rocks. It overlies unit 2 between Lute and Foghorn Creeks where it hosts the Rexspar uranium-fluorite mineralization. Originally these rocks were included within unit 2 (unit EBAf of Schiarizza and Preto, 1984); it is more likely that they are lateral equivalents of unit 3a.

* This project is a contribution to the Canada/British Columbia Mineral Development Agreement.

British Columbia Ministry of Energy, Mines and Petroleum Resources, Geological Fieldwork, 1985, Paper 1986-1.

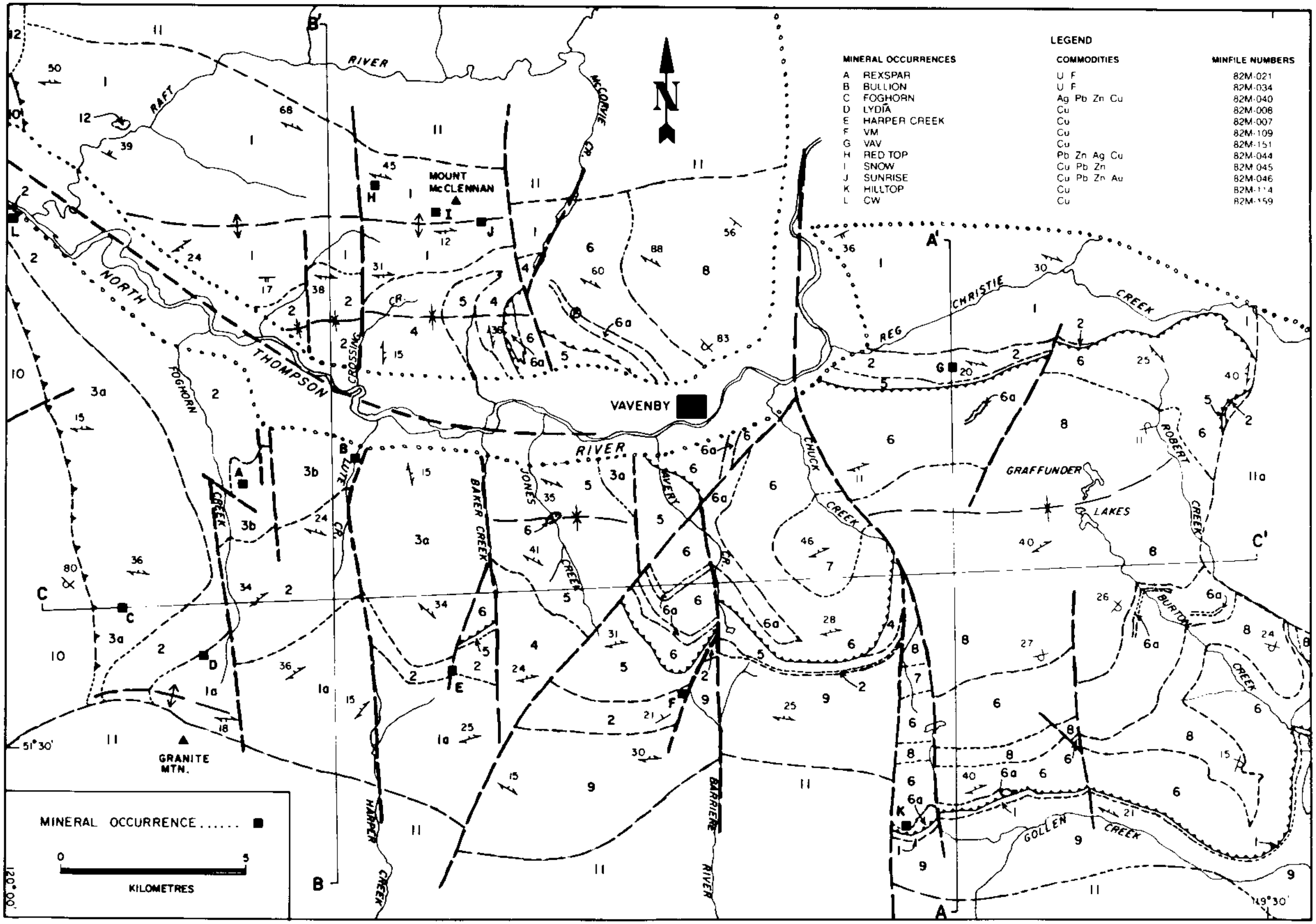


Figure 9-1. Generalized geological map of the Vavenby area.

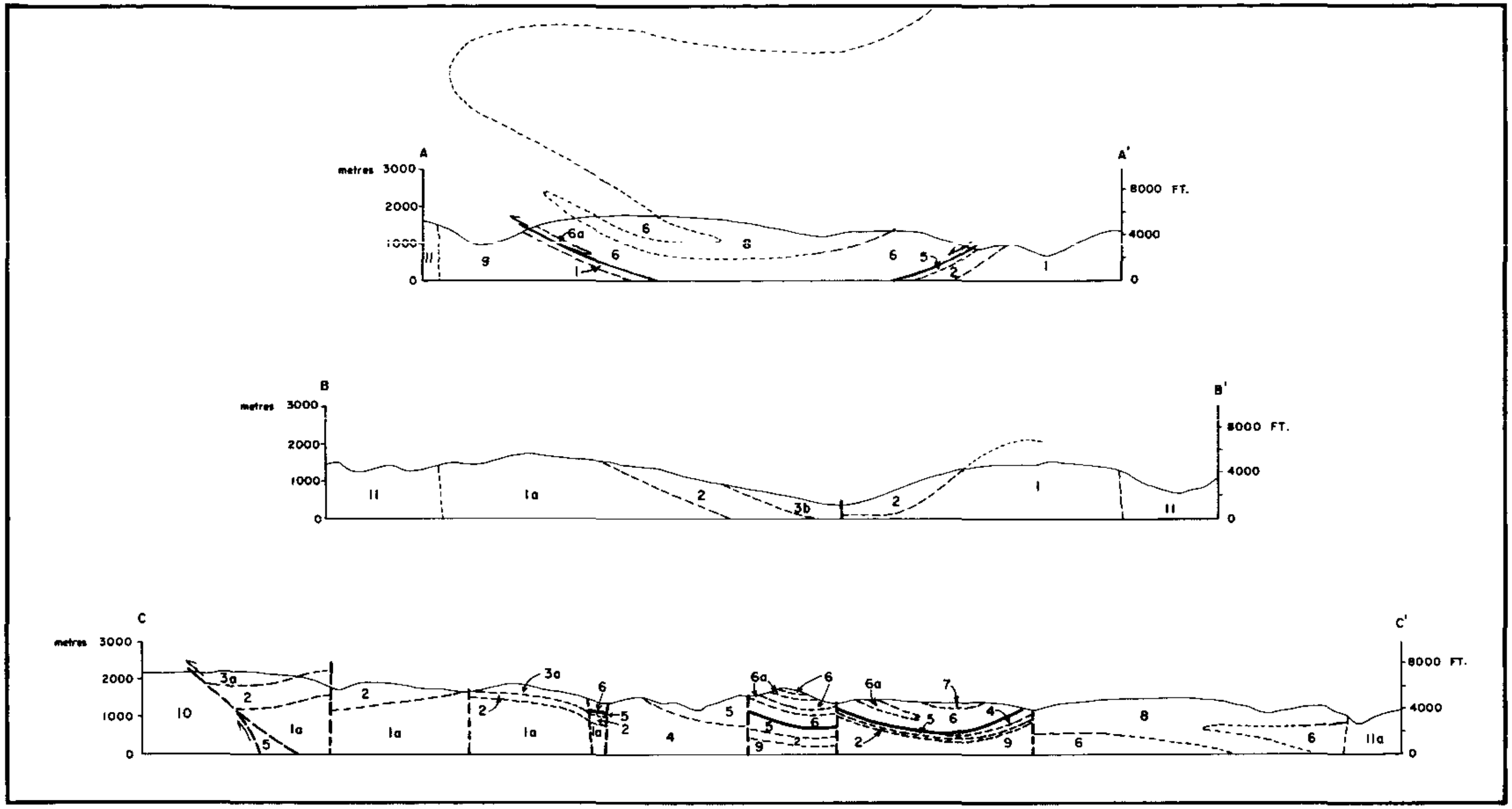


Figure 9-2. Vertical cross-sections to accompany Figure 9-1.

LEGEND

MIOCENE OR PLIOCENE

12 OLIVINE BASALT

CRETACEOUS

11 GRANITE AND GRANODIORITE, 11a INCLUDES ABUNDANT PEGMATITE

DEVONIAN TO PERMIAN

FENNELL FORMATION

10 BASALT, GABBRO, CHERT, MINOR AMOUNTS OF SANDSTONE, LIMESTONE, INTRAFORMATIONAL CONGLOMERATE

DEVONIAN (?)

9 GRANITIC ORTHOGNEISS

LOWER CAMBRIAN AND OLDER (?) TO MISSISSIPPIAN

EAGLE BAY FORMATION (UNITS 1 TO 8)

8 GRIT, QUARTZITE, CHLORITE-MUSCOVITE-QUARTZ SCHIST

7 INTERMEDIATE METATUFF, QUARTZITE, CHLORITE-SERICITE-QUARTZ SCHIST, LIMESTONE, DOLOMITE-CHLORITE SCHIST

LOWER CAMBRIAN AND OLDER (?) TO MISSISSIPPIAN *(CONTINUED)*

EAGLE BAY FORMATION (UNITS 1 TO 8) *(CONTINUED)*

6 CALCAREOUS CHLORITE SCHIST AND GREENSTONE DERIVED FROM MAFIC VOLCANIC ROCKS, LESSER AMOUNTS OF CHLORITIC DOLOSTONE AND LIMESTONE. 6a — LIGHT GREY LIMESTONE

5 DARK GREY PHYLLITE INTERCALATED WITH SILTSTONE, SANDSTONE, GRIT AND PEBBLE CONGLOMERATE. LESSER AMOUNTS OF LIMESTONE AND DOLOSTONE

4 GRIT, QUARTZITE, CHLORITE-MUSCOVITE-QUARTZ SCHIST. LESSER AMOUNTS OF LIMESTONE, CHLORITE SCHIST, AND DARK GREY PHYLLITE

3 3a — CHLORITE-SERICITE SCHIST DERIVED FROM QUARTZ HORNBLENDE-FELDSPAR CRYSTAL-LITHIC TUFFS AND (?) PORPHYRITIC FLOWS. 3b — FELDSPAR PORPHYRY, FELDSPATHIC SCHIST, SERICITE-FELDSPAR-QUARTZ SCHIST, METAVOLCANIC BRECCIA, TRACHYTE

2 SERICITE-QUARTZ PHYLLITE DERIVED LARGELY FROM FELSIC TO INTERMEDIATE VOLCANICS. LESSER AMOUNTS OF CHLORITE PHYLLITE, DARK GREY PHYLLITE AND SILTSTONE, SERICITIC QUARTZITE, AND PYRITIC CHERT (EXHALITE?)

1 QUARTZITE, CHLORITE-MUSCOVITE-QUARTZ SCHIST. LESSER AMOUNTS OF LIMESTONE, CALC-SILICATE SCHIST, LIGHT TO DARK GREY PHYLLITE AND GREEN CHLORITE SCHIST. 1a — INCLUDES ABUNDANT ORTHOGNEISS AND QUARTZ-SERICITE SCHIST DERIVED FROM QUARTZ PORPHYRY

UNIT 4

Unit 4 consists of light to medium greenish grey grit, quartzite, and chlorite-sericite-quartz schist with minor amounts of intercalated dark grey phyllite, limestone, and chlorite schist. It sits beneath unit 5 in the vicinity of Jones Creek but both above and below unit 5 on the slopes south of Mount McClennan, possibly due to isoclinal folding of the two units. A thin wedge of grit, quartzite, limestone, and chlorite schist, which occurs between units 5 and 6 on the slopes west of Chuck Creek, is tentatively included within unit 4, but may actually be a structurally imbricated sliver of units 6 and 8. Unit 4 is lithologically similar to, and possibly correlative with, parts of unit EBS of Schiarizza and Preto (1984), which outcrops in a northwest-trending belt between Adams Lake and the Barriere River.

UNIT 5

Unit 5 consists mainly of dark grey phyllite with intercalated siltstone, sandstone, grit, and minor amounts of pebble conglomerate. It also includes medium to dark grey limestone and pale greenish grey schistose chloritic and sericitic dolostone. Unit 5 lies stratigraphically above unit 2 throughout most of the area, but locally is above (or within?) unit 4. Unit 5 is correlated with lithologically identical rocks in the Barriere Lakes area which have yielded several collections of Lower and Upper Mississippian conodonts (unit EBP of Schiarizza and Preto, 1984).

UNIT 6

Unit 6 consists mainly of medium to dark green calcareous chlorite schist, dolomite-chlorite schist, and relatively massive greenstone that are derived from mafic volcanic and volcaniclastic rocks. It also includes minor amounts of sericite-chlorite schist containing hornblende, feldspar, and rare quartz crystals which was derived from intermediate crystal tuffs and/or porphyritic flows. Thin lenses and beds of white crystalline limestone and rusty weathering schistose dolomite occur locally throughout the unit. A horizon of light grey limestone up to several hundred metres in thickness (unit 6a) forms prominent bluffy outcrops within the unit north and south of Vavenby. This limestone is clearly correlative with the Tshinakin limestone of the Adams Lake-Johnson Lake area which is also enclosed within a thick succession of mafic metavolcanic rocks (unit EBG of Schiarizza and Preto, 1984). Fossils collected from unit 6a, 4 kilometres northwest of Vavenby, were identified as *archaeocyathids* by B. S. Norford of the Geological Survey of Canada in Calgary. This indicates an Early Cambrian age for unit 6a at this locality.

Unit 6 sits structurally above unit 5 in several fault-bounded blocks on the south side of the North Thompson River between Chuck and Baker Creeks. This contact is inferred to be a thrust fault because unit 5 is thought to be of Mississippian age while unit 6 is now known to be, at least in part, Early Cambrian in age. A thrust relationship between unit 6 and underlying rocks is substantiated, on structural grounds, in the area east of Chuck Creek and on the north side of the North Thompson River south of the McCorvie Lakes. In these areas unit 6 and structurally overlying rocks of unit 8 are overturned, while the structurally underlying rocks of units 1, 2, 4, and 5 are in their regionally persistent and presumably right-way-up orientation.

Rocks correlative with unit 6 in the Barriere Lakes-Adams Plateau area (unit EBG of Schiarizza and Preto, 1984) were also inferred on structural grounds to be in fault contact with underlying Devono-Missippian rocks correlative with units 2, 3, and 5 of this report (Schiarizza, 1983; Schiarizza and Preto, 1984). The Early Cambrian age of the Tshinakin limestone established during the present study corroborates this interpretation.

UNIT 7

Unit 7 consists of light to medium green crystal-lithic metatuff, similar to that of unit 3a, with lesser amounts of intercalated limestone, dolomite-chlorite schist, platy quartzite, and chlorite-sericite-quartz schist. It occurs only in the vicinity of Chuck Creek where it sits structurally above unit 6.

UNIT 8

Unit 8 consists of light to medium grey-green quartzite, grit, and chlorite-muscovite-quartz schist with relatively minor amounts of intercalated dark grey phyllite and dolomite-chlorite schist. It sits structurally above unit 6 in the steeply dipping belt east of McCorvie Lakes and in the core of the Graffunder Lakes synform east of the Chuck Creek fault (Figs. 9-1 and 9-2). It also occurs as a belt internally within unit 6 on the south limb of the synform, where it is presumably infolded into unit 6. Graded beds at a number of places within unit 8, including the southern margin of the belt within unit 6, are overturned; therefore unit 8 actually lies stratigraphically beneath unit 6 and is inferred to be Early Cambrian and/or older in age.

DEVONIAN (?) ORTHOGNEISS (UNIT 9)

Unit 9 comprises quartzo-feldspathic orthogneiss. It is typically a weakly to moderately foliated rock consisting of lenses and augen of quartzo-feldspathic material enclosed by 'seams' of chlorite-sericite schist. Locally it grades to virtually massive granitic rock or conversely to strongly foliated chlorite-sericite schist containing large 'eyes' of quartz. Biotite is an important component of the gneiss within the thermal aureole of the Baldy batholith.

The orthogneiss occurs mainly as a north-dipping belt up to 3.5 kilometres wide, which extends along the north margin of the Baldy batholith from the east end of the map-area to the northeast-trending fault west of the Barriere River. In the east it lies beneath, and presumably intrudes, unit 1; in the west it is beneath unit 2. Farther west substantial amounts of orthogneiss occur within both units 1a and 2; there, however, it is not sufficiently well defined to be mapped separately and shown on the geological map. Similar orthogneiss also occurs within unit 2 rocks south of Reg Christie Creek.

The unit 9 orthogneiss is lithologically identical to intrusive units within felsic to intermediate metavolcanic schist exposed along the southern part of Adams Lake (unit EBAi of Schiarizza and Preto, 1984). There, the orthogneiss is believed to be genetically related and of similar age to Devonian volcanics that it intrudes. Devonian orthogneiss also occurs along a belt which extends for more than 70 kilometres between Adams and Shuswap Lakes (Okulitch, *et al.*, 1975). Unit 9 is therefore considered likely to be of Devonian age.

FENNELL FORMATION (UNIT 10)

Basalt, gabbro, chert, and related rocks of the Fennell Formation outcrop mainly south of the North Thompson River along the western edge of the map-area, where they were studied by the writer in 1980 and 1981 (Schiarizza, 1981, 1982, 1983). In this area an east-dipping thrust fault juxtaposes them against unit 3a of the Eagle Bay Formation. A small sliver of Fennell Formation chert, cherty argillite, and fine to medium-grained greenstone also occurs along the western edge of the map-area directly north of the river. There it is unconformably overlain to the north by Miocene basalt (Fig. 9-1). These Fennell rocks are inferred to be separated from unit 1 of the Eagle Bay Formation by the same east-dipping thrust fault that separates the Fennell from unit 3a further south. This relationship may persist to the northwest into the Bonaparte Lake map-area where, on the north side of the Raft batholith, Campbell and Tipper (1971) mapped an east-dipping thrust fault between the Fennell Formation and structurally overlying rocks which may be equivalent to unit 1 of this report.

CRETACEOUS GRANITIC ROCKS (UNIT 11)

Cretaceous granite and granodiorite (unit 11) of the Raft and Baldy batholiths intrude Eagle Bay rocks along the northern and southern margins of the map-area respectively. Intrusion postdated regional metamorphism and most of the penetrative deformation within the Eagle Bay succession, but appears to have been synchronous with relatively late folding about east-west-trending axes. Both batholiths are cut by northerly trending faults of probable Early Tertiary age. In contrast to the abrupt northern contact of the Baldy batholith, the southern margin of the Raft batholith is marked by a broad zone of intermixed metasedimentary and granitic rocks. Cordierite (?), andalusite, and sillimanite occur in pelitic schists of unit 1 at several localities within, and just south of, the contact zone of the Raft batholith.

Cretaceous granite also occurs along the eastern edge of the map-area, east of Robert Creek. This body (unit 11a) includes abundant pegmatite as well as distinctly foliated granitic phases.

MIOCENE BASALT (UNIT 12)

Flat-lying, undeformed basalt flows, which are well exposed along the Clearwater River to the northwest (Campbell and Tipper, 1971), extend as far east as the northwestern corner of the map-area (Fig. 9-1). A small patch of basalt which unconformably overlies unit 1 quartzites on the northwest slopes of the Raft River valley, 3.5 kilometres north of the confluence with the North Thompson River, is apparently a detached erosional remnant of these flows. These basalts are the easternmost representatives of an extensive mass of Late Miocene to Pliocene plateau lavas which cover much of the area to the west and northwest of the map-area (Campbell and Tipper, 1971).

STRUCTURE

The mesoscopic structural fabric within the map-area is dominated by the following five generations of structures:

(1) An early metamorphic foliation, axial planar to very rare small isoclinal folds, which is locally observed to be discordant to and/or folded about the dominant second generation schistosity.

(2) Variably oriented, but most commonly north to east-plunging isoclinal folds; the dominant synmetamorphic schistosity is axial planar. Throughout most of the area this schistosity is parallel to bedding.

(3) Northwest-trending folds and crenulations with axial planar crenulation cleavage. Axial surfaces generally dip steeply to the northeast or southwest, but in a small area north and south of Vavenby, northwest-trending folds display a gently northwest-dipping axial planar crenulation cleavage.

(4) East-west-trending upright folds, kinks, and crenulations that probably formed during emplacement of the Early to Middle Cretaceous Raft and Baldy batholiths.

(5) Upright, northerly trending folds, kinks, and crenulations of probable Tertiary age. The folds are often most prominently developed adjacent to northerly trending faults.

The most conspicuous macroscopic structures within the map-area are upright east-west-trending folds, and steep northerly trending faults. These folds are relatively young, and probably related to the emplacement of the Raft and Baldy batholiths. Locally they cause inversions in the predominantly northerly dip direction of bedding and schistosity within the map-area. Two such areas are across an antiform-synform pair between Mount McClennan and the North Thompson River, and across a synformal hinge that passes through the Graffunder Lakes, east of the Chuck Creek fault. The northerly trending faults cut the east-west folds as well as all other structures and rock units in the area except the Miocene basalts. The faults, and related northerly trending fractures, are often infilled by basaltic or lamprophyre dykes. They are probably Early Tertiary in age (Okulitch, 1979; Schiarizza, 1982) and related to the fifth generation of Mesoscopic structures. A northwest-trending fault which follows the North Thompson River valley in the western part of the map-area (Figs. 9-1 and 9-2, section B-B') is also a late structure, but it may be more closely related to fourth generation east-west folds.

A large overturned fold, possibly related to the second generation of mesoscopic folds, is inferred from overturned bedding in graded unit 8 grit beds in the area east of the Chuck Creek fault. Beds are overturned within both the main mass of unit 8, which structurally overlies unit 6, and in the belt of unit 8 grit and quartzite that is infolded (?) into unit 6. This relationship indicates that both unit 8 and unit 6 are overturned; together they are inferred to occupy the inverted limb of the fold. The fold may be southerly directed (Figs. 9-1 and 9-2, section A-A'), since this is consistent with the pattern of fold and thrust vergence elsewhere in the region (Okulitch, 1979; Schiarizza and Preto, 1984). The thrust fault which is inferred to separate the overturned limb from underlying right-way-up Eagle Bay rocks is probably related to the folding. This same thrust, or one of the same generation of faults, presumably separates Early Cambrian unit 6 rocks from underlying, largely Devono-Mississippian rocks elsewhere in the area. It is not known, however, whether unit 6 rocks west of the Chuck Creek fault and south of the North Thompson River are upright or overturned.

MINERAL OCCURRENCES

The locations of the most important mineral occurrences in the map area are indicated on Figure 9-1. Uranium-fluorite mineralization occurs in trachytic rocks of unit 3b at the Rexspar deposit along Foghorn Creek (Preto, 1978) and at the Bullion showing on lower Lute Creek. The Harper Creek deposit is a large, low-grade copper deposit within unit 2; inferred reserves are 90 000 000 tonnes grading 0.4 per cent copper. Similar low-grade copper mineralization occurs within unit 2 at the CW showing southeast of Clearwater, at the VM showing southwest of Avery Lake, and at several locations in the vicinity of the VAV showings south of Reg Christie Creek. The dominantly felsic to intermediate metavolcanic rocks of units 2 and 3a are considered also to be potential hosts to polymetallic massive sulphide-barite deposits such as the Homestake and Rea deposits in the Adams Lake-Johnson Lake area to the south (Schiarizza and Preto, 1984; White, 1985; Höy and Goutier, this volume). More or less stratiform lenses of pyrite and pyrrhotite with lesser sphalerite, galena, and chalcopyrite occur at the Red Top, Snow, and Sunrise showings in the vicinity of Mount McClennan. These showings occur at a similar stratigraphic level within a succession of quartzite, chlorite-muscovite-quartz schist, quartz-sericite schist, limestone, calc-silicate schist, and skarn within unit 1. There are a number of other occurrences within the map-area that are not shown on Figure 9-1; most are quartz veins containing pyrite and/or pyrrhotite with variable amounts of galena, sphalerite, and chalcopyrite.

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British Columbia Geological Survey
Geological Fieldwork 1985

GOLD ASSOCIATED WITH A REGIONALLY DEVELOPED MID-TERTIARY PLUTONIC EVENT IN THE HARRISON LAKE AREA SOUTHWESTERN BRITISH COLUMBIA (92G/9; 92H/3, 4, 5, 6, 12)

By G. E. Ray

INTRODUCTION

Recent studies by the British Columbia Ministry of Energy, Mines and Petroleum Resources indicate that a regional episode of Mid-Tertiary plutonism in the Harrison Lake area, approximately 100 kilometres east of Vancouver, is associated with widespread vein-type gold mineralization. This magmatic event was structurally controlled and resulted in the emplacement of numerous, variably sized plutons along a major, northwesterly trending lineament (Fig. 10-1). These plutons intrude a variety of sedimentary and volcanic rocks that range in age from Pennsylvanian to Cretaceous; the plutons are diorite to quartz diorite to granodiorite in composition and yield K/Ar (biotite) ages between 19 and 26 Ma (Table 10-1). In part, the lineament follows the Harrison Lake fracture system, which is associated with regional hot spring activity (Fig. 10-1); the location of its northwesterly continuation beyond Harrison Lake is uncertain. Southeastward, it is traceable to the 48th parallel in Washington State where it is probably marked by the 20 to 22-Ma-old Cloudy Pass and Cascade Pass plutons (Crowder, *et al.*, 1966; Misch, 1966; Grant, 1969).

The largest pluton along the lineament, the composite Chilliwack batholith, straddles the Canada-United States border approximately 125 kilometres east-southeast of Vancouver (Fig. 10-1); it yields K/Ar ages between 16 and 35 Ma (Richards and White, 1970; Richards and McTaggart, 1976; Vance, 1985). This batholith exceeds 950 square kilometres in area, and is spatially associated with at least 10 separate gold-bearing properties, including two former producing gold mines (Boundary Red Mountain and Lone Jack). Further north, numerous smaller bodies of similar age and mineralogy to the Chilliwack batholith occur sporadically along the lineament for more than 100 kilometres. The two most northern areas of Mid-Tertiary, diorite-related gold mineralization occur on Harrison Lake at Doctors Point and at the RN-Geo property; both lie close to the Harrison Lake fracture, being situtated 95 kilometres northeast and 100 kilometres east of Vancouver respectively (Fig. 10-1). The Doctors Point property is being explored by Rhyolite Resources Inc. and Harrison Lake Gold Mines Ltd., while the RN-Geo property was recently optioned by Abo Oil Corporation to Kerr Addison Mines Ltd.

THE GEOLOGY OF GOLD PROPERTIES ASSOCIATED WITH THE MID-TERTIARY PLUTONISM

The Rhyolite Resources Inc.-Harrison Lake Gold Mines Ltd. property at Doctors Point, on the western shore of Harrison Lake (Fig. 10-1), represents the most northerly example of Mid-Tertiary, diorite-related precious metal mineralization yet identified along the Harrison Lake lineament. Drilling has outlined approximately 132 300 tonnes grading 3.5 grams gold per tonne on the property. The area is underlain by a variety of intermediate to basic volcanic and volcaniclastic rocks, together with some metasedimentary rocks of Early Cretaceous (Middle Albian) age. These are intruded by five diorite-quartz diorite plutons that range from less than 50 metres to more than 1 kilometre in diameter. The plutons are surrounded by hornfelsic envelopes up to 250 metres in width. The gold and silver is hosted in long, narrow, gently dipping mineralized veins that contain abundant quartz, pyrite, and arsenopyrite; geochemically they are sporadically enriched in bismuth, antimony, and mercury. The veins show an overall spatial association to the pluton margins, and some pass without interruption from diorite out into the hornfels. The veins were apparently controlled by, and injected along low angle, cone sheet fractures developed during the later stages of the diorite intrusion. K/Ar ages obtained from biotite and hornblende samples suggest the diorites were emplaced between 19 and 25 Ma ago, while K/Ar analysis on muscovite taken from a gold-bearing vein suggests the mineralization took place 23 Ma ago (Table 10-1).

In 1983 and 1984, Abo Oil Corporation completed a drilling and bulk sampling program on their RN-Geo property, at the southern end of Harrison Lake (Fig. 10-1); this yielded some promising gold values (Huber, 1983); the property is currently being explored by Kerr Addison Mines Ltd. The area is underlain by deformed and hornfelsed metapelites of presumed Mesozoic age; these are intruded by several, small diorite-quartz diorite plutons between 50 and 200 metres in diameter. Gold is hosted in quartz veins and stringers that intersect the plutons; the veins consist of several variably orientated sets; locally they form closely spaced stockworks which may be suitable for bulk mining. The veins carry visible gold together with pyrite and pyrrhotite; there is sporadic geochemical enrichment of arsenic and bismuth but no mercury enhancement. A K/Ar analysis on hornblende suggests the diorites were emplaced 26 Ma ago, while analysis on sericite taken from a gold-bearing quartz vein indicates that mineralization occurred 24.5 Ma ago (Table 10-1). This is essentially synchronous with the plutonism and mineralization at Doctors Point.

The Laidlaw gold property, which is about 14 kilometres southwest of Hope (Fig. 10-1), is described by McClaren (1971). A sequence of deformed metasedimentary rocks are intruded by several small, elongate diorite-quartz diorite bodies that are less than 75 metres in width. These bodies are probably related to the Mount Barr batholith which lies 6 kilometres further south (Fig. 10-1); this batholith covers 160 square kilometres and has yielded K/Ar biotite ages between 16 and 24 Ma (Richards and White, 1970; Richards and McTaggart, 1976). Native gold at the Laidlaw property is hosted in two quartz vein sets which cut the diorite bodies; these veins also carry pyrrhotite, arsenopyrite, chalcopyrite, and secondary marcasite, as well as traces of bismuth tellurides.

The remaining 10 properties containing probable Mid-Tertiary gold mineralization lie close to the main Chilliwack batholith in both Canada and the U.S.; details on the U.S. properties is given by Moen (1969). The Lone Jack and Boundary Red Mountain properties (Fig. 10-1) were producing mines during the early part of this century. At the Boundary Red Mountain mine, gold-bearing quartz veins follow the sheared intrusive contact between a diorite body and older metasedimentary rocks. The veins contain minor amounts of pyrite, chalcopyrite, and pyrrhotite, and traces of bismuth tell-

British Columbia Ministry of Energy, Mines and Petroleum Resources, Geological Fieldwork, 1985, Paper 1986-1.

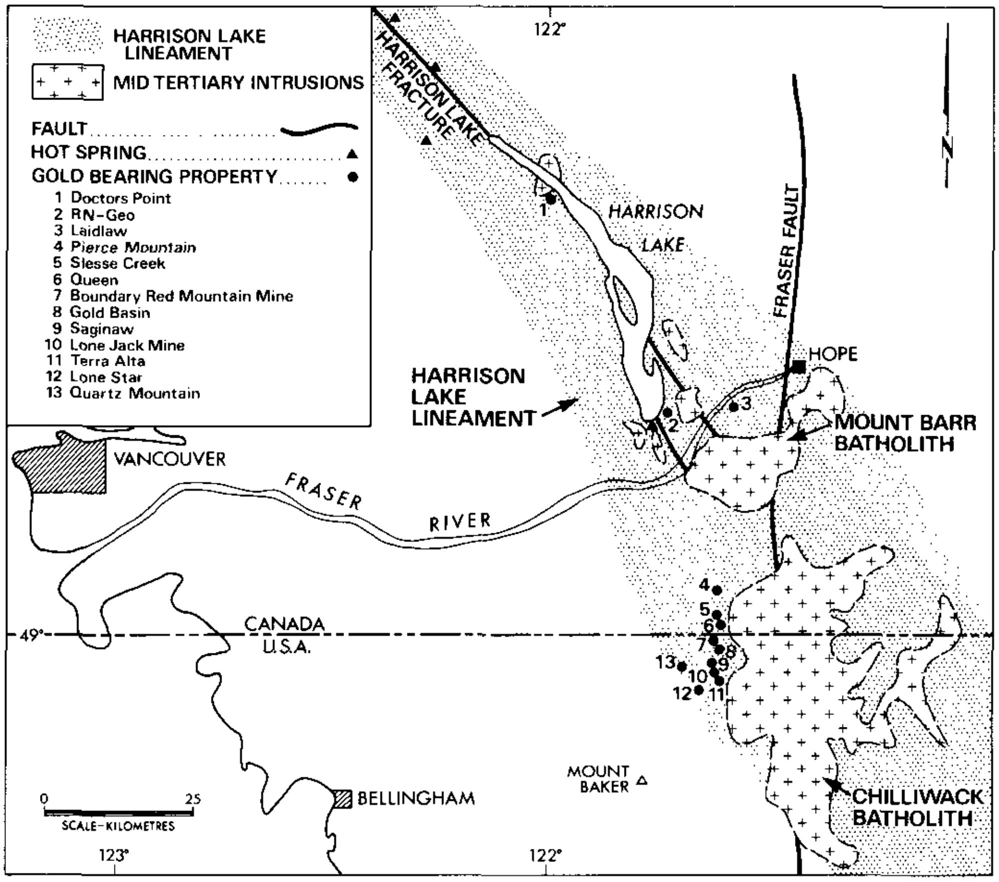

Figure 10-1. Location of gold occurrences and related Mid-Tertiary plutons along the Harrison Lake lineament.

TABLE 10-1

K/Ar AGES FROM THE HARRISON LAKE AREA

SAMPLE NO.	UTM CO-ORDINATES	MINERAL	%K	Ar^{40*1}	COMMENTS	AGE (Ma)
RR 54	591200E; 5465100N	Hornblende	0.19 ± 0.002	0.1915	Taken from diorite pluton at the RN mine exploratory adit, Harrison Lake	25.7 ± 1.0
RR 55	591200E; 5465100N	Sericite	8.38 ± 0.13	8.021	Taken from a gold-bearing quartz-sericite-pyrrhotite vein, RN mine exploratory adit, Harrison Lake	24.5 ± 1.0
RR 56	573100E; 5500100N	Biotite	6.91 ± 0.02	6.268	Drill core from the Doctors Bay pluton (diorite)	23.2 ± 0.8
RR 56	573100E; 5500100N	Hornblende	1.112 ± 0.01	1.083	Drill core from the Doctors Bay pluton (diorite)	24.7 ± 1.0
RR 64A	573250E; 5499950N	Muscovite	8.65 ± 0.03	7.695	Taken from kaolin-muscovite alteration halo adjacent to a gold-bearing quartz sulphide vein that cuts the Doctors Bay pluton	22.7 ± 0.8
RR 127	572300E; 5501600N	Biotite	7.40 ± 0.02	5.907	Taken from the Doctors Point pluton (quartz diorite)	20.4 ± 0.8
RR 127	572300E; 5501600N	Hornblende	0.391 ± 0.002	0.295	Taken from the Doctors Point pluton (quartz diorite)	19.3 ± 0.8

[1] $\times 10^{-6}$ cc/gm

All samples collected by G. E. Ray.

Potassium analyses completed at the British Columbia Ministry of Energy, Mines and Petroleum Resources Laboratory.

Argon analyses completed by J. Harakal, Geochronology Laboratory, University of British Columbia.

uride. In 1916 the Boundary Red Mountain mine produced 11 460 tonnes of ore grading 24 grams gold per tonne, while total gold production between 1913 and 1946 was valued at just under 1 million U.S. dollars.

At the Lone Jack mine, the quartz veins occupy fissures in phyllitic schists; no dioritic rocks are seen at the mine, but outcrops of the main Chilliwack batholith lie only 1.5 kilometres east of the property. The veins carry visible gold with pyrite, pyrrhotite, and traces of bismuth tellurides. Moen (1969) estimates that gold production from the Lone Jack mine between 1902 and 1924 valued approximately 555 000 U.S. dollars.

Gold-bearing veins at the Pierce Mountain, Slesse Creek, Gold Basin, and Quartz Mountain properties (Fig. 10-1) are all spatially associated with dioritic bodies that intrude metasedimentary rocks; the veins at the Lone Star property carry bismuth tellurides.

EXPLORATION GUIDES FOR MID-TERTIARY PRECIOUS METAL MINERALIZATION ALONG THE HARRISON LAKE LINEAMENT

Since many of the Mid-Tertiary plutons emplaced along the Harrison Lake lineament are associated with precious metal mineralization, a search for other intrusive bodies of this age should represent a viable exploration method for gold in the region. Furthermore, outlining possible northwesterly and southeasterly extensions of both the lineament and the Harrison Lake fracture system could result in the discovery of other mineralized plutons. For example, the Cascade Pass and Cloudy Pass plutons, and parts of the Snoqualmie batholith in Washington State (Baadsgaard, *et al.*, 1961; Crowder, *et al.*, 1966; Misch, 1966), probably belong to this intrusive suite, and thus could have associated vein-type gold mineralization. It should also be noted that the east-west dimension of the lineament is unknown; it may be considerably wider than shown on Figure 10-1. Many of the mineralized intrusive bodies located to date are relatively small; consequently the reconnaissance style of geological mapping completed in the region 30 or more years ago may have overlooked many small plutons. These could be located and outlined by prospecting followed by detailed geologic mapping and K/Ar analyses to determine their intrusive ages. The Geological Survey of Canada is currently conducting a mapping program in the Hope (west half) map sheet (J.W.H. Monger, personal communication, 1985) which will provide more geological data on the Harrison Lake area.

Many of the Mid-Tertiary gold-bearing veins in the region contain bismuth tellurides, consequently regional and detailed geochemical exploration for this type of mineralization could use bismuth (and gold) as pathfinder elements. The use of mercury, arsenic, and antimony could be successful locally. At Doctors Point the veins are geochemically enriched in these elements, while at the RN-Geo and Laidlaw properties, mercury is absent, and arsenic and antimony enrichment is weak and sporadic. Arsenic enrichment is not reported at either the Boundary Red Mountain or Lone Jack mines.

CONCLUSIONS

The Harrison Lake lineament and fracture system of southwestern British Columbia, and its southeastern extension into Washington State, is marked by a 19 to 26-Ma period of dioritic-quartz dioritic plutonism which is temporally and genetically related to 13 separate areas of gold mineralization. These Mid-Tertiary plutons vary in size from the composite Chilliwack batholith, which covers 950 square kilometres, down to small bodies less than 50 metres across. The gold ± silver mineralization is generally hosted in quartz veins filling tension fractures and is commonly associated with bismuth tellurides; however, the degree of arsenic, mercury, and antimony geochemical enrichment associated with the mineralization is highly variable. Many mineralized veins in the region are hosted either within the diorite bodies or close to their intrusive margins, where competency differences resulted in brittle, open space fracturing. The morphology of the mineralized veins is highly variable; it includes shallow-dipping features controlled by cone sheet fracturing, stockwork and crackle breccia veinlets, and steeply dipping veins injected along the sheared margins of the plutons.

Exploration for this Mid-Tertiary precious metal mineralization should involve prospecting, geological mapping, and geochronology to locate and identify other plutons of this age in the Harrison Lake area and along projected northwesterly and southeasterly extensions of the lineament. Follow-up exploration using soil and silt sampling could use gold as well as bismuth, arsenic, antimony, and mercury as pathfinder elements.

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THE GEOLOGY OF THE CAROLIN MINE GOLD DEPOSIT IN SOUTHWESTERN BRITISH COLUMBIA AND THE GEOCHEMISTRY OF ITS REPLACEMENT SULPHIDE-ALBITE-QUARTZ-GOLD MINERALIZATION (92H/11)

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Former Mine Geologist, Carolin Mines Ltd.

The Carolin gold deposit lies approximately 20 kilometres northeast of Hope in southwestern British Columbia. It occurs in the Coquihalla gold belt which, in addition to Carolin mine, contains four former producers as well as 19 minor gold occurrences (Ray, 1983). Most of these are gold-bearing quartz veins hosted in tension, quartz-filled fractures. However, mineralization at Carolin mine is of the mesothermal, epigenetic, replacement type; it is characterized by the introduction of sulphides, albite, quartz, and gold.

When production started in 1982, reserves at Carolin mine were estimated to be 1.5 million tonnes grading 4.8 grams gold per tonne, at a cutoff grade of 2.7 grams gold per tonne. Jurassic metasedimentary rocks of the Ladner Group host the mineralization, close to their unconformable contact with an older greenstone basement of spilitized oceanic ridge basalts (Spider Peak Formation), and their faulted contact with ultramafic rocks of the Coquihalla serpentine belt (Cairnes, 1924, 1929). This ultramafic belt lies within a major crustal fracture, the Hozameen fault, and exceeds 50 kilometres in discontinuous strike length; it is over 2 kilometres wide in the Carolin mine area. Ladner Group rocks are largely fine-grained, distal turbidites; however, gold mineralization is preferentially hosted in the coarser grained wackes, lithic wackes, and conglomerates that predominate in the basal part of the sequence (Ray, *et al.*, 1983).

During the first year of the mining operation, precise geological controls of the gold mineralization were uncertain. Surface mapping in the mine area indicated that both the Ladner Group and the stratigraphically underlying Spider Peak Formation were tectonically inverted, and subsequently deformed into large-scale, upright to asymmetric folds (Ray, *et al.*, 1983). Underground mapping later demonstrated that gold mineralization is both lithologically and structurally controlled (Shearer and Niels, 1983). It is preferentially concentrated in more competent and permeable sedimentary beds in the tectonically thickened hinge regions of a disrupted, asymmetric antiform. As a result, orebodies exhibit a saddle reef-like morphology and the deposit plunges gently northwest, subparallel to the antiformal axis (Ray and Niels, 1985a). Polished section studies indicate that pyrite dominates the upper parts of the deposit and pyrrhotite the deeper parts (Shearer, 1982). The precise age of mineralization is unknown, but the pyrite-pyrrhotite zoning suggests that the deposit is upright, and thus younger than the tectonic overturning that affected the host rocks. However, the presence of folded, post-ore quartz veins suggests that mineralization either predated or accompanied the episode of upright to asymmetric folding.

Mineralization at Carolin mine is characterized by sulphide disseminations and veinlets, deformed, multiphase quartz veins, and intense albitic alteration; however, not all areas containing these features are enriched in gold. Opaque minerals make up between 1 and 15 per cent of the ore; these are, in decreasing order of abundance, pyrrhotite, arsenopyrite, pyrite, magnetite, chalcopyrite, bornite, and gold; traces of sphalerite occur sporadically. Visible gold is rare; most forms small grains up to 0.02 millimetre in size that generally occur as inclusions in the pyrite and arsenopyrite crystals or as rims on the pyrite and chalcopyrite. Gold is also found independent of the sulphides as minute grains within some quartz, calcite, and feldspar crystals. Magnetite is the oldest opaque mineral in the ore; it is probably unrelated to the mineralization since it shows no spatial relationship to either gold or sulphides. The paragenesis of the opaque minerals is as follows: (1) contemporaneous deposition of arsenopyrite, pyrite, and gold, (2) pyrrhotite, (3) chalcopyrite and some gold.

There are at least three generations of albitization (Ray, *et al.*, 1983); the earliest was apparently coeval with the sulphide-gold mineralization and is fine-grained and disseminated throughout the ore. The subsequent two generations produced veins and masses containing coarse-grained, well-twinned albite crystals; locally, angular fragments of sulphide-rich ore are engulfed by the youngest albitic phase. The deposit is surrounded by an albitic envelope (Ray and Niels, 1985b); drill hole data indicate that it extends at least 60 metres beyond the mineralization. (In early 1986, analytical results are expected from a detailed surface lithogeochemical sampling program around the deposit; these should outline the full dimensions of this albitic envelope).

Geochemical analyses on samples collected from drill holes intersecting the deposit reveal complex and variable major and trace element zoning patterns; the most dramatic changes in element abundances occur within and immediately above the hangingwall sections of the ore zones (Ray and Niels, 1985b). Mineralization does not have associated anomalous mercury or bismuth values, and gold/silver ratios vary throughout the deposit from 1:1 to 1:22. Statistical analysis indicates that gold has a strong to moderate positive correlation with Na_2O, S, CO_2, Sb, Mo, Cu, As, and Ag, and a strong to moderate negative correlation with Al_2O_3, MgO, K_2O, H_2O, and BaO. No significant correlation between gold and SiO_2, Fe_2O_{3T}, CaO, TiO_2, MnO, or Pb was apparent. Unlike many epigenetic gold deposits, K_2O/Na_2O ratios decrease markedly as the auriferous horizons are approached. The gold mineralization is marked by distinct zones of barium and potassium depletion that are generally twice as thick as their associated gold-bearing horizons; this type of depletion could form valuable drill targets. Furthermore, the wide albitic envelope around the deposit suggests that lithogeochemical sampling for areas of sodium enrichment represents a viable exploration tool to locate similar gold deposits in the district.

On a district scale, the main controls of mineralization in the Coquihalla gold belt, including the Carolin mine deposit, are the presence of host rocks suitable for the development of tectonically induced permeability, and close proximity (<400 metres) to the Hozameen fault, the Coquihalla serpentine belt, and the Ladner Group basal unconformity (Ray, 1984).

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PRELIMINARY REPORT ON THE HEDLEY MAPPING PROJECT (92H/8, 82E/5)

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Mascot Gold Mines Ltd.

INTRODUCTION

The Hedley area is situated approximately 40 kilometres east-southeast of Princeton, in southwestern British Columbia. The main objectives of this three-year project, which was initiated in 1985, include:

(a) To geologically map, at a scale of 1:20 000, the Hedley area.
(b) To examine the geochemistry, controls, and regional setting of the numerous gold deposits in the Hedley district, including the former Nickel Plate, Hedley Mascot, Canty, French, and Goodhope mines.
(c) To outline a stratigraphic succession for the Mesozoic sedimentary sequence in the Hedley district and establish, if possible, its structural history and its relationship to both the Paleozoic sequences to the east and the predominantly volcanic Upper Triassic Nicola Group to the west.
(d) To date the limestones in the area by conodont extraction, and the dioritic Hedley intrusions by K/Ar and U/Pb methods. These intrusions are believed to be genetically related to some of the gold-bearing skarns in the district.
(e) To determine what changes take place in whole rock and trace element geochemistry across the Nickel Plate mine ore zone. This will also enable a geochemical comparison to be made between the precious metal-bearing skarns at Hedley and at Tillicum Mountain (*see* Ray, *et al.*, this volume).
(f) To compare the geochemistry between the skarn-altered and unaltered Hedley intrusions.

REGIONAL GEOLOGY

Placer gold was discovered in the Hedley area in the 1860's, but it was not until the turn of the century that gold-bearing garnet pyroxene skarns were found near the summit of Nickel Plate Mountain (Fig. 12-1). This led to the opening of several mines on the Nickel Plate property which were in operation until the mid-1950's; these produced approximately 46 million grams (1.5 million ounces) of gold. Due to their economic potential, the areas around the gold producers were mapped and studied in detail (Camsell, 1910; Warren and Cummings, 1936; Billingsley and Hume, 1941; Dolmage and Brown, 1945; Lee, 1951); less attention was devoted to either the regional geology or comparing the various gold deposits in the district. Important publications relevant to the regional geology include those by Bostock (1930, 1940a, 1940b), Rice (1947), and Little (1961).

The Hedley region lies within the Intermontane Belt of the Canadian Cordillera. The area between Whistle Creek and Stemwinder Mountain (Fig. 12-1) is largely underlain by a predominantly sedimentary sequence belonging to the Upper Triassic Nicola Group (Rice, 1947). This sequence has been subdivided by various geologists into numerous formations (*see* Rice, 1947, p. 13) but for the purposes of this report it is informally separated into a younger 'Whistle Creek sequence' to the west and an older 'Hedley sequence' to the east (Fig. 12-1). The latter comprises a generally west-dipping succession of thin-bedded, calcareous and cherty siltstones and argillites with thin, impure limestones; some beds in the sequence contain appreciable amounts of fine-grained volcaniclastic material. Limestone samples collected from the succession by Monger and Tempelman-Kluit of the Geological Survey of Canada, yielded conodonts of Carnian to Early Norian age (M. J. Orchard, pers. comm., 1985). One 30-metre-thick limestone bed, the 'Sunnyside limestone' (Figs. 12-1 and 12-2) is traceable for several kilometres along strike (Camsell, 1910; Bostock, 1930, 1940a).

West of Henri Creek (Fig. 12-1), the Hedley sequence passes stratigraphically up into the Whistle Creek sequence. This contains some thin-bedded siltstones and argillites in its lower portion, but higher in the succession it is characterized by wackes, crystal tuffs, volcanic breccias, and minor volcanic flows (Fig. 12-2). One distinguishing feature is its general lack of limestones, and the presence at its base of a limestone boulder conglomerate which is informally named the 'Henri Creek conglomerate' (Fig. 12-1). Sedimentary indicators show that the Hedley and Whistle Creek sequences in this section consistently young westward. Measurements of crossbeds and flame structures indicate that the entire Hedley sequence, and the lower, thin-bedded section of the Whistle Creek sequence, were deposited by north to northeast-directed paleocurrents (Fig. 12-1).

East of Winters Creek (Fig. 12-1) is a highly deformed package of cherts, argillites, and greenstones which have been divided into the Independence, Bradshaw, Old Tom, and Shoemaker Formations (Bostock, 1940a; Little, 1961). Relationships between these units is uncertain. Upper Devonian and Triassic microfossils have been recovered from some of these rocks (J.W.H. Monger, pers. comm., 1985), and a faulted unconformity may separate this Paleozoic package from the Hedley sequence further west (Fig. 12-2).

Two plutonic suites intrude the Hedley and Whistle Creek sequences (Figs. 12-1 and 12-2). The oldest is believed to be Middle Jurassic in age and comprises massive, coarse-grained diorites, gabbros, and quartz diorites of the Hedley intrusions (Rice, 1947). They form major stocks up to 1.5 kilometres in diameter as well as swarms of thin sills, up to 200 metres in thickness and over 1 kilometre in length. The second plutonic suite, the Similkameen intrusions, comprises coarse, massive granodiorite of presumed Middle to Late Jurassic age. These intrusions generally form large bodies such as the Pennask pluton which outcrops west of Stemwinder Mountain, and a granodiorite body outcropping between Winters Creek and Hedley township, which is informally named the Cahill Creek pluton (Fig. 12-1).

British Columbia Ministry of Energy, Mines and Petroleum Resources, Geological Fieldwork, 1985, Paper 1986-1.

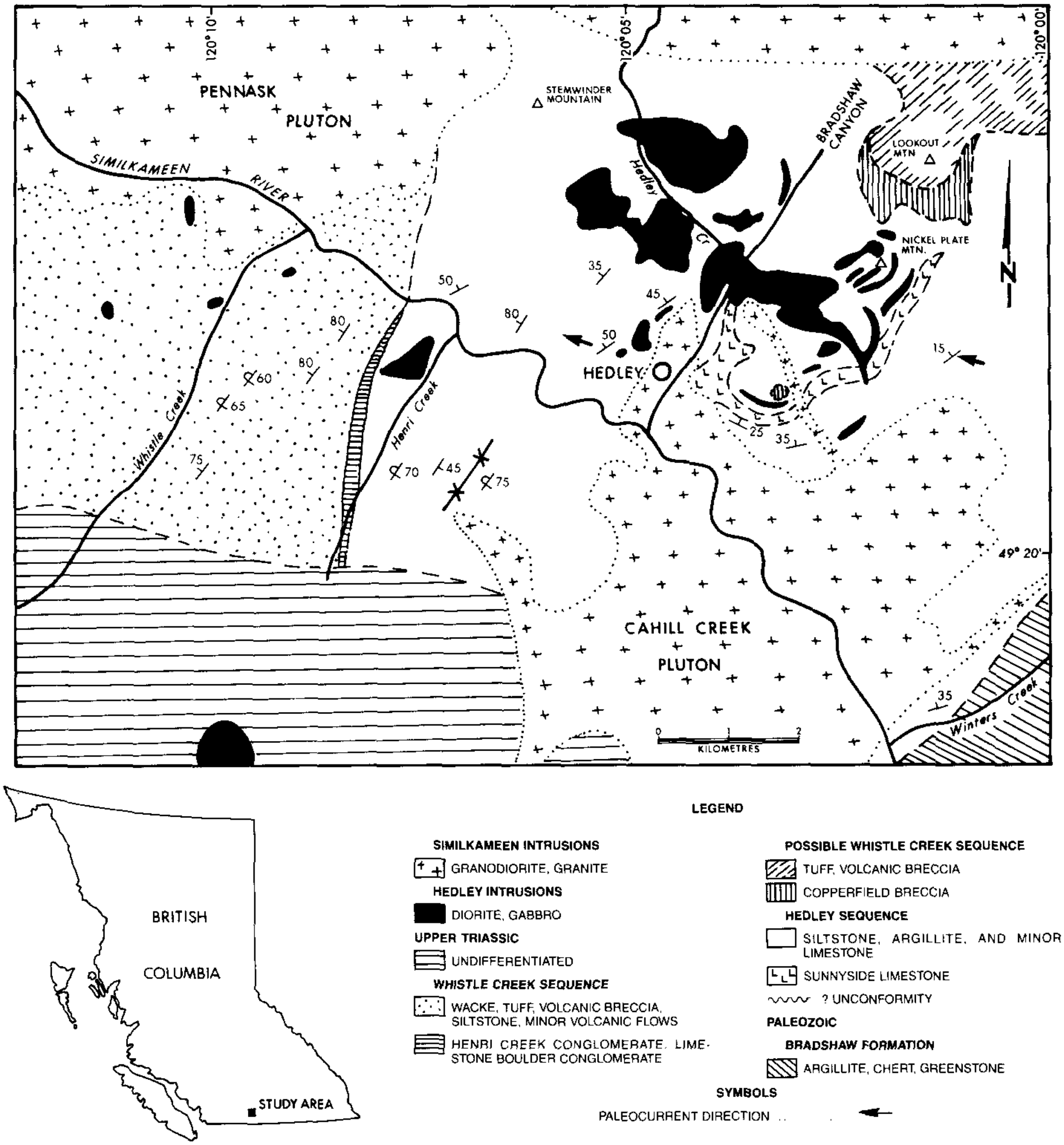

Figure 12-1. Simplified geology of the Hedley area. (Adapted after Bostock (1940a) and data obtained during this preliminary study).

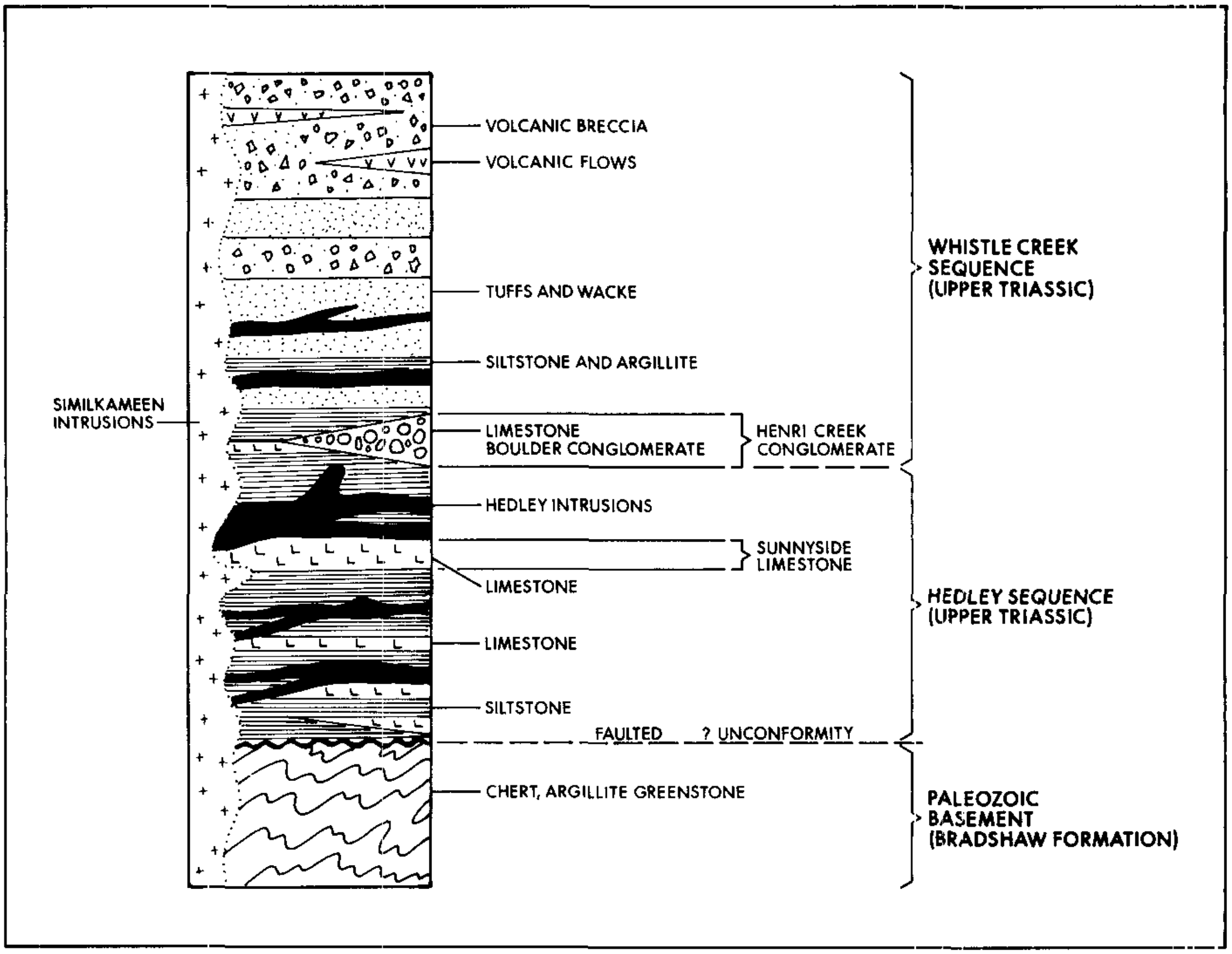

Figure 12-2. Schematic section illustrating the stratigraphy of the Hedley area.

Varying degrees of sulphide-bearing skarn alteration are developed along the margins of many of the Hedley intrusions in the district. Some previous workers (Billingsley and Hume, 1941; Dolmage and Brown, 1945) considered this plutonic suite to be genetically related to the gold mineralization at the Nickel Plate and Hedley Mascot mines. Country rocks up to 1.5 kilometres from the margins of the younger Similkameen intrusions are commonly hornfelsed; some skarn alteration is also locally present adjacent to the Cahill Creek pluton, but it is generally sulphide poor and not auriferous.

GEOLOGY OF THE HEDLEY AND WHISTLE CREEK SEQUENCES

North of the Similkameen River the Hedley sequence underlies an area between Winters Creek and Stemwinder Mountain, while south of the river it lies between Henri Creek and the western margin of the Cahill Creek pluton (Fig. 12-1). In the east its stratigraphic base probably lies close to Winters Creek where it may unconformably (?) overlie the highly deformed Paleozoic Bradshaw Formation basement. North of the Similkameen River, the Hedley sequence dips west to northwest at angles between 15 and 85 degrees; consistent sedimentary top indicators show that the sequence in this area is structurally upright (Fig. 12-1). South of the river, the Hedley and Whistle Creek sequences are generally west dipping, except in the Henri Creek area where they are locally overturned.

The Hedley sequence mainly comprises a thin-bedded succession of siltstones, black argillites, and minor wackes that are commonly interbedded with 1 to 10-metre-thick impure limestone beds; some calcareous units are finely tuffaceous. The siltstones and argillites are either calcareous or siliceous and cherty; sedimentary structures, such as graded beds, crossbeds, ball-and-pillow structures, and flame structures are locally preserved. The Hedley sequence is interpreted to represent a distal turbidite succession with some minor pelagic material.

The base of the Whistle Creek sequence south of the Similkameen River is marked by the Henri Creek conglomerate, which reaches 200 metres in thickness, and is traceable for more than 3 kilometres along strike; its northern extension across the river is not known. The conglomerate varies from clast to matrix supported and is characterized by abundant, well-rounded to angular pebbles, cobbles, and boulders of limestone up to 1 metre in diameter. Rare clasts of argillite, siltstone, wacke, chert, crystalline quartz, and both felsic plutonic and volcanic rocks are also present. The limestone clasts vary considerably in appearance, from grey to buff to pink in colour, from fine to coarse grained, and from massive to thin bedded; some limestone boulders contain abundant fragments of bivalve shells and crinoid stems. A few boulders are composed of a limestone conglomerate comprising grey limestone clasts cemented in a calcareous matrix; other, less common boulders consist of chert pebble conglomerate with a gritty calcareous matrix.

Some of the larger, elongate, siltstone clasts are deformed and exhibit soft sediment deformation structures, which suggests that they were unlithified when incorporated into the conglomerate. The conglomerate matrix varies from massive to thin bedded and locally shows evidence of chaotic slumping and soft sediment disruption. Conodonts extracted from some limestone boulders give Carnian ages (J.W.H. Monger and M. J. Orchard, pers. comm., 1985), while radiolarians of Permian age were extracted from one chert pebble (F. Cordey, pers. comm., 1985). The Henri Creek conglomerate is interpreted to be an olistostrome; it probably results from the sudden slumping of an unstable accumulation of reef debris down a steep submarine slope, and the chaotic deposition of this mass onto a sequence of unlithified, deeper water turbidites.

Stratigraphically overlying the Henri Creek conglomerate are some thin-bedded siltstones and argillites, which pass upward into poorly bedded to massive, coarser grained wackes, crystal and crystal-lithic tuffs, and volcanic breccias (Fig. 12-2). In contrast to the underlying Hedley sequence, limestones and calcareous sedimentary rocks are generally absent and the presumed upper parts of the succession contain thin volcanic flows which may be equivalent of Norian-age Nicola Group volcanic rocks deposited further west in the Merritt and Princeton areas (McMillan, 1979; Preto, 1979).

The Henri Creek conglomerate shows many similarities in composition, texture, and stratigraphic position to a controversial unit, the 'Copperfield breccia' (Camsell, 1910; Bostock, 1930; Billingsley and Hume, 1941) which outcrops south of Lookout Mountain (Fig. 12-1). The Copperfield breccia contains abundant limestone clasts and, like the Henri Creek conglomerate, apparently separates two contrasting sequences. Stratigraphically and structurally underlying the Copperfield breccia is the thinly bedded Hedley sequence, while structurally above it, north and northwest of Lookout Mountain, are tuffs and volcanic breccias (Bostock, 1940a; Lee, 1951). The Copperfield breccia is locally silicified and skarn altered; some altered outcrops contain rounded cavities up to 15 centimetres in diameter lined with coarse crystals of the scapolite group mineral, mizzonite $(Na,K)Ca(Si,Al)_6,O_{12}Cl$ (J. Kwong, pers. comm., 1985); these cavities were probably formed by the solution and removal of some clasts.

The Henri Creek conglomerate and the Copperfield breccia are possibly correlative which could mean that the tuffs and volcanic breccias near Lookout Mountain belong to the Whistle Creek sequence. This correlation has implications regarding the geology between Lookout and Stemwinder Mountains, since the absence of the Copperfield breccia and overlying tuffaceous rocks west of Bradshaw Canyon (Fig. 12-1) supports previous suggestions of high-angle, easterly directed reverse faulting along the creek (Camsell, 1910; Billingsley and Hume, 1941). (Note: Bradshaw Canyon is situated approximately 3 kilometres northeast of Hedley (Fig. 12-1); it should not be confused with Bradshaw Creek situated 2 kilometres south of Winters Creek).

STRUCTURAL GEOLOGY IN THE HEDLEY AREA

Sedimentary rocks north of the Similkameen River consistently dip west to northwest at gentle to steep angles with no evidence of structural overturning. However, south of the river both the Hedley and Whistle Creek sequences are locally overturned and dip steeply eastward. A weak, steeply inclined fracture cleavage and associated bedding-fracture cleavage intersection lineation are locally seen west of Bradshaw Canyon and south of the Similkameen River (Fig. 12-1). These indicate that the sequences occupy the western limb of a major anticline, whose axis plunges 20 to 35 degrees in a south to southwest direction; this anticline is presumably cored by the older Paleozoic rocks east of Winters Creek. No fracture cleavage or mineral lineations were seen west of Bradshaw Canyon; consequently the plunge direction of the anticlinal axis in that area is unknown. No related small-scale folds were observed in the Hedley and Whistle Creek sequences; however, a large-scale, overturned syncline with a southerly plunging fold axis and an axial plane dipping 60 degrees east is present east of Henri Creek (Fig. 12-1).

In contrast to the Hedley and Whistle Creek sequences, the Paleozoic rocks east of Winters Creek contain some tight minor folds; these folds support the interpretation that these rocks represent a basement that was folded prior to the unconformable (?) deposition of the Hedley sequence.

CONCLUSIONS

The Hedley district is underlain by a predominantly Upper Triassic sedimentary succession that is divisible into a younger Whistle Creek sequence to the west, and an older Hedley sequence to the east. The Hedley sequence overlies, possibly unconformably, a deformed basement that includes the Bradshaw Formation (Figs. 12-1 and 12-2).

The Hedley sequence hosts Nickel Plate and Hedley Mascot gold-bearing skarn mineralization. It largely represents a distal turbidite succession characterized by thin-bedded, impure calcareous sedimentary rocks. The stratigraphically overlying Whistle Creek sequence is marked by the presence of coarser grained volcanogenic sedimentary rocks and volcanic breccias, and an absence of calcareous rocks. Both the Hedley sequence and the lower, turbiditic portion of the Whistle Creek sequence were deposited by paleocurrents moving in a west to northwest direction. Thin volcanic flows at the top of the Whistle Creek sequence may be an easterly extension of Nicola Group volcanic rocks. Thus sedimentation in the Hedley district initially involved the deposition of distal turbidites originating from an easterly source, followed by coarse volcanogenic sedimentation, possibly derived from the Nicola volcanic arc further west.

The base of the Whistle Creek sequence is the Henri Creek conglomerate which is interpreted to be a limestone-boulder-bearing olistostrome. This conglomerate may be correlative with the 'Copperfield breccia' which outcrops north of the Similkameen River on Lookout Mountain; thus tuffaceous rocks on Lookout Mountain and volcanic breccias further northeast could belong to the Whistle Creek sequence.

Structurally, the Hedley and Whistle Creek sequences occupy the western limb of a major anticline which has a steep, easterly dipping axial plane and a southerly plunging fold axis; this anticline is apparently cored further east by Paleozoic rocks of the Bradshaw Formation.

Throughout the district many of the older Hedley diorite intrusions are spatially associated with sulphide-rich skarn alteration which sporadically carries gold. However, the margins of the younger Similkameen intrusions are also locally associated with weak skarn alteration, which is generally sulphide poor and appears to be barren.

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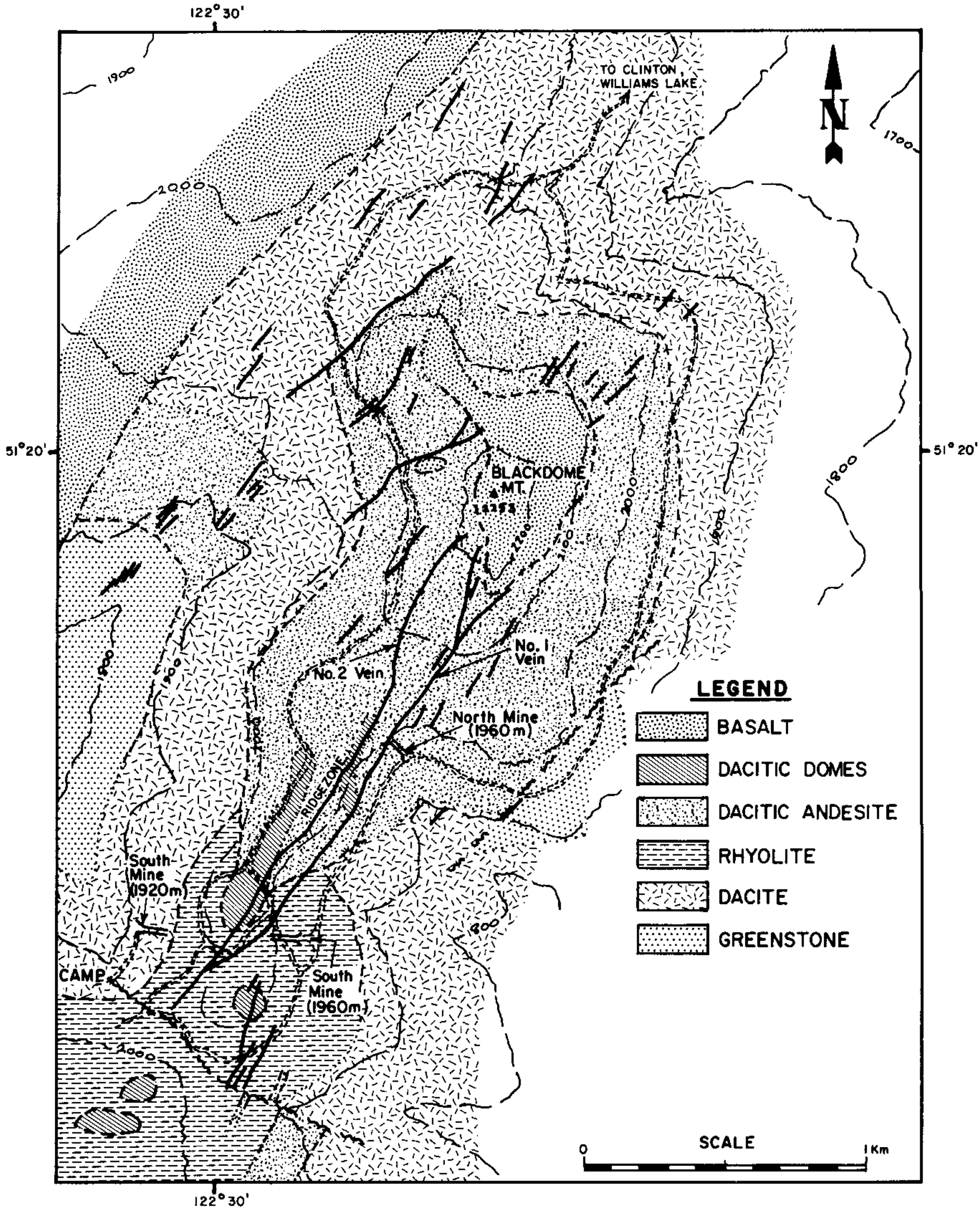

Figure 13-1. Geological setting of the Blackdome gold deposit.

BLACKDOME DEPOSIT (92O/7E, 8W)

By E. L. Faulkner

INTRODUCTION

This report is an update on progress at the property since the reviews by B. N. Church (1980 and 1982). Exploration and development at this gold and silver property (Mineral Inventory 92O-053) has led to a production decision and the start of construction. This report is based largely on company reports, plus some stratigraphic information not previously available and personal observations from property visits and fieldwork during 1984 and 1985.

LOCATION AND ACCESS

The mine is approximately 70 kilometres northwest of Clinton on the southwest spur of Blackdome Mountain and is reached from either Clinton or Williams Lake via the Empire Valley road. Most of the present workings are at an elevation of more than 1 900 metres.

EXPLORATION

Trenching, diamond drilling, and underground exploration and development since 1980 has concentrated on two persistent vein systems, the No. 1 and No. 2 veins, which parallel the southwest spur of Blackdome Mountain (Fig. 13-1). The northeast portion of the No. 1 vein, referred to as the North Mine zone, was explored under an option agreement to Heath Steele Mines Ltd. from an adit at elevation 1 960 metres. Blackdome Exploration Ltd. explored the southwest parts of both veins, referred to as the Ridge zone, from a second adit at 1 960 metres and a third adit at 1 920 metres. Favourable results led to a production decision and the start of construction during the summer of 1985. The first production from stockpiled development ore is expected in mid-1986.

GEOLOGY

The area is underlain by Cretaceous and Tertiary volcanic and volcaniclastic rocks and related feeder dykes. The strata can be grouped into seven units (from oldest to youngest): greenstone, dacite, lower andesite, rhyolite, dacitic andesite, dacitic domes, and basalt (Figs. 13-1 and 13-2).

Greenstone: The oldest rocks in the mine area are chloritic andesite flows, tuffs, and agglomerate exposed in some of the lower creek valleys and also intersected in drill holes.

Dacite: Lying unconformably above the greenstone is a sequence of porphyritic dacite flows with some discontinuous tuff horizons. The dacite is fine grained, greenish grey, and porphyritic. It weathers to a medium grey or brownish grey.

Lower Andesite: An irregular and patchy sequence of mostly pyroclastic rocks occurs at the base of the rhyolite and parts of the dacitic andesite. It consists of welded tuffs, lapilli tuffs, and volcanic breccias of andesite composition. The breccia is particularly coarse in places with closely spaced bombs and blocks indicating proximity to a vent.

Rhyolite: In the southwest part of the mine area is a sequence of pale, flow-banded rhyolite, welded tuff, and lapilli tuff. Irregularly interspersed is coarse to very coarse polymictic breccia. Lack of sorting and limited lateral extent suggest a localized slump or lahar origin.

Dacitic Andesite: Underlying much of Blackdome Mountain is a sequence of grey-weathering, dark grey to greenish grey dacitic andesite flows. These are frequently porphyritic with pale plagioclase laths up to 5 millimetres long. Dyke-like bodies of similar composition occur in the southwest part of the map-area.

Dacitic Domes: Dacitic andesite underlies part of the Ridge Zone and forms thin dome-shaped outliers further southwest. Dacitic andesite in the domes has a lower total iron content than the underlying dacitic andesite unit and weathers to a distinctive pale grey colour. These two rock units are probably comagmatic. A sample taken from one of the domes yielded a K/Ar age of 51.5 ± 1.9 Ma (Church, personal communication).

Basalt: Dark brown to black basalt and weakly porphyritic olivine basalt flows form the peak of Blackdome Mountain and occur extensively further northwest. A conspicuous but thin brick red agglomerate occurs at the base of the basalt wherever it is exposed. Basalt from Blackdome Mountain yielded a K/Ar age of 24 ± 0.8 Ma (Church, personal communication).

STRUCTURE

A northeasterly trend dominates the structure of veins and host rocks in the mine area as a result of tensional forces in a northwest-southeast direction during Eocene time. Blackdome Mountain and the dacitic domes form a northeasterly line of eruptive centres along the axis of a broad anticline with a shallow northeasterly plunge. Feeder dykes strike northeast. Flows generally strike northeast also, with gentle dips to the northwest or southeast seldom exceeding 20 degrees. The dips are not entirely depositional; in the Ridge zone, the direction of flow lineations and the direction of dip differ by up to 30 degrees, indicating that the ridge zone has been uplifted relative to the summit area.

There are at least 12 quartz veins or vein systems within the map-area. Although the surface trace of some of the veins is sinuous, they generally strike north 40 degrees east, with moderate to steep northwesterly dips. The veins commonly follow shear zones. The veins occupy tensional openings; where movement on the faults has been determined, it is normal.

ECONOMIC GEOLOGY

The gold and silver mineralization occurs in typical epithermal quartz veins, most of which are hosted by rhyolite and dacitic andesite. Above tree line the veins either outcrop or occur beneath areas containing quartz float. Below tree line they have been found by trenching precious metal soil geochemical anomalies.

The veins vary from a few centimetres to a few metres in width and from weak stringer zones to sheeted, vuggy veins composed almost entirely of quartz. The best precious metal values occur only in veins with a high percentage of quartz, but abundant quartz does not guarantee precious metal values.

The most persistent and best mineralized veins identified to date are the No. 1 and No. 2 veins, which parallel the Ridge zone and extend up to the southwest spur of Blackdome Mountain. Both veins are characterized by a gouge and breccia-filled shear zone from a few centimetres to 1.5 metres thick with brecciated or sheeted and sometime vuggy white to grey quartz on one or both sides of the

British Columbia Ministry of Energy, Mines and Petroleum Resources, Geological Fieldwork, 1985, Paper 1986-1.

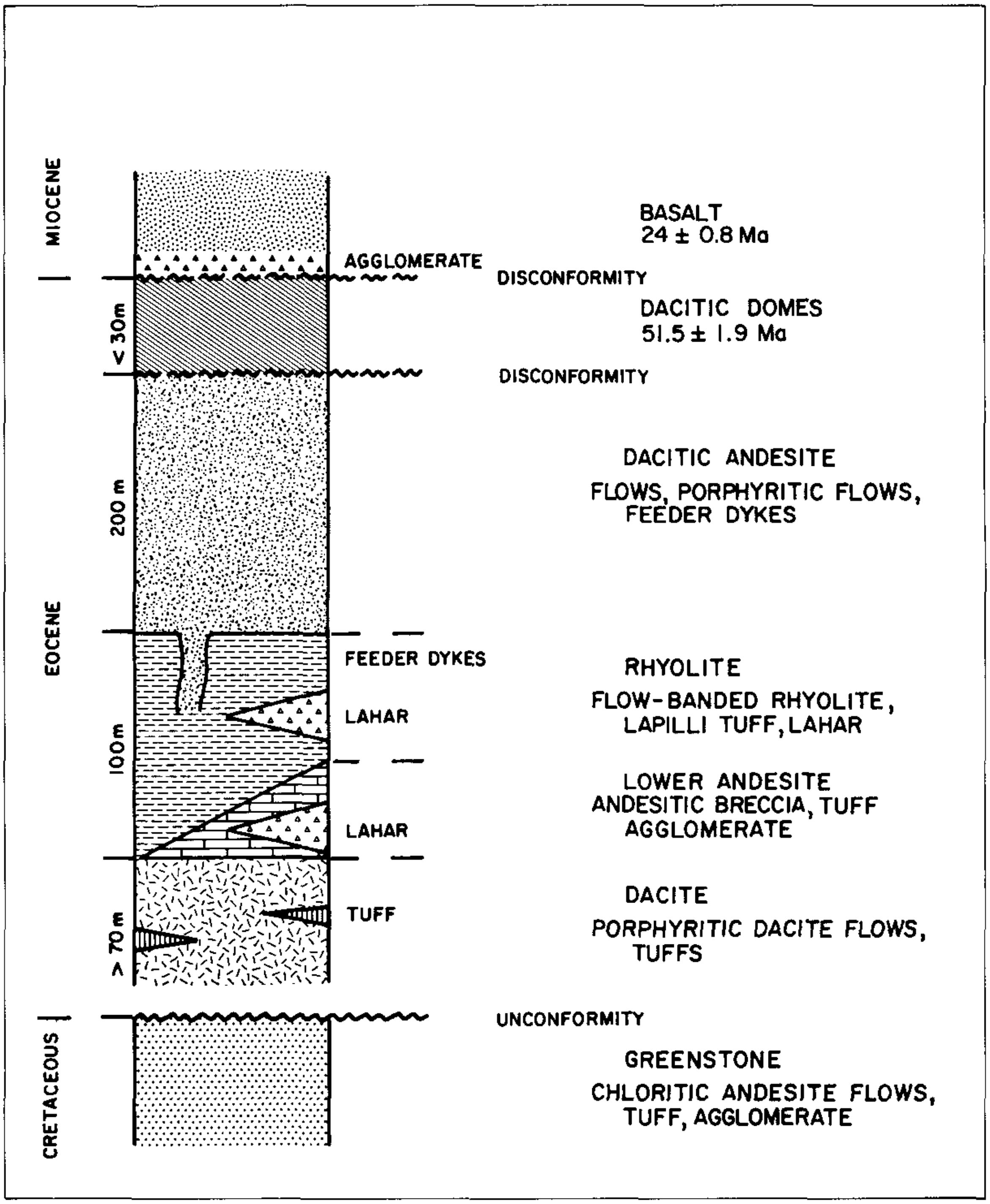

Figure 13-2. Generalized stratigraphic column for rocks in the vicinity of the Blackdome gold deposit.

shear zone. Total vein width exceeds 3 metres in places. Movement was normal, typically with a displacement of 20 to 30 metres across both veins. The No. 2 vein has a steeper dip in the Ridge zone than the No. 1 vein (75 degrees versus 60 degrees) so they converge at depth and to the southwest. From surface trenches and on the 1 920-metre level, it appears that the No. 1 vein branches off the No. 2 vein. Diamond drilling has shown that the vein system and mineralization continue below the 1 920-metre level; the system is considered open at depth.

Metallic minerals are sparse, seldom exceeding 0.5 per cent. Ore minerals are very fine-grained native gold and silver, electrum, acanthite, or argentite and freibergite. The gold to silver ratio is 0.17-0.27:1. Minor amounts of pyrite, pyrrhotite, chalcopyrite, sphalerite, and galena are present; marcasite, digenite, bornite, covellite, chalcocite, and arsenopyrite have also been identified.

Despite local assays of a few tens of grams of gold per tonne, visible gold is rare. A few colours and sulphide grains were panned from gouge taken from the No. 2 vein. Coupled with the sheeted vein structure, this suggests that movement on the shear zone occurred during as well as after mineralization.

Wallrock alteration typically occurs only within approximately 1 metre of the vein and takes the form of bleaching, silicification, and, locally, extensive argillic alteration.

Ore grades occur in the most silicified parts of the veins and generally form steeply plunging 'bonanza-type' shoots with a strike length seldom exceeding 30 metres; as defined by assay cutoffs, there is no obvious shape or pattern. Ore grades have been cut by approximately 30 per cent below raw average grades, using a running-average method to cut high gold assays. Proven and probable ore reserves are 185 000 tonnes grading 27.23 grams per tonne gold and 128.9 grams per tonne silver (undiluted).

MINING

The ground is poor in parts of the vein systems. Mining plans are for trackless, cut-and-fill mining, with a planned dilution of 21 per cent. If sufficient time can be allowed to drain the ore, it should be possible to keep dilution well below this figure in most parts of the veins seen to date. The ore is mostly free milling, with the remainder of the precious metals recoverable by flotation. A trommel and gravity circuit is planned to handle clay-bearing gouge in the ore.

CONCLUSION

Mineralization at the Blackdome mine is similar to many epithermal precious metal-quartz vein deposits of the 'bonanza' type occurring in the western United States and Mexico. Typically these deposits are tensional vein systems in felsic to intermediate calc-alkaline flows and pyroclastic rocks of Tertiary age.

ACKNOWLEDGMENTS

I wish to thank Blackdome Exploration Ltd. for their ready hospitality and for providing valuable information from company files. In particular I wish to thank C. M. Lalonde and R. L. Roscoe for taking time out from their busy schedules for numerous discussions. B. N. Church kindly made available information from his previous fieldwork at the property. The radiometric age determinations were provided by J. E. Harakal, University of British Columbia.

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BRITISH COLUMBIA REGIONAL GEOCHEMICAL SURVEY (RGS) RELEASE PRELIMINARY RESULTS (93G/E1/2, 93H/W1/2, plus parts of 93H/E1/2)

By E. L. Faulkner

INTRODUCTION

Data from the joint Canada/British Columbia reconnaissance Regional Geochemical Survey completed in the summer of 1984 were released at 0830 hours PDT on 27th June 1985 in Prince George, Vancouver, and Victoria as province of British Columbia open file BC-RGS-12-1984 and Geological Survey of Canada Open File 1107.

The survey covers approximately 14 800 square kilometres with an average sample density of one sample per 13 square kilometres. Stream sediment samples were analysed for zinc, copper, lead, nickel, cobalt, silver, manganese, arsenic, molybdenum, iron, mercury, uranium, vanadium, cadmium, antimony, tungsten, barium, and loss-on-ignition. Stream waters were analysed for uranium, fluorine, and pH.

Each open file package contains a sample location map, British Columbia Ministry of Energy, Mines and Petroleum Resources Mineral Inventory Maps, 21 geochemical maps, and a text of field, analytical, and statistical data. Packages are available at a cost of $50.00 *each from: Publications Distribution, 552 Michigan Street,* Victoria, B.C. V8V 1X4.

Information in this year's release, which was not available in the 1984 release, includes analyses for vanadium, cadmium, barium, and loss-on-ignition, the Mineral Inventory maps, surficial geological information, and histograms and regional trend maps for each element.

RESULTS

Number of packages sold:

Prince George	17
Vancouver	20
Victoria	3
TOTAL	40

An additional 19 packages were sold after the release date for a total of 59 to October 8, 1985.

A count of mineral claims in good standing in the release area (excluding Crown-granted leases) was made before the field season, the day before the release, and after the field season. The results are as follows:

Date:	26 April 1985	26 June 1985	8 October 1985
Claim units:	5685	5853	6924
2-post claims:	326	346	432

There was only modest staking prior to the release (168 claim units and twenty 2 post claims) but a total of 1 071 claim units and eighty-six 2 post claims were staked on or after the release date.

Three areas accounted for much of the activity:

(1) 93G/7E and 93G/8 — this is a much faulted area of the Quesnel Trough southwest of Hixon with a number of coincident high contrast antimony, arsenic, and mercury anomalies.

(2) 93H/3W and 93H/12E — these two areas are both in the Bowron River valley on the faulted eastern edge of the Slide Mountain terrane. They show coincident high contrast barium anomalies and moderate contrast mercury anomalies with some spot high arsenic values.

COMMENTS

(1) The inclusion of histograms and regional trend maps in this release was particularly well received.

(2) The addition of barium to the list of elements analysed for led to significant staking in two areas.

(3) The turnout on the release date was below average but the activity generated was much higher than anticipated. This was especially so as the area includes a major urban centre, is almost entirely accessible by vehicle, and has been well prospected and heavily staked in the past.

(4) This release also generated interest that is not reflected in the preceding figures; there was a moderate amount of 'anticipation' or 'pre-emptive' staking in the area during the 1984 field season. One major company and two juniors indicated that announcement of the Regional Geochemical Survey was a factor in the staking and location of their 1984 field programs.

(5) Although it is too early to assess the results of this year's staking, one major company traced an anomalous area to mineralization in place.

British Columbia Ministry of Energy, Mines and Petroleum Resources, Geological Fieldwork, 1985, Paper 1986-1.

BRITISH COLUMBIA REGIONAL GEOCHEMICAL SURVEY (RGS) RELEASE PRELIMINARY RESULTS (93G/E1/2, 93H/W1/2, plus parts of 93H/E1/2)

By E. L. Faulkner

INTRODUCTION

Data from the joint Canada/British Columbia reconnaissance Regional Geochemical Survey completed in the summer of 1984 were released at 0830 hours PDT on 27th June 1985 in Prince George, Vancouver, and Victoria as province of British Columbia open file BC-RGS-12-1984 and Geological Survey of Canada Open File 1107.

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British Columbia Ministry of Energy, Mines and Petroleum Resources, Geological Fieldwork, 1985, Paper 1986-1.

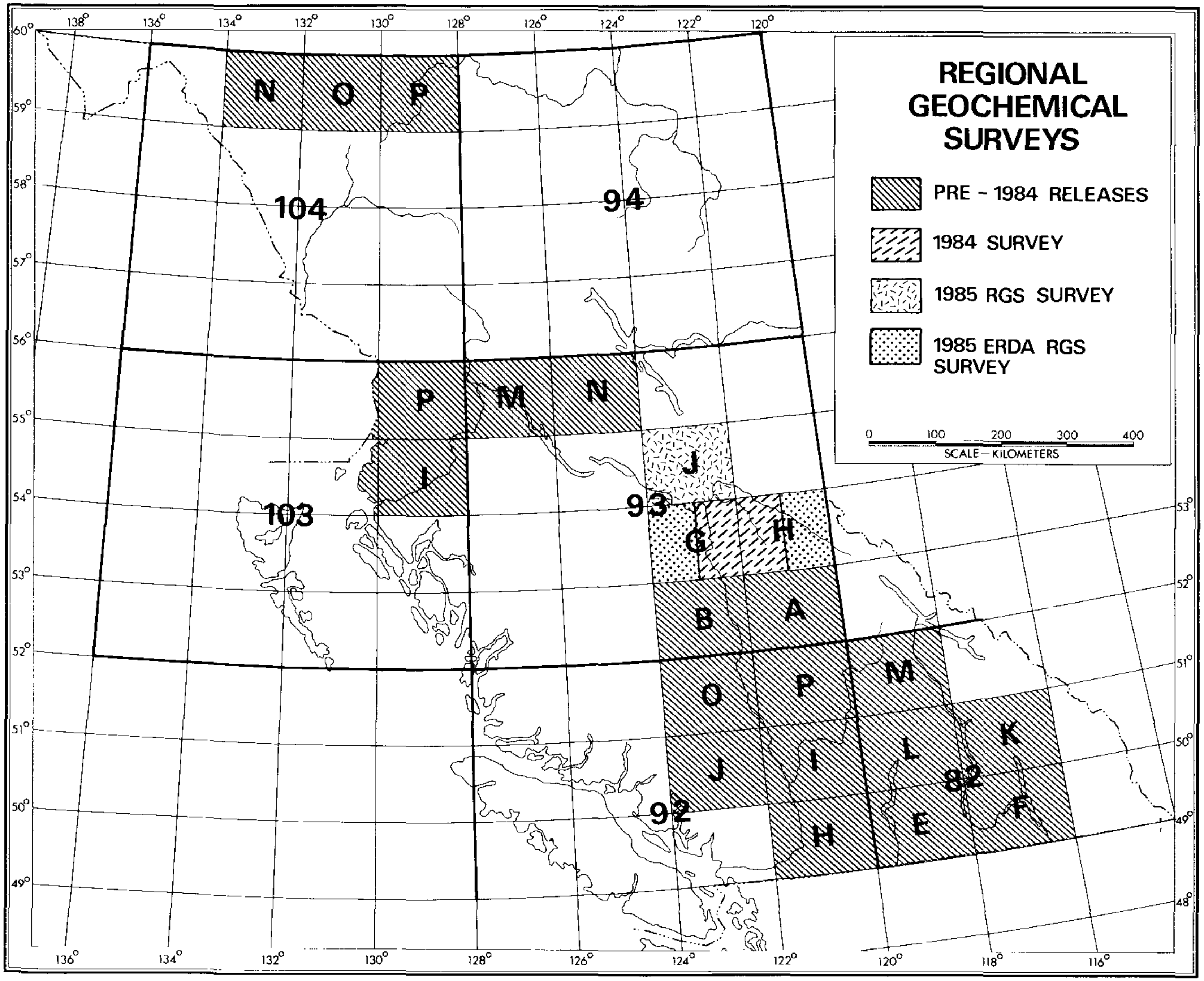

Figure 15-1. Location map for regional geochemical surveys carried out in British Columbia.

REGIONAL GEOCHEMICAL SURVEYS* RGS 13 — PRINCE GEORGE 93G/W 1/2 AND McBRIDE 93H/E 1/2 RGS 14 — McLEOD LAKE 93J

By A. J. Boronowski and W. M. Johnson

The British Columbia Ministry of Energy, Mines and Petroleum Resources conducted a regional geochemical silt and water sampling survey during July, August, and early September 1985 which covered NTS 93J, the western half of 93G, and the eastern half of 93H (Fig. 15-1).

The ministry organized and supervised all components of RGS 13. Sampling and analytical work were funded from the first year of the British Columbia/Canada Mineral Development agreement. Data processing will be carried out by the Department of Energy, Mines and Resources.

For RGS 14 the ministry funded organization, supervision, and sample collection activities while the Department of Energy, Mines and Resources funded the commercial sample preparation, analyses, and data processing. Field supervision for both surveys was carried out by A. J. Boronowski under the direction of W. M. Johnson.

When they become available field and analytical data are processed, then plotted or to maps at a scale of 1:250 000. Field data and statistics are summarized in an accompanying publication. The open files are expected to be released in June, 1986.

To date twenty-two map-areas covering approximately 293 350 square kilometres have been sampled in British Columbia; average density ranges from one site per 12.5 square kilometres to one site per 15 square kilometres with two map sheets (103I and P) sampled at twice this density.

Field sampling for RGS 14 was carried out by Hi-Tec Resource Management Ltd. and for RGS 13 by McElhanney Engineering Services Ltd. Contractor's crews consisted of an average of five men. Access was good on 93G/W 1/2, but poor on 93J and 93H/E 1/2 due either to muskeg or mountainous terrain. Helicopters were used to collect samples that were inaccessible by truck, motorcycle, or boat. Helicopters were chartered by McElhanney Engineering Services Ltd. from Northern Mountain Inc. based in Prince George and by Hi-Tec Resource Management Ltd. from Airlift Corp. based out of Abbotsford. RGS 14, covering 14 300 square kilometres, was sampled at 1088 sites for an average coverage of one sample for 13.14 square kilometres. RGS 13, covering 14 150 square kilometres, was sampled at 1047 sites for an average of one sample for 13.52 square kilometres.

Water samples are analysed for uranium, fluorine, and pH. Stream sediments are analysed for zinc, copper, lead, nickel, cobalt, silver, manganese, iron, arsenic, molybdenum, tungsten, mercury, uranium, antimony, and cadmium

The survey areas are underlain by the economically favourable Slide Mountain, Cache Creek, Takla, and Hazelton Groups, the ultramafics of the Trembleur Intrusions, and felsic intrusions of Cretaceous and Tertiary age. Exploration has been conducted for gold, platinum, and nickel within the Slide Mountain Group, but no zoned Alaskan-type ultramafics have been reported. Copper-gold mineralization has been explored for in the felsic intrusions. Base and precious metal values are reported from volcanics of the Slide Mountain Group. Some exploration for base metals has also been conducted in the metasedimentary rocks. The ultramafics and adjoining areas have been examined for nickel, asbestos, and precious metals. The Pinchi Lake fault strikes across two of the map-areas and is the focus of exploration for mercury and precious metals. The Rocky Mountain Trench and Thrust Belt zone, which strikes across two of the map-areas, has potential for hosting carbonatites. The map-areas have not undergone intensive mineral exploration due to thick glacial drift and lack of mineral showings. The geochemical survey results will provide information for appraising the economic mineral potential of these overburden covered, apparently less mineralized areas.

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* This project is a contribution to the Canada/British Columbia Mineral Development Agreement.
British Columbia Ministry of Energy, Mines and Petroleum Resources, Geological Fieldwork, 1985, Paper 1986-1.

TABLE 16-1

SAMPLE DESCRIPTION	CU ppm	MO ppm	ZN ppm	AG ppm	CD ppm	NI ppm	CO ppm	AU ppb FA+AA
BLACKWATER MOUNTAIN AREA (93G/2)								
Panned Stream Sediment Samples								
93G858001	106	12	574	0.6	4.8	154	44	10
93G858002	48	1	116	0.4	0.1	248	38	<10
93G858003	50	1	100	0.4	0.4	90	20	<20
93G858004	16	1	76	0.4	0.4	56	16	<10
93G858005	NSS	NSS	NSS	NSS	NSS	NSS	NSS	<50
93G858007	124	22	178	0.1	3.0	54	16	<20
93G858008	30	1	144	0.4	0.4	68	18	<10
93G858009	116	6	260	1.4	0.8	114	34	17200
93G858010	50	1	164	0.1	1.0	72	18	<10
93G858011	68	4	240	0.4	1.2	90	22	1500
93G858012	82	8	216	0.8	0.6	98	28	280
93G858013	76	4	410	0.4	3.2	116	28	70
93G858014	32	4	92	0.1	1.4	38	12	<50
93G858015	36	1	134	0.1	1.2	56	16	<10
93G858016	774	1	116	0.6	0.4	70	22	<50
93G858017	62	1	212	0.1	1.0	80	24	1300
93G858018	60	1	236	5.2	0.8	86	24	21000
93G858019	120	6	534	0.6	3.6	140	40	50
Silt Stream Sediment Samples								
93G857001	71	9	470	0.5	5.0	142	45	<5
93G857002	27	1	47	0.1	0.1	243	15	<5
93G857003	64	2	73	0.4	0.9	190	25	<5
93G857004	27	1	138	0.2	0.1	90	13	<5
93G857005	113	17	830	1.3	17.0	375	55	<5
93G857006	29	1	46	0.1	1.0	39	11	<5
93G857007	95	9	410	1.5	14.0	148	56	<5
93G857008	43	1	150	0.2	1.9	59	21	<5
93G857009	38	1	84	0.1	0.5	51	17	340
93G857010	31	1	105	0.1	0.6	41	12	<5
93G857011	38	1	148	0.1	0.9	49	17	5
93G857012	39	1	82	0.1	0.2	42	17	<5
93G857013	57	2	358	0.6	3.3	108	27	<5
93G857014	41	1	128	0.1	0.8	55	12	<5
93G857015	40	1	180	0.2	1.4	60	18	50
93G857016	45	1	75	0.1	0.1	43	17	<5
93G857017	35	1	135	0.2	0.8	46	13	10
93G857018	34	1	135	0.1	0.8	46	13	10
93G857019	66	5	435	0.4	4.2	125	38	<5

SAMPLE DESCRIPTION	PB ppm	CO ppm	FE per cent	AS ppm	SB ppm	AU ppb FA+AA
CLEAR MOUNTAIN AREA (93H/6)						
Panned Stream Sediment Samples						
93H858001	252	164	40.00	166	13.2	<50
93H858002	180	176	18.40	380	15.6	60
93H858003	160	166	34.40	320	12.0	<20
93H858004	306	162	36.00	300	11.2	360
93H858005	270	280	>40.00	146	14.4	<10
93H858006	166	190	>40.00	260	12.4	20
93H858007	314	266	>40.00	240	13.2	1000
93H858008	250	172	>40.00	300	7.6	<10
93H858009	180	180	>40.00	300	34.8	<10
93H858010	210	200	>40.00	240	16.0	100
93H858011	326	180	38.00	220	20.0	80
93H858013	150	160	37.20	520	12.0	130
93H858014	196	190	>40.00	320	16.8	<10
93H858015	186	200	>40.00	320	14.4	250
93H858016	164	166	>40.00	280	15.6	10
93H858017	160	154	37.20	220	8.0	550
Silt Stream Sediment Samples						
93H857002	22	23	5.30	30	3.6	<5
93H857003	31	23	5.40	33	2.2	20
93H857004	30	23	5.20	46	2.4	15
93H857005	19	19	4.00	14	1.2	5
93H857006	20	24	5.20	24	1.2	5
93H857007	26	22	4.60	20	1.4	5
93H857008	29	27	5.70	20	1.0	<5
93H857009	21	23	5.20	30	1.8	<5
93H857010	24	27	5.30	29	1.4	<5
93H857011	37	23	5.10	22	2.0	15
93H857012	2	8	2.40	6	0.1	<5
93H857013	29	32	6.40	60	2.8	30
93H857014	23	20	5.10	27	2.2	<5
93H857015	22	19	4.70	29	1.7	<5
93H857016	10	12	3.00	7	0.4	15
93H857017	9	13	3.30	8	0.3	10

1985 ORIENTATION SURVEY A FOLLOW UP OF TWO 1984 REGIONAL GEOCHEMICAL SURVEY GEOCHEMICALLY ANOMALOUS DRAINAGES BY PANNED STREAM SEDIMENT AND SILT SAMPLING BLACKWATER MOUNTAIN AREA (93G/2) AND CLEAR MOUNTAIN AREA (93H/6)

By A. J. Boronowski

INTRODUCTION

The purpose of this follow-up survey was to compare the usefulness of silt sampling versus panned stream sediment sampling. The method of the study was to follow up two separate geochemically anomalous drainages discovered during the 1984 Regional Geochemical Survey (British Columbia Regional Geochemical Survey 12, Geological Survey of Canada Open File 1107) with panned stream sediment and silt sampling.

The two geochemically anomalous drainage basins chosen have diverse geology and potential for several deposit types. One basin was thought to have potential for hosting precious metal deposits, the other, base metal deposits with associated precious metal values. As well, there were no mineral claims and no assessment work had been recorded in these areas.

BLACKWATER MOUNTAIN AREA (93G/2)
(Figs. 16-1, 16-2)

A creek draining the eastern flank of the Blackwater Mountain area contains silts which are geochemically anomalous (greater than the 95th percentile) in copper, molybdenum, zinc, silver, cadmium, nickel, and cobalt. The area is underlain by rocks of the Pennsylvanian and Permian Cache Creek Group. The geochemical expression suggests that the area has potential for oceanic-type, mafic volcanic hosted base metal deposits with precious metal values.

CLEAR MOUNTAIN AREA (93H/6)
(Figs. 16-3, 16-4)

Dominion Creek drains the western flank of Clear Mountain. Stream silt samples from this drainage are geochemically anomalous (greater than the 95th percentile) in lead, cobalt, iron, arsenic, and antimony.

The area is underlain by rocks of the Hadrynian Yankee Belle, Cunningham, and Isaac Formations, and the Miette Group. The Isaac Formation underlies a large portion of the historically important gold-producing area of Wells-Barkerville. As well, Dominion Creek lies along what appears to be a northwesterly trending structure which shows up clearly on some of the Regional Geochemical Survey geochemical trend maps, for example, the arsenic map. The target is a precious metal deposit.

FIELD AND ANALYTICAL METHODS

Silt sampling, data recording, sample preparation, and analytical work were carried out according to standard Regional Geochemical Survey methods (British Columbia Regional Geochemical Survey 12, Geological Survey of Canada Open File 1107: Geological Survey of Canada Paper 74-52).

Panned concentrate sampling involved 10 mesh (2 millimetres) wet sieving of stream sediment material until two gold pans were filled, then panning the sediment down to a constant volume which was equal to one-tenth of the original sample.

In preparation for analysis the panned concentrate sample was passed through a heavy liquid separation (specific gravity 2.96). Sink material was separated into magnetic and non-magnetic fractions using a handheld magnet. The non-magnetic fraction was pulverized to 100 mesh and submitted for analysis.

DATA

Statistical data from 1984 Regional Geochemical Survey 12 indicate that silts collected from the Blackwater Mountain and Clear Mountain areas have the following geochemical values for the 95th percentile:

Blackwater Mountain Area
Cache Creek Group

Cu	65.0 ppm
Mo	2.0 ppm
Zn	180.0 ppm
Ag	0.2 ppm
Cd	2.0 ppm
Ni	99.0 ppm
Co	21.0 ppm

Clear Mountain Area
Miette Group

Pb	23.0 ppm
Co	25.0 ppm
Fe	5.5 per cent
As	15.0 ppm
Sb	0.6 ppm

Yankee Belle, Cunningham, and *Isaac Formations*

Pb	21.0 ppm
Co	18.0 ppm
Fe	4.3 per cent
As	15.0 ppm
Sb	0.5 ppm

Sample locations and analytical results from the 1985 follow-up survey are plotted on Figures 16-1 to 16-4. Analytical results are presented in Table 16-1.

RESULTS

In the Blackwater Mountain area results from the silt and panned stream sediment sampling surveys indicate a possible zonation from south to north of the following geochemical values: nickel-cobalt to copper-molybdenum-zinc-silver-cadmium-nickel-cobalt to silver-gold.

Insufficient data preclude the determination of statistical values for gold. However, interesting gold values were obtained from the silts and panned stream sediment samples collected in the extreme northern portion of the area. These silt samples contain gold values ranging between 10 and 340 parts per billion. Only two of these silts contain geochemical values equal to the 95th percentile. Panned stream sediment samples collected in this area have gold values ranging from less than 10 to 21 000 parts per billion.

In the Clear Mountain area results from the silt and panned stream sediment sampling survey indicate geochemically anomalous values that increase toward the geological contact that separates the Miette Group from the Yankee Belle, Cunningham, and Isaac Formations.

CONCLUSIONS

The Blackwater Mountain area contains a zonation of anomalous geochemical values from south to north of nickel-cobalt to copper-molybdenum-zinc-silver-cadmium-nickel-cobalt to silver-gold. The geochemical signature is expressive of a mafic volcanic hosted deposit with precious metal values.

The panned stream sediment survey reflected the results obtained by the silt survey. However, panned stream sediment sampling proved useful in delineating an area of high geochemical gold values in the Blackwater Mountain area, which is not as apparent in the silt survey. A panned stream sediment survey would be useful in outlining areas of anomalous gold values discovered during regional silt sampling surveys or as a follow up to anomalous pathfinder elements. The latter were the basis of this study.

Regional silt sampling surveys are a quick and cost-effective method of testing the potential of a catchment basin for hosting base metal deposits. Gold results were too vague to determine the usefulness of standard silt sampling when testing an area for gold mineralization.

The Clear Mountain area contains a linear zone that is geochemically anomalous in lead-cobalt-iron-arsenic-antimony. This zone parallels the contact between the Miette Group and the Yankee Belle, Cunningham, and Isaac Formations. This survey is an example where the pathfinder elements arsenic and antimony did not indicate gold mineralization. The anomalous iron content may have scavenged the geochemically anomalous elements.

RECOMMENDATIONS

More research is required to determine if silt sampling is a viable method of testing an area for gold mineralization.

Possibly Regional Geochemical Survey silts collected in areas either suspected of containing gold mineralization or known to contain anomalous pathfinder elements should be analysed for gold. An alternative is to return to these areas and conduct a panned stream sediment survey.

More orientation surveys are needed to determine the most cost effective method of testing areas for gold mineralization. Variables should include field methods and laboratory techniques.

Sample location notes and summary statistics contained in the Regional Geochemical Survey open file reports should be studied prior to conducting follow-up programs.

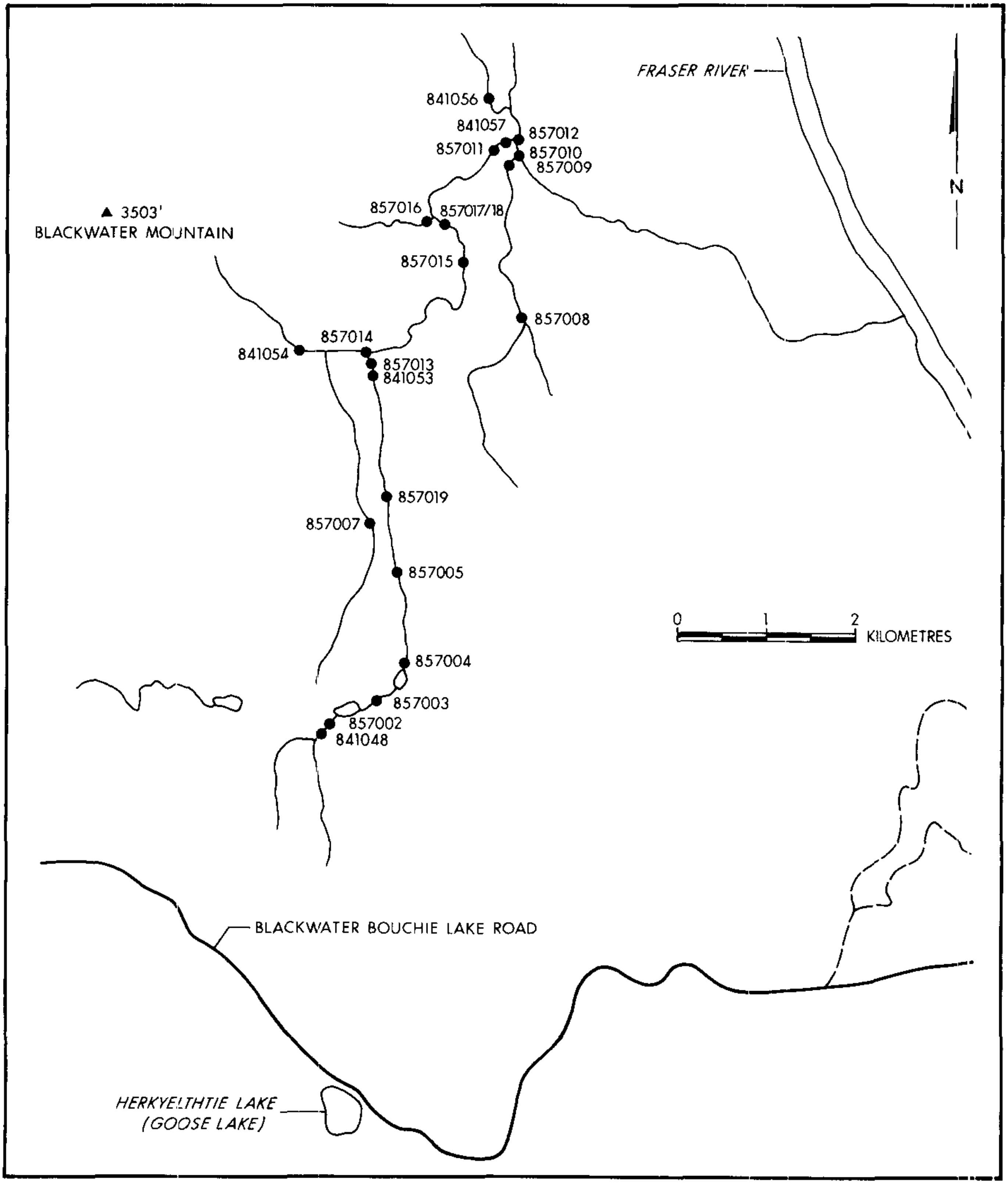


Figure 16-1. Sample locations, Cottonwood Canyon (93G/2).

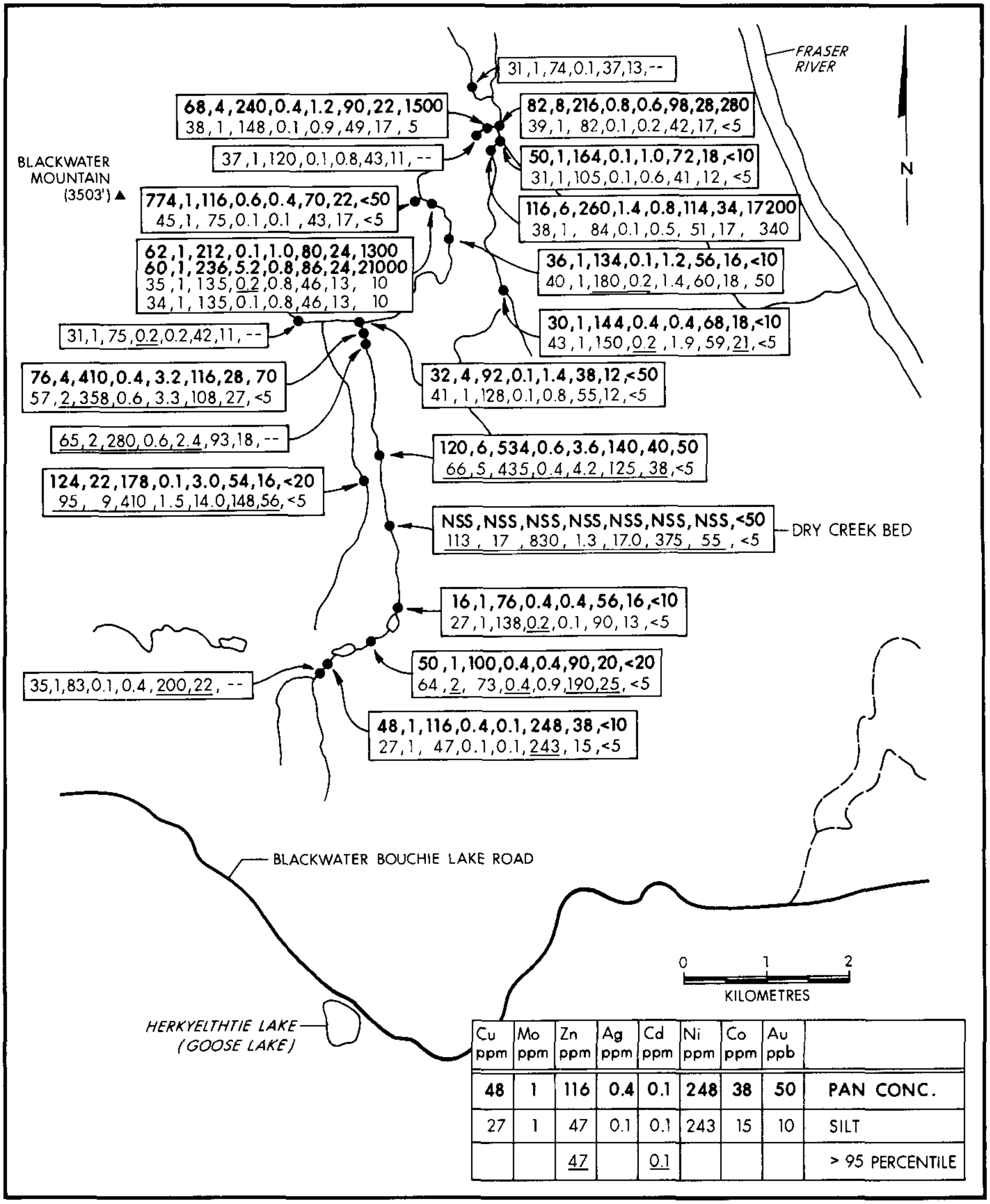


Figure 16-2. Assay data, Cottonwood Canyon (93G/2).

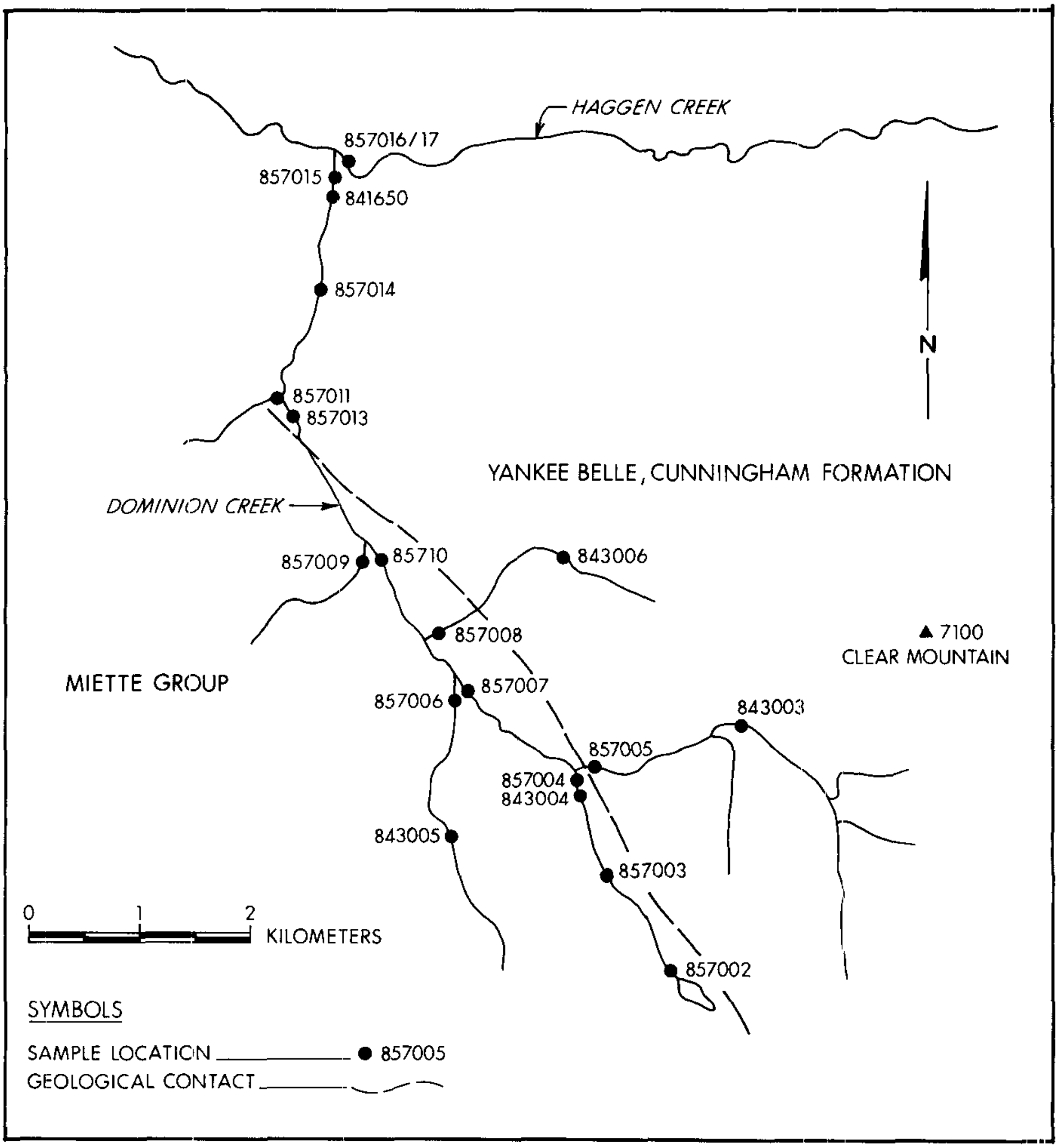
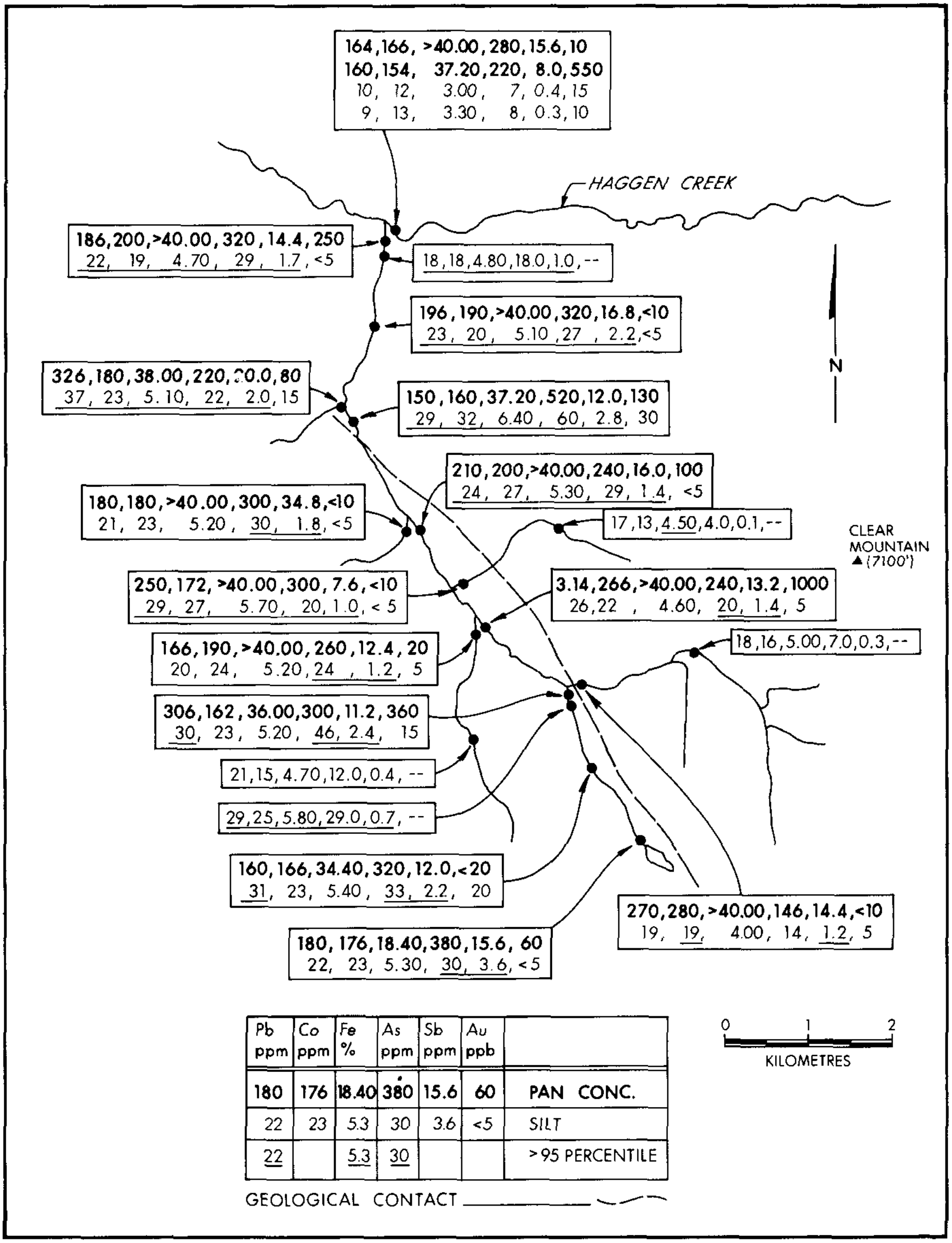


Figure 16-3. Sample locations, Dominion Creek, Indianpoint Lake (93H/6).



Pb ppm	Co ppm	Fe %	As ppm	Sb ppm	Au ppb	
180	176	18.40	380	15.6	60	PAN CONC.
22	23	5.3	30	3.6	<5	SILT
22		5.3	30			>95 PERCENTILE

Figure 16-4. Assay data, Dominion Creek, Indianpoint Lake (93H/6).

THE BOB CREEK GOLD-SILVER PROSPECT (93L)

By B. N. Church

INTRODUCTION

The Bob Creek prospect (MI 93L-009) is centred 10.6 kilometres south of Houston at 800 metres elevation. The showing is approximately 1.4 kilometre by dirt road east of Buck Creek and the Buck Flats road (Fig. 17-1).

The property comprises the Buck and Lorne claim blocks which are relocated from previous claims including the old Porphyry Dyke, Horseshoe, and Gold Brick claim groups.

The property was visited briefly by the writer in June and August 1972, August 1980, and July 1984.

TABLE 17-1
TABLE OF CHEMICAL ANALYSES

	1	2	3	4
Oxides recalculated to 100:				
SiO_2	77.13	72.64	69.29	51.77
TiO_2	0.54	0.49	0.42	2.76
Al_2O_3	13.11	14.59	15.88	17.32
Fe_2O_3	3.38	2.17	2.03	2.08
FeO	0.31	1.13	3.54	7.14
MnO	0.33	0.24	0.67	0.13
MgO	0.40	0.72	1.08	5.52
CaO	0.13	1.36	2.23	6.96
Na_2O	0.63	0.09	0.03	4.28
K_2O	4.03	6.57	4.83	2.04
	100.00	100.00	100.00	100.00
Oxides as determined:				
$+H_2O$	2.09	2.63	2.18	3.01
$-H_2O$	0.34	0.10	0.14	0.17
CO_2	0.07	1.47	3.98	3.32
P_2O_5	0.01	0.17	0.22	0.69
S	0.03	1.42	1.09	0.04
Molecular Norm:				
Qz	55.4	41.3	41.1	—
Or	24.8	40.3	29.9	12.0
Ab	5.9	0.9	0.3	38.2
An	0.7	7.0	11.6	22.0
Wo	—	—	0.0	5.0
En	1.2	2.1	3.1	3.4
Fs	—	—	3.7	1.3
Fo	—	—	—	8.8
Fa	—	—	—	3.3
Il	0.8	0.7	0.6	3.8
Mt	—	1.7	2.2	2.2
He	2.8	0.5	—	—
Cr	8.4	5.5	7.5	—

Key to Analyses:

1. Hazelton maroon tuff breccia, near Bob Creek.
2. Mineralized rhyolite breccia, 'Ore zone.'
3. Altered quartz porphyry, west of Snoopy II adit, canyon area.
4. Bob Creek gabbro, on hillcrest east of Buck Flats road.

Much appreciation for company information is owing Dave Barr of DuPont of Canada Exploration Ltd. and Mark Rebagliati and Ian Trinder of Selco Divison, B.P. Resources Canada Ltd.

EXPLORATION AND DEVELOPMENT HISTORY

A small amount of placer gold was recovered from Bob Creek prior to 1905. In 1914 claims were staked covering the apparent source area, which proved to be a zone of altered rocks exposed upstream in the canyon of Bob Creek. Some exploratory tunnelling was completed by 1927. According to Lang (1929, p. 93A): 'A short adit has been driven into the right side of the canyon, exposing disseminations and small seams of pyrite, sphalerite, and a little galena, but no definite vein is exposed. About 100 yards (90 metres) upstream, a second short adit has been driven in the left side of the canyon where a 3-inch (7.6-centimetre) stringer is stated to have assayed: gold, 0.06 ounces (2.1 grams per tonne); silver, 41 ounces (1 400 grams per tonne); lead, 3 per cent; zinc, 11 per cent.'

A small mill was set up on the property in 1933 and three years later operations began under the direction of Houston Gold Mines Ltd. According to reports, 77 tonnes of ore was produced averaging gold, 3.5 grams per tonne; silver, 35 grams per tonne; and zinc, 1. per cent.

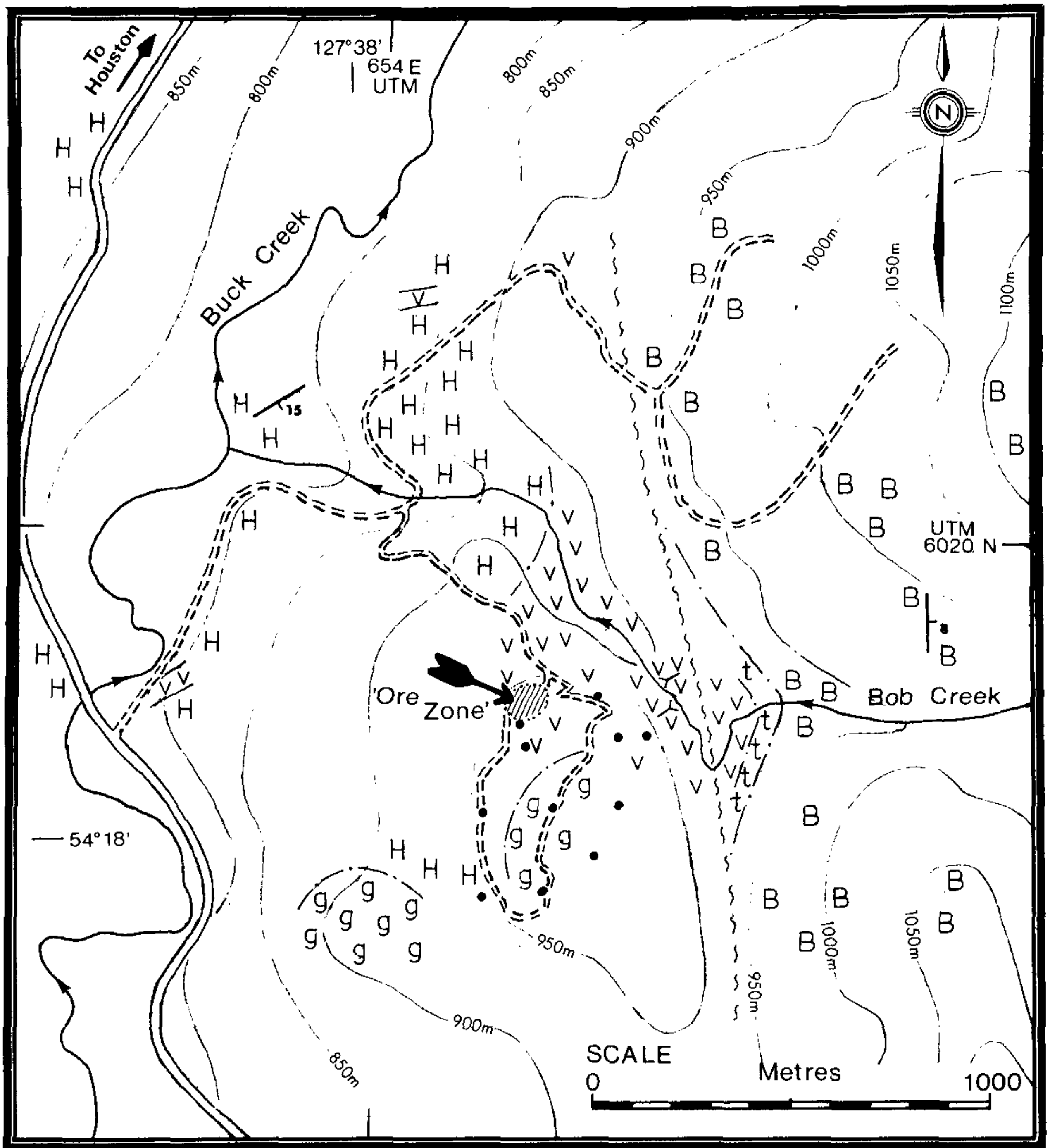
The property was the focus of intermittent exploration in subsequent years. Some of the more important drilling programs were conducted by the Premier Gold Mining Company in 1945 (three diamond-drill holes totalling 240 metres), Denison Mines Ltd. in 1961 (eight drill holes totalling 155 metres), Asarco Exploration Company of Canada Ltd. in 1968 (seven holes totalling 640 metres), and DuPont of Canada Exploration Ltd. in 1978 (six holes totalling 751 metres). Most recently, Selco Division of B.P. Resources Canada Ltd. completed a major program in 1984 consisting primarily of eight diamond-drill holes totalling 1 247 metres.

In addition to the drilling, a number of geochemical and geophysical programs were completed. In 1965 Triform Mining Ltd. joined with Coast Exploration Ltd. to geochemically test 4 100 metres of bulldozer trenching and stripping. Later Minwealth Explorations Ltd. performed airborne magnetic and EM surveys and a geochemical program. In 1978 DuPont completed 13 kilometres of pulse EM survey and geological mapping. Cominco Ltd. did a thorough review of the property in 1981 and followed this with an IP survey, and soil, silt, and lithogeochemical studies.

GEOLOGICAL SETTING

The rocks in vicinity of the Bob Creek prospect consist predominantly of gently dipping volcanic formations of Jurassic, Cretaceous, and Tertiary ages, a small gabbro stock, and a number of dykes.

The oldest rocks are mostly maroon volcanics of the Hazelton Group similar to the Lower (?) Jurassic assemblage on Mcrice Mountain located to the west. These are exposed along the lower course of Bob Creek and on the valley slopes near the confluence of Bob Creek and Buck Creek in the west part of the map-area (Fig 17-1). The most common unit is massive tuff breccia with a few thin intercalations of accretionary lapilli and siltstone. The volcanic



LEGEND

BEDDED AND EFFUSIVE ROCKS

TERTIARY

| B | *BUCK CREEK VOLCANICS*

UPPER CRETACEOUS

| t | TIP TOP HILL VOLCANICS

| V | RHYOLITE BRECCIA AND QUARTZ FELDSPAR PORPHYRY

JURASSIC

| H | HAZELTON VOLCANICS

INTRUSIVE ROCKS

| g | BOB CREEK GABBRO

SYMBOLS

DIAMOND-DRILL HOLE .... ●

Figure 17-1. Geological sketch map of the Bob Creek prospect.

TABLE 17-2
RADIOMETRIC DATES BY POTASSIUM/ARGON ANALYSES

No.	Lat.	Long.	Rock	Mineral	K%	Ar^{40*} $\times 10^{-6}$cc/gm	Ma
1	54°18.5′	126°37′	Feldspar porphyry	Biotite	6.79	21.739	80.6 ± 2.8
2	54°18.1′	126°37.2′	Quartz porphyry	Sericite	8.42	26.099	78.1 ± 2.8

clasts are mostly dacitic with some rhyolite admixture (Table 17-1, No. 1). A thin shale facies from this section has been intersected in the exploration drilling. Although the base of the formation is not seen, the total thickness certainly exceeds several hundred metres.

The host rock for mineralization is a belt of altered felsic volcanic rocks, about 600 metres wide, exposed in the canyon of Bob Creek. These are quartz-feldspar porphyry feeder dykes and breccias equivalent in age to the Upper Cretaceous Okusyelda Hill and Duck Lake volcanic rocks and intrusions (Church, 1972, p. 359).

The slightly younger Tip Top Hill Formation overlies the felsic volcanics east of the canyon. These rocks are brown, somewhat altered, andesitic tuffs and breccias; they form an erosional remnant immediately underlying the Tertiary sequence.

The youngest beds are assigned to the Buck Creek Formation. These rocks comprise about 500 metres of Early Tertiary fine-grained dacitic lavas and breccias exposed along the upper course of Bob Creek and on the hills and ridges in the east part of the map-area. The layering of this sequence, displayed on the valley walls, dips about 8 degrees easterly.

The 'Bob Creek gabbro' crops out on the crests of two low hills south of the canyon. This is a somewhat altered, medium to fine-grained stock intruding the Jurassic and Cretaceous volcanic rocks. Normative mineral calculations indicate a quartz deficiency similar to many gabbros (Table 17-1, No. 4).

Several feldspar porphyry dykes intrude the Hazelton rocks. The largest of these is observed in a road cut where the Bob Creek and the main Buck Flats roads join, and on a logging road north of Bob Creek. These dykes contain subhedral clusters of plagioclase, 0.5 centimetre across, in a matrix of fine-grained feldspar, biotite, and quartz. Potassium/argon age determination of a biotite separate from these rocks gives an Upper Cretaceous age of 80.6 ± 2.8 Ma (Table 17-2, No. 1) similar to the Duck Lake intrusion.

MINERALIZATION

The felsic effusive rocks exposed on the canyon of Bob Creek are a composite of hydrothermally altered breccias, including some round clast vent breccias, and quartz-feldspar porphyry feeder dykes. Normative calculations from whole rock chemical analyses suggest high quartz and alkali feldspar content typical of many unaltered rhyolites (Table 17-1, Nos. 2 and 3).

The alteration of these rocks is intense, consisting mostly of kaolinization with local sericitization and silicification. Limonite is developed on many outcrops as a result of oxidation and leaching of sulphides.

The main sulphide minerals are pyrite and sphalerite with lesser amounts of galena and chalcopyrite. These occur as disseminations, stringers, and in quartz veinlets of apparent random orientation.

The main target of exploration is a zone of high lithogeochemical values midway between the canyon and the north contact of the Bob Creek gabbro. This 'Ore zone' is an ellipical 80 by 50-metre area with gold and silver assays ranging to more than 4 ppm and 35 ppm respectively.

The age of mineralization has been determined to be 78.1 ± 2.8 Ma from potassium/argon analyses of sericitized biotite from a hydrothermally altered porphyry from the canyon area (Table 17-2, No. 2). It is noted that this is only slightly younger than unaltered biotite feldspar porphyry dykes of the region which have been correlated with the Duck Lake intrusion and Okusyelda volcanic event.

According to Caelles (1982): '. . . the Au-Ag (Zn-Pb-Cu) mineralization in the Buck Creek property is epigenetic, deposited by circulation of hydrothermal fluids that are very likely genetically related to the predominantly felsic volcanism. If this hypothesis is correct, lithological control of mineralization could be important, mainly through control of mineralizing fluid circulation by rock porosity and permeability.'

Malingering hydrothermal activity may be responsible too for the altered condition of the Tip Top Hill andesites and the Bob Creek stock. In accordance with this, the 'Ore zone,' which is proximal to the stock, coincides with the end phase of a rhyolite to andesite and gabbro, Upper Cretaceous eruptive cycle.

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TABLE 1. COMPUTER PROGRAM IN TI BASIC TO DETERMINE MOLECULAR NORM MINERALOGY FROM MAJOR OXIDE WEIGHT PER CENT

```
100 REM "XXXXXXXXXXXXXXXXXX"
110 REM "X                X"
120 REM "X MOLECULAR NORM X"
130 REM "X                X"
140 REM "X   B.N. Church  X"
150 REM "X                X"
160 REM "XXXXXXXXXXXXXXXXXX"
170 PRINT
190 A=.01667
200 A1=.01251
210 A2=.01962
220 A3=.01252
230 A4=.01392
240 A5=.02481
250 A6=.01783
260 A7=.03226
270 A8=.02124
280 INPUT "SAMPLE NO. =":Z
290 INPUT "WT.% SIO2  =":B
300 INPUT "WT.% TIO2  =":B1
310 INPUT "WT.% AL2O3 =":B2
320 INPUT "WT.% FE2O3=":B3
330 INPUT "WT.% FEO   =":B4
340 INPUT "WT.% MGO   =":B5
350 INPUT "WT.% CAO   =":B6
360 INPUT "WT.% NA2O =":B7
370 INPUT "WT.% K2O   =":B8
380 C=A*B
390 C1=A1*B1
400 C2=A2*B2
410 C3=A3*B3
420 C4=A4*B4
430 C5=A5*B5
440 C6=A6*B6
450 C7=A7*B7
460 C8=A8*B8
470 D=C+C1+C2+C3+C4+C5+C6+C7+C8
480 E=C*100/D
490 E1=C1*100/D
500 E2=C2*100/D
510 E3=C3*100/D
520 E4=C4*100/D
530 E5=C5*100/D
540 E6=C6*100/D
550 E7=C7*100/D
560 E8=C8*100/D
570 REM E=SI E1=TI E2=AL
575 REM E3=FE+++ E4=FE++ E5=MG
580 REM E6=CA E7=NA E8=K CATION %
590 M1=5*E8
600 M2=5*E7
610 K=(E2-E7)-E8
620 G=E6*2
630 GOTO 680
640 M3=K*5/2
650 M4=(E6-M3/5)*2
660 M5=0
670 GOTO 720
680 IF G>K THEN 640
690 M3=E6*5
700 M5=K-M3*2/5
710 M4=0
720 M6=E5*2
730 M7=E1*2
740 GOTO 800
750 M8=(E4-E1)*3
760 O=E3-M8*2/3
770 M9=0
780 R3=M9/2
790 GOTO 850
800 IF (E3/2)>=(E4-E1)THEN 750
810 M8=E3*3/2
820 M9=(E4-E1-M8/3)*2
830 O=0
840 R3=M9/2
850 S1=E-((M1*3/5)+(M2*3/5)+(M3*2/5)+(M4/2)+(M6/2)+(M9/2))
860 PRINT "SAMPLE NO. =",Z
870 PRINT "NORMATIVE %"
880 PRINT
890 PRINT "QUARTZ      ",S1
900 PRINT "ORTHOCLASE  ",M1
910 PRINT "ALBITE      ",M2
920 PRINT "ANORTHITE   ",M3
930 PRINT "WOLLASTONITE",M4
940 PRINT "ENSTATITE   ",M6
950 PRINT "FERROSILITE ",M9
960 PRINT "ILMENITE    ",M7
970 PRINT "MAGNETITE   ",M8
980 PRINT "HEMATITE    ",O
990 PRINT "CORUNDUM    ",M5
1000 PRINT
1010 IF S1<0 THEN 1040
1020 PRINT
1030 END
1040 PRINT "UNDERSATURATED"
1050 PRINT "OPX GOES TO OV"
1060 PRINT
1070 F=(M6+M9)/2
1080 S2=E-(((M1/5)*3)+((M2/5)*3)+((M3/5)*2)+(M4/2))
1090 Y=(F-S2)*2
1100 X=F-Y
1110 I=2*X
1120 J=Y+(Y/2)
1130 L=(M6/(M6+M9))*I
1140 P=(M9/(M6+M9))*J
1150 T=(M6/(M6+M9))*J
1160 U=(M9/(M6+M9))*I
1170 PRINT "ENSTATITE  =",L
1180 PRINT "FERROSILITE=",U
1190 PRINT "FORSTERITE =",T
1200 PRINT "FAYALITE   =",P
1210 PRINT
1230 IF I<0 THEN 1260
1240 PRINT
1250 END
1255 PRINT
1260 PRINT "FELDSPATHOIDAL"
1270 PRINT "OLV+NEPH NORM"
1280 PRINT
1290 H=(E5/2)+E5
1300 N=(R3/2)+R3
1310 S3=S2-(R3/2)-(E5/2)+(E7*3)
1320 V=(S3-E7)/2
1330 W=E7-V
1340 Q=V*5
1350 Z=W*3
1360 PRINT "ORTHOCLASE  ",M1
1370 PRINT "NEPHELINE   ",Z
1380 PRINT "ALBITE      ",Q
1390 PRINT "ANORTHITE   ",M3
1400 PRINT "WOLLASTONITE",M4
1410 PRINT "FORSTERITE  ",H
1420 PRINT "FAYALITE    ",N
1430 PRINT "ILMENITE    ",M7
1440 PRINT "MAGNETITE   ",M8
1450 PRINT "HEMATITE    ",O
1460 PRINT "CORUNDUM    ",M5
1470 PRINT
1480 PRINT
1490 PRINT
1495 PRINT
1500 PRINT
1510 END
```

British Columbia Geological Survey
Geological Fieldwork 1985

A COMPUTER PROGRAM FOR THE DETERMINATION OF MOLECULAR NORMS FOR THE FINE-GRAINED AND ALTERED ROCKS OF THE BOB CREEK AREA (93L/7)

By B. N. Church

The determination of normative mineral compositions from major oxide analyses offers a method of comparison of coarse or medium-grained igneous rocks with fine-grained or altered equivalents. To this end, Barth (1952, pp. 76-82) described the necessary simplified calculations following the 'Niggli procedure,' whereby oxide weights for each rock are transformed to equivalent molecular units. The resulting 'molecular norm' is considered to be simpler and a better approximation of modal mineralogy than the traditional CIPW 'weight norm' (Wahlstrom, 1955, pp. 82-85).

In Table 18-1 a computer program to assist in study of the igneous rocks of the Bob Creek prospect (*see* accompanying report), and fine-grained effusives in general. This program is specifically for the TI 99-4/A computer, however, with some slight modifications it is readily adaptable to any microcomputer with Basic language facility.

Weight per cent for the nine most important oxides in igneous rocks, including TiO_2, FeO, and Fe_2O_3, are input into the program. Output is molecular percentage for as many as 14 of the most common anhydrous and non-carbonate end member minerals, including olivine and nepheline for silica deficient samples.

The method is demonstrated using Chayes' (1975) average compositions (Table 18-2) and four analyses from the Bob Creek area. Negative normative quartz indicates undersaturation in silica. This negative value causes conversion of some or all of enstatite and ferrosilite to forsterite and fayalite. Additional undersaturation results in conversion of albite to nepheline. (There is no provision for leucite in this program). Small negative values for magnetite can usually be ignored as this simply indicates that ferrous iron is less than titanium, which is sometimes the case in oxidized and altered rocks.

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TABLE 18-2
AVERAGE COMPOSITIONS OF COMMON VOLCANIC ROCKS
(Chayes, 1975)

	1	2	3	4	5	6
SiO_2	71.56	65.33	58.19	58.28	56.70	45.56
TiO_2	0.32	0.62	0.82	0.86	0.84	2.55
Al_2O_3	13.58	15.58	17.22	18.28	19.06	14.61
Fe_2O_3	1.58	2.37	3.09	2.93	2.71	4.27
FeO	1.10	2.33	4.05	2.00	1.70	7.38
MnO	0.07	0.12	0.15	0.19	0.21	0.18
MgO	0.47	1.62	3.22	1.20	1.04	8.45
CaO	1.41	4.31	6.81	3.05	2.62	10.23
Na_2O	3.80	3.72	3.29	6.63	7.55	3.20
K_2O	4.19	2.27	1.68	4.82	5.17	1.40
P_2O_5	0.12	0.18	0.23	0.25	0.22	0.59
H_2O	1.96	1.54	1.33	1.47	1.99	1.56
Molecular Norms:						
Qz	28.3	22.1	12.4	—	—	—
Or	25.5	13.8	10.2	28.3	30.3	3.5
Ne	—	—	—	5.6	15.3	2.2
Ab	35.0	34.4	30.2	49.9	41.7	25.6
An	7.2	19.6	27.9	5.9	2.8	21.8
Wo	—	1.0	2.7	3.7	4.0	12.0
Eu	1.3	4.6	9.1	—	—	—
Fs	0.2	1.1	3.0	—	—	—
Fo	—	—	—	2.5	2.1	17.9
Fa	—	—	—	—	—	3.8
Il	0.5	0.9	1.2	1.2	1.2	3.6
Mt	1.7	2.5	3.3	2.8	2.2	4.6
He	—	—	—	0.1	0.4	—
Cr	0.3	—	—	—	—	—

Key to Analyses:
1 — Rhyolite, 2 — Dacite, 3 — Andesite, 4 — Trachyte, 5 — Phonolite, 6 — Basalt

British Columbia Ministry of Energy, Mines and Petroleum Resources, Geological Fieldwork, 1985, Paper 1986-1.

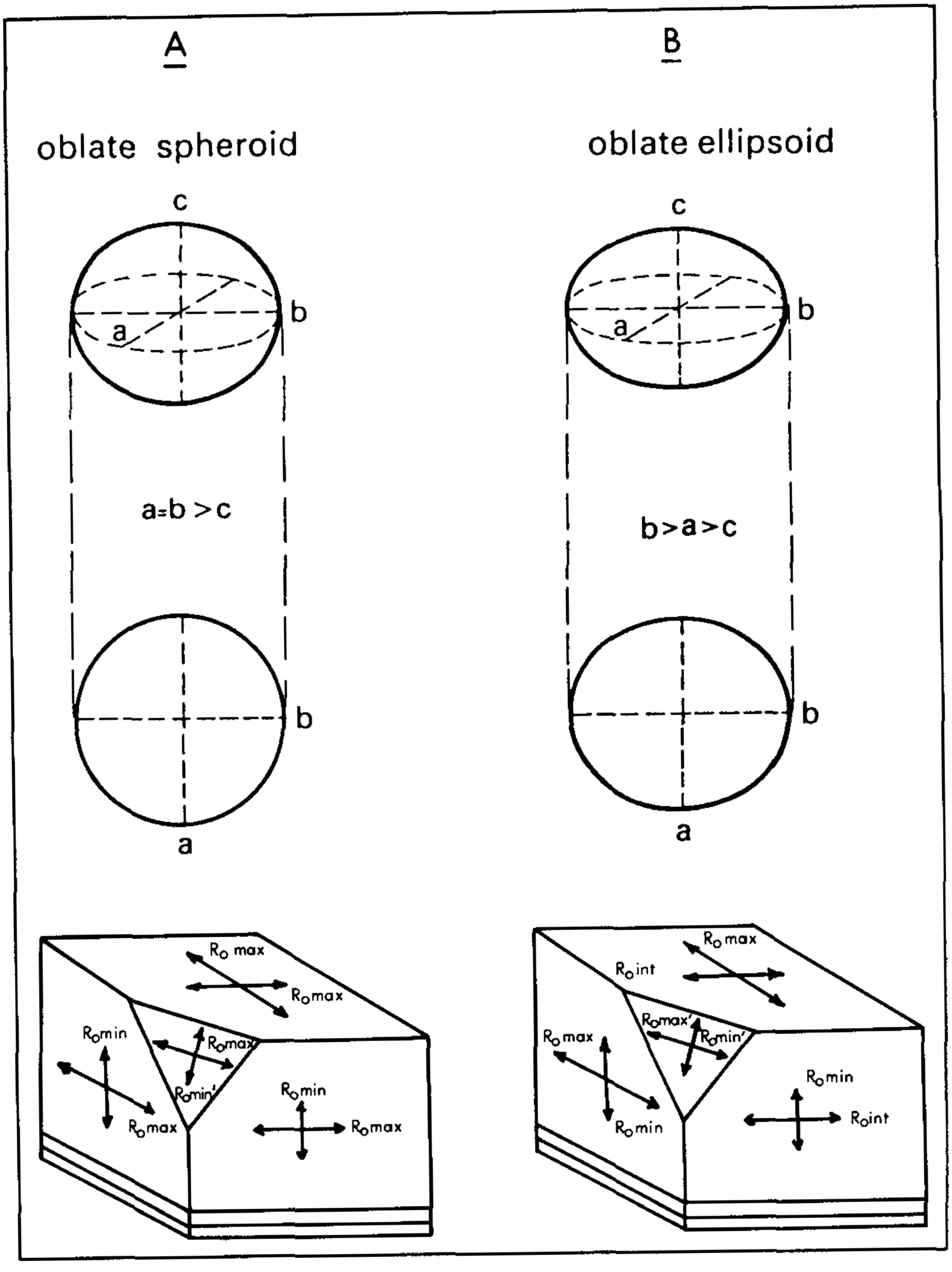

Figure 19-1. Reflectance indicatrix shapes and corresponding reflectance readings which may be obtained from a block of coal for uniaxial (a) and biaxial (b) coals.

BIAXIAL REFLECTING COALS IN THE PEACE RIVER COALFIELD (93O, P, I)

By W. E. Kilby

INTRODUCTION

Vitrinite has traditionally been considered to have a uniaxial negative reflectance indicatrix. The validity of common reflectance measures such as $\bar{R}_o$ max and $\bar{R}_o$ m (mean maximum and mean random vitrinite reflectance) is based on this assumption. However, an increasing number of biaxial reflectance indicatrixes are being reported from coals of various ranks from around the world (Cook, *et al.*, 1972; Stone and Cook, 1979; Hower and Davis, 1981; Levine and Davis, 1984).

The objective of this preliminary study was to examine a variety of coals from the Peace River Coalfield to determine if any biaxial reflecting coals are present, and to devise a methodology to identify these coals from particle samples.

As part of the study 19 oriented coal samples were collected from various locations in the central and northern portions of the coalfield. Sections parallel to the three major cleat planes, face, butt, and bedding, were examined for each sample. The results of these measurements are presented and discussed. In addition, two computer programs were developed to predict the results of reflectance analysis of particle samples from biaxial coals. The resulting theoretical analysis data were used to devise a useful graphical technique for indicatrix determination.

BACKGROUND

Traditionally, vitrinite has been considered to have a uniaxial negative reflectance figure. In such a figure three mutually perpendicular axes describe an oblate spheroid with the short c axis, R_o min, oriented normal to bedding, and the two remaining long a and b axes, R_o max, being equal in length and oriented in the plane of bedding (Fig. 19-1). It is assumed that as the rank of a coal increases the sheet-like aromatic molecules within the coal grow in directions normal to the maximum stress direction. Most commonly maximum stress would be due to overburden loading, therefore the coal molecules would grow in a horizontal direction (Stack, *et al.*, 1975). This process is not well understood and the physical change caused by metamorphism may indeed be a stacking of the aromatic molecules (Murchison, 1978). Irrespective of the actual physical changes, it is well documented that the maximum reflectance direction lies in all directions in the plane of bedding in areas where the maximum stress direction was vertical and normal to bedding. Figure 19-1a illustrates this situation where a = b>c. Examination of this indicatrix from any direction will yield a unique maximum reflectance value, R_o max, and a minimum reflectance value, R_o min′, that varies from the true minimum to the true maximum. Only in the case of sections normal to bedding are true R_o max and R_o min values observed. The common coal rank measure, $\bar{R}_o$ max, is based on this relationship. Any section through the indicatrix will yield the R_o max value. By taking the mean of the R_o max values from the many sections, the true value is estimated. The scatter of R_o max values being due to random measurement errors.

With a biaxial reflectance indicatrix all three principle reflectance axes are of different lengths, b>a>c (Fig. 19-1b). Only sections which contain the b axis will provide the true, R_o max, value.

Random sections of a biaxial indicatrix will not produce a normal distribution about the true maximum reflectance because there are two reflectance axes of different values being measured rather than the two axes of one reflectance value as in the case of uniaxial negative indicatrixes. Biaxial reflectance indicatrixes form where stresses other than solely overburden loading are present. It is still not understood if post-coalification stress is responsible or syn-coalification deformation or both.

ORIENTED COAL SAMPLES

Oriented coal samples from the Gates and Gething Formations were obtained from a variety of structural settings in the northern half of the coalfield (Fig. 19-2). Samples were collected from natural outcrops, mine pit walls, and adit faces. Samples consisted of coal blocks approximately 20 centimetres on a side with adequate markings so their original orientation could be restored. Three roughly perpendicular sections were obtained, one parallel to each of the three cleat directions. These small samples were mounted in cold set epoxy in 3.8-centimetre molds, and polished according to standard techniques. Sample examination was performed with a Leitz MPV3 reflecting light microscope with 546 nm wavelength light in oil with a refractive index of 1.518.

Only structureless vitrinite was used to determine reflectance values, and only if it occurred as continuous bands (vitrinite A). Traverses were made across the sample and readings taken on each vitrinite band. The maximum and minimum reflectance values along with their orientations, were recorded. Once it was established that the shape of the indicatrix on any section would be an ellipse, a more rapid measurement technique became justified. The standard procedure is to monitor the reflectance value as the sample is rotated 360 degrees on the microscope stage to determine the maximum and minimum reflectance values. The modification was based on work by Ting (1978), who described a procedure requiring three readings at a 45-degree angular separation to arrive at the maximum and minimum axis lengths of an ellipse. A variation of this procedure was employed, where five readings, each 45 degrees apart, were recorded. A computer program was written to generate three determinations of R_o max and R_o min from these five readings as well as the orientation of the R_o max reading for each determination. The three determinations from each set-up provide a means of evaluating the validity of the readings. Between three and ten set-ups were made on each section depending upon the number of vitrinite bands present. Results of these measurements are presented in Table 19-1.

Significant problems were anticipated and encountered in analysing oriented sections of coal. Other workers have had similar difficulties (Ting, pers. comm.) and some have utilized compromise techniques (Stone and Cook, 1979). Several reasons for these problems are:

(1) sections may not be oriented exactly as desired, which is particularly important when dealing with the bedding plane section;

(2) different vitrinite bands may be encountered on different sections;

British Columbia Ministry of Energy, Mines and Petroleum Resources, Geological Fieldwork, 1985, Paper 1986-1.

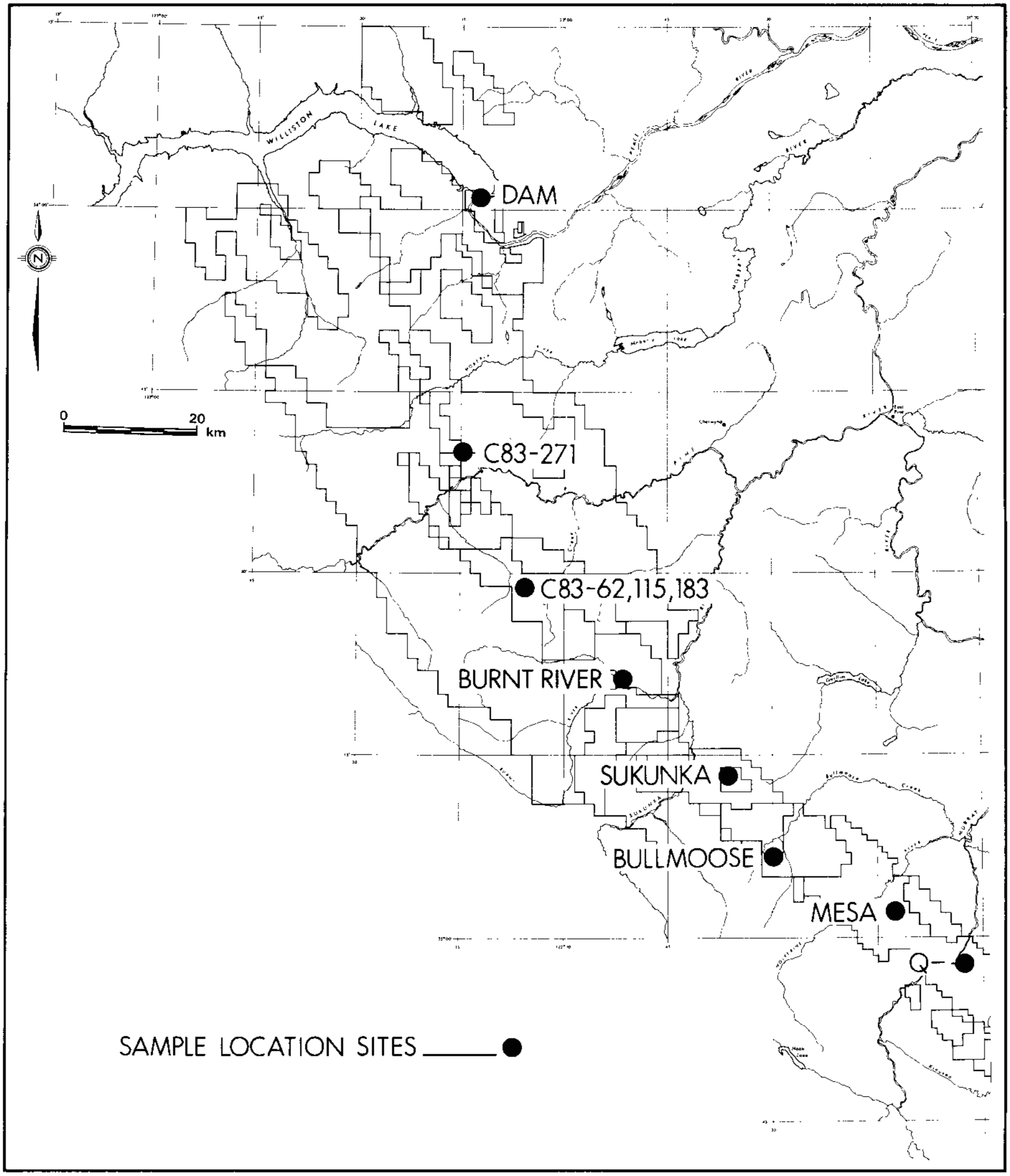

Figure 19-2. Location map of oriented sample collection sites.

TABLE 19-1
VITRINITE REFLECTANCE VALUES OBTAINED FROM THREE MUTUALLY PERPENDICULAR SECTIONS CUT THROUGH ORIENTED COAL SAMPLES

Sample No.	Bed Max	Bed Min	Bed Bi	Face Max	Face Min	Face Bi	Butt Max	Butt Min	Butt Bi	Formation
Peace River										
DAM	1.56	1.43	0.13	1.48	1.13	0.35	1.54	1.08	0.46	Lower Gething
Burnt River										
BR-60	1.81	1.56	0.25	1.62	1.24	0.38	1.72	1.35	0.37	Lower Gething
BR-U	1.82	1.71	0.12	1.72	1.38	0.34	1.83	1.42	0.38	Lower Gething
Sukunka	1.43	1.35	0.09	1.40	1.19	0.20	1.39	1.19	0.19	Upper Gething
Bullmoose										
Bull 84A	1.30	1.22	0.08	1.27	1.10	0.17	1.13	1.01	0.15	Gates
A1	1.18	1.11	0.07	1.27	1.05	0.22	1.25	1.10	0.14	Gates
A2	1.26	1.18	0.08	1.34	1.08	0.26	1.22	1.06	0.16	Gates
Bull 84B	1.20	1.11	0.09	1.21	1.10	0.25	1.28	1.15	0.13	Gates
B1	1.21	1.11	0.11	1.21	1.07	0.13	1.20	1.01	0.19	Gates
B2	1.25	1.21	0.05	1.25	1.04	0.22	1.23	1.01	0.22	Gates
Bull 84C	1.27	1.16	0.11	1.27	1.10	0.18	1.20	1.08	0.12	Gates
Bull 84E	1.06	0.97	0.08	1.02	0.89	0.13	1.05	0.93	0.11	Gates
E1	1.13	1.07	0.06	1.12	0.92	0.20	1.15	0.97	0.17	Gates
Quintette										
Mesa L	1.47	1.39	0.08	1.43	1.14	0.29	1.33	1.11	0.21	Gates
Q8202	1.48	1.35	0.12	1.45	1.20	0.24	1.44	1.17	0.28	Gates
Q8203	1.34	1.25	0.09	1.12	0.96	0.16	1.16	0.97	0.19	Gates
Q8204	1.58	1.51	0.07	1.55	1.29	0.26	1.51	1.22	0.29	Gates
Q8501	1.50	1.37	0.13	1.45	1.23	0.22	1.47	1.18	0.28	Gates
SQ108	1.48	1.35	0.13	1.39	1.15	0.24	1.43	1.25	0.18	Gates

(3) due to the plastic nature of coal, multiple vitrinite orientations may be present on a single section;
(4) only one vitrinite band is encountered on the bedding plane section and its values may not coincide with the mean values of the other sections.

Stone and Cook (1979), in an effort to overcome the problems associated with the bedding plane section, used four sections cut normal to bedding to calculate a bedding plane section of the indicating surface (CBPSIS). The results of their procedure were often non-elliptical shapes which may be due to the technique. In this study, all actual bedding plane sections had good elliptical reflectance distributions.

Examination of the average bireflectance value (difference between R_o max' and R_o min') on each section aids in interpreting the shape of the indicatrix. If the bedding clear section contained two equal reflectance axes, the bireflectance would be zero or very small due to random errors. Indeed this value, with a few exceptions, is much smaller on the bedding section than on the face or butt sections (Table 19-1). This suggests that the bedding section is quite close to the orientation of the a-b plane in most cases.

In addition to obtaining the reflectance values from each section, the orientations of the maximum apparent reflectance axis were determined. As noted in Table 19-1, all samples had some bireflectance on the bedding plane section. When the orientation of the maximum reflectance direction on the bedding section was compared to the cleat orientation, it was found to fall between the two cleat directions. In the few samples where the face and butt cleats were distinctly non-perpendicular, the maximum reflectance direction bisected the acute angle between the cleat traces.

The orientation of the maximum reflectance values from the bedding sections of two Burnt River samples, BR-U and BR-60, are parallel, with an azimuth of about 135 degrees. The maximum reflectance direction on the face cleats trends down slightly to the south, and the maximum reflectance direction on the butt section is parallel to bedding. These samples were collected from seams about 60 metres apart stratigraphically and about 400 metres apart laterally. The presence of similarly oriented indicatrixes which are not aligned parallel to bedding is a strong argument for syn or post-tectonic coalification in this area. When the reflectance values of the three sections of sample BR-U are plotted on an isometric block (Fig. 19-3), they are consistent with a biaxial indicatrix (Fig. 19-1b)

In samples with bedding plane bireflectances near those obtained from the sections normal to bedding, one of two explanations must be assumed given that the section is in fact oriented parallel to bedding:

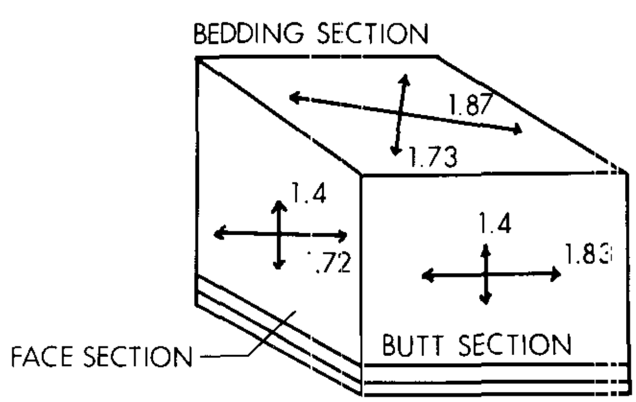

Figure 19-3. Schematic representation of the reflectance readings obtained from sample BR-U.

(1) If the bedding section maximum reflectance is similar to the maximum values from the other two sections, then the indicatrix is not aligned with bedding — a strong argument for post-tectonic coalification.

(2) If the maximum reflectances from the face and butt cleats fall between the maximum and minimum bedding reflectance values, the sample likely has a biaxial reflectance indicatrix.

A trend of undetermined significance is present between the Bullmoose and Quintette samples. The bedding section maximum from the Quintette samples is in all cases larger than the maximum values obtained on the other two sections. At Bullmoose the bedding plane maximum is, with two minor exceptions, equal to or less than the maximum values obtained from the face and butt cleat sections.

Oriented samples provide the means to determine the orientation of reflectance indicatrixes but are fraught with problems when trying to determine the absolute values of the indicatrix. The heterogenous nature of coal and the variability of vitrinite reflectance values all lead to data that is often difficult to interpret. Because of these problems and the additional sample collection and preparation requirements, it was desirable to develop a method of determining if a sample had a biaxial reflectance pattern from data obtainable from the standard particle samples.

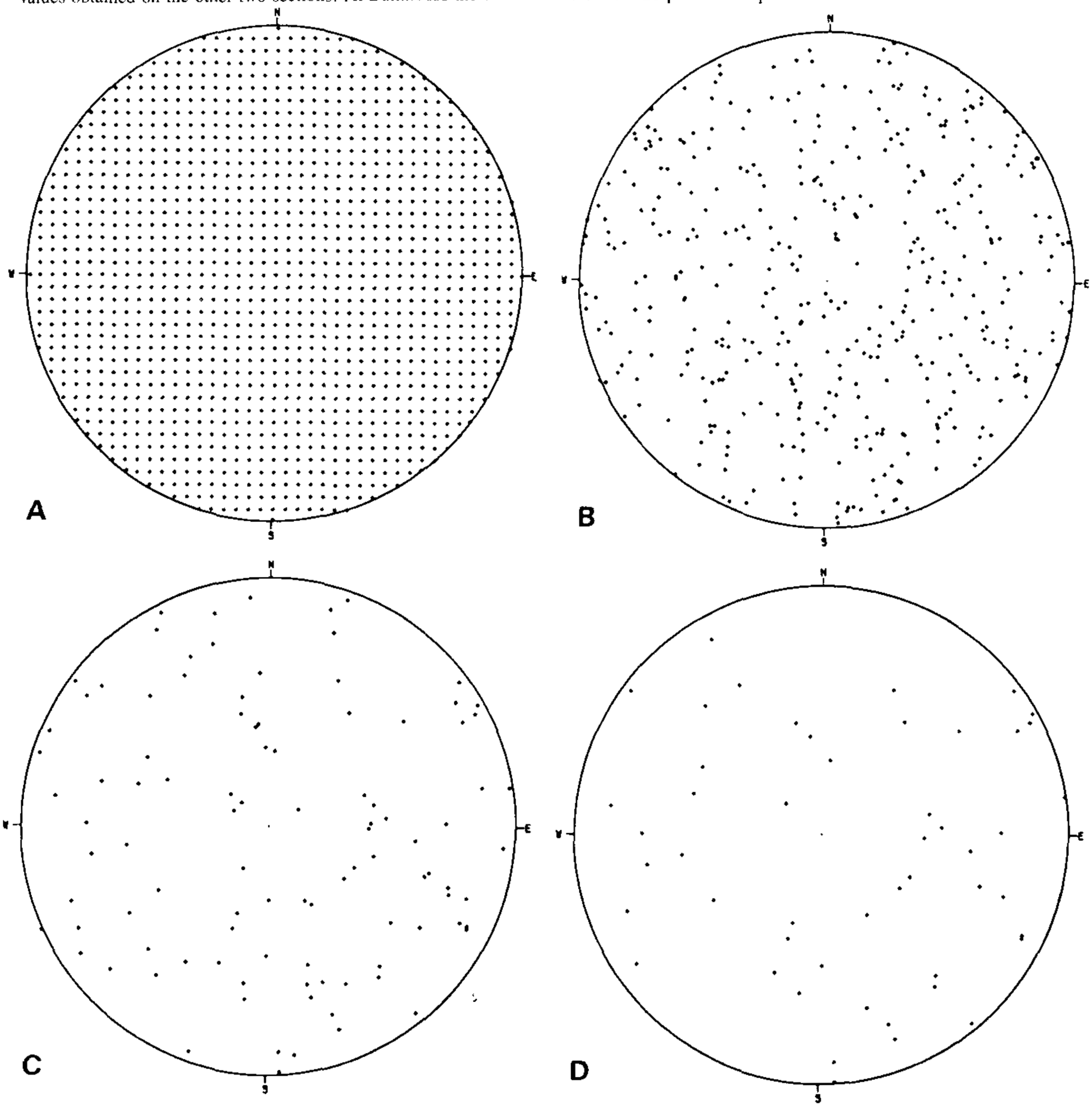

Figure 19-4. Equal area (Schmitt) projection of generated orientation data. (a) 1 257 evenly distributed orientations, (b) 500 random orientations, (c) 100 random orientations, (d) 50 random orientations.

THEORETICAL PARTICLE SAMPLE INVESTIGATION

To investigate various statistical and graphical techniques for their ability to discern biaxial coals from particle samples, test data was required. Particle samples consist of crushed coal (−20 mesh) held in a mounting medium of epoxy or plastic. One surface is polished and examined. This polished surface intersects many coal particles, each with no predefined orientation (random). Two computer programs were designed to simulate the results of this type of analysis on coal with different reflectance indicatrixes. RANDATA generated various sized populations of random orientations. These orientations represented the random orientations at which the polished surface of a mount would cut individual coal grains and thus the reflectance indicatrix. Four different sized populations are displayed on equal area projections on Figure 19-4. Hypothetical reflectance indicatrixes were simulated in the program BI-COAL. This program accessed the desired file of random orientations and calculated what the maximum and minimum reflectances would be on the sections corresponding to these orientation data. The reflectance values for the three axes were used to define the shape of the indicatrix, and a standard deviation value was entered to account for naturally occurring variance in measurements.

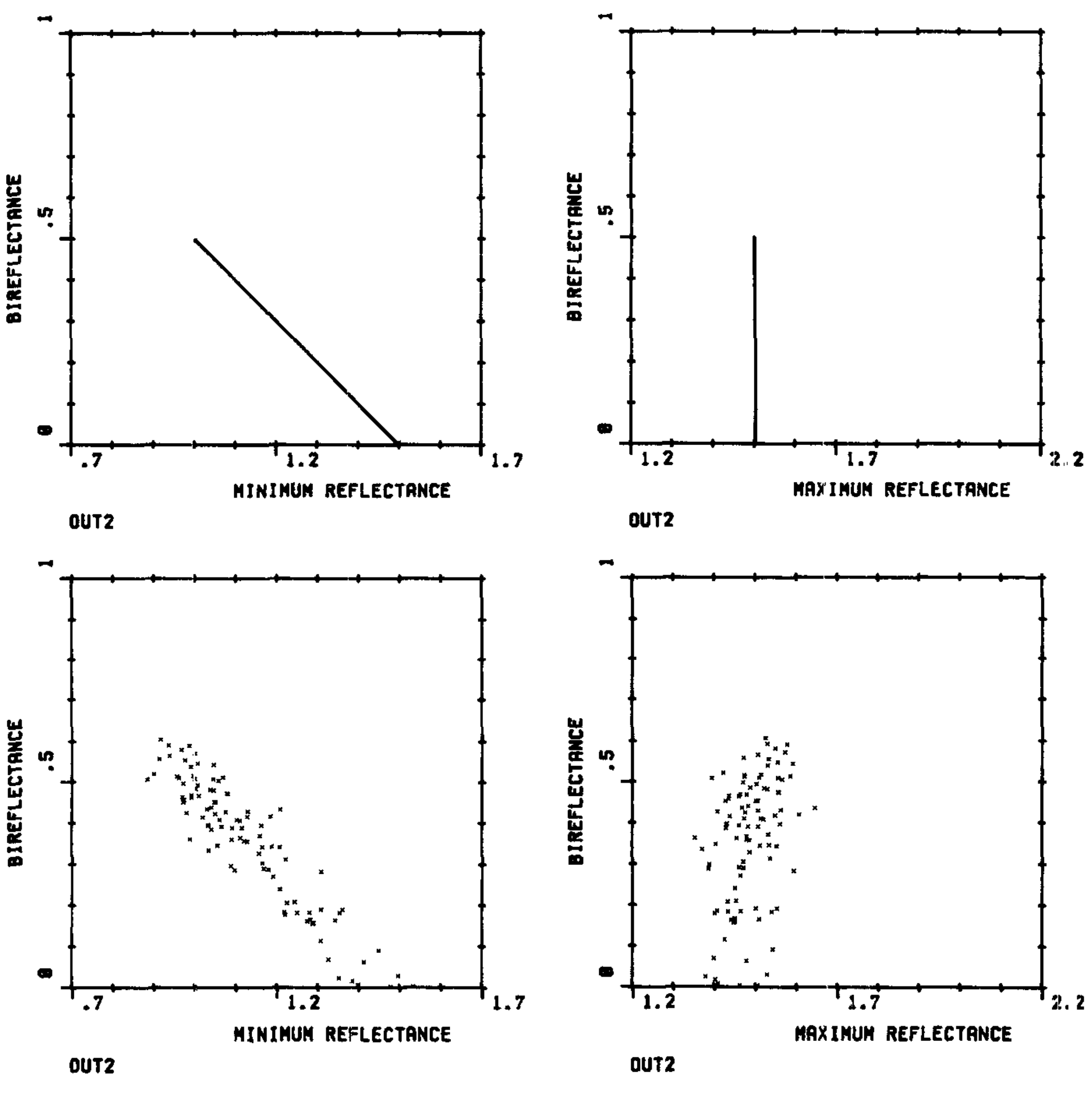

Figure 19-5. Uniaxial negative indicatrix reflectance data. a = 1.5%, b = 1.5%, c = 1%. (a) theoretical with no variance, (b) theoretical with 0.05% standard deviation and 100 random sections.

Histograms have traditionally been used to examine the maximum reflectance populations. Histograms produced by a variety of indicatrix shapes have some distinctive non-gaussian shapes but if large measurement variances are present these shapes are easily disguised. Cumulative frequency plots have often been used to check for normality of reflectance reading populations, but they were found to be difficult to interpret for biaxial populations. The best interpretation tool was a combination of two cross-plots (Figs. 19-5 and 19-6). These two plots have the bireflectance (R_o max'–R_o min') plotted on the abscissa, and the maximum and minimum reflectances plotted on the two ordinate axes. To insure clarity in this paper each sample is represented by these two plots. In practice the two data distributions would be posted on one cross-plot but with distinctive symbols so they could be visually separated.

Data from a uniaxial negative population would form a straight line on each plot (Fig. 19-5). On the R_o bi (bireflectance) versus R_o min' (minimum reflectance) plot, the line would have a negative slope and run from the R_o max value and zero bireflectance to the R_o min value and a bireflectance equal to R_o max–R_o min. The R_o bi versus R_o max' (maximum reflectance) plot has a vertical line with horizontal coordinate equal to R_o max and a vertical distribution from zero to the maximum possible bireflectance (R_o max–R_o min). In natural populations the data points would be normally scattered about these two lines. Figure 19-5b shows the effect of a standard deviation of 0.05 per cent reflectance.

Theoretical biaxial populations produce plots in which data points fall within zones defined by parallelograms rather than on discrete lines (Fig. 19-6). The horizontal dimension of the zones correspond to the possible range of values between the relevant reflectance axes, a-c difference for the R_o bi versus R_o min' plot and a-b difference for the R_o bi versus R_o max' plot. The vertical dimensions correspond to the difference between the previously mentioned axes. The parallelogram shaped zones which describe the data distribution in the two cross-plots are mutually dependent with regard to their dimensions. The two zones share a common boundary which represents the R_o int value. The diagonal edges of the zones must be at 45 degrees. The areas of the two zones must be equal. The upper bounding diagonal lines of each plot share a common x-intercept with the vertical non-common boundary of the other plot. Due to the ellipsoidal shape of the indicatrixes and the fact that not all sections will contain a maximum reflectance value, the data have higher probabilities of plotting in certain portions of the parallelograms. The combination of these two plots allows the values of the three reflectance axes to be accurately determined. The intermediate axis value is determined first, then the maximum and minimum values can be determined by utilizing two measurements. The absolute values of R_o max and R_o min can be read off the horizontal scales and cross-checked by the fact that the horizontal widths of the two zones at any bireflectance value must be equal.

Examination of the R_o bi versus R_o max' plot illustrates whether a population is uniaxial negative (the most common form). This plot would show a vertically oriented band of data points normally distributed about a central line (Fig. 19-5b). If the band of points has a slope, it is indicative of either a uniaxial positive or biaxial reflectance indicatrix; both situations are anomalous and deserve additional investigation. The R_o bi versus R_o max' plot from a biaxial negative indicatrix could be confused with a uniaxial negative figure depending upon the amount of random error and the R_o int–R_o max difference. But the two should be distinguishable by the form of the data distribution about a central vertical line. A uniaxial negative population will be concentrated at the centre, while a biaxial positive population will tend to be concentrated along the vertical edges and across the top (Figs. 19-5b and 19-6c).

Histograms of the maximum reflectance values obtained from the generated populations plotted on Figures 19-5 and 19-6 are given on Figure 19-7. The shapes of these histograms can be distinctive as in the case of the biaxial neutral and biaxial negative data but when random error is included many of the subtleties of the histogram shapes are destroyed. The cross-plot displays are affected to a much smaller extent (Fig. 19-8).

PARTICLE SAMPLES

Four particle samples from previous stratigraphic studies were selected for re-examination on the basis that their histogram patterns were either bimodal or had broad peaks, which suggested the presence of a biaxial reflectance indicatrix. A particle sample was also prepared for sample BR-U because oriented section work had shown it to be a biaxial reflecting coal.

Fifty vitrinite particles were examined for each sample with R_o max' and R_o min' values being recorded. Histograms and the two cross-plots (R_o bi versus R_o min' and R_o bi versus R_o max') were prepared and interpreted (Fig. 19-9).

Interpretation of the cross-plots for sample BR-U duplicated the results previously obtained by the oriented section technique. The sample is biaxial negative with a reflectance indicatrix having the following dimensions: a = 1.70 per cent, b = 1.89 per cent, c = 1.35 per cent. The histogram from this sample is obviously bimodal.

Sample C83-62 had a well-defined, bell-shaped histogram pattern of R_o max' values but the cross-plots show distinctly that the sample is biaxial positive (Fig. 19-9b). Determined reflectance axes values for this sample are: a = 1.51 per cent, b = 1.70 per cent, c = 1.41 per cent.

Sample C83-115 produced a histogram distribution of R_o max' values which had a very wide peak (Fig. 19-9c). The R_o bi versus R_o max' cross-plot had a distribution pattern best described by a positively sloping zone and was thus not uniaxial negative. A small maximum bireflectance of 0.2 per cent made interpretation of this sample difficult. The R_o bi versus R_o min' plot could be interpreted as scatter about a vertical line at 1.35 per cent R_o min'. This would mean a uniaxial positive indicatrix with dimensions: a = 1.17 per cent, b = 1.37 per cent, c = 1.17 per cent. The author prefers the biaxial positive interpretation with indicatrix dimensions of a = 1.25 per cent, b = 1.35 per cent, c = 1.16 per cent.

Sample C83-183 has a broad poorly peaked histogram shape (Fig. 19-9). The cross-plots suggest a biaxial negative reflectance indicatrix with axis dimension of a = 1.68 per cent, b = 1.90 per cent, c = 1.40 per cent.

Sample C83-271 had a well-peaked, bell-shaped R_o max' distribution (Fig. 19-9e). The cross-plots show the sample to be biaxial negative with reflectance axes dimensions of a = 1.32 per cent, b = 1.42 per cent, c = 1.20 per cent.

All five particle samples examined were prepared from single piece grab samples or chip samples representative of thin seams. The four samples with identifier prefixes of C83- were from borehole core samples. This method may produce difficult to interpret results if used with samples representing large seams due to potential reflectance variance between vitrain bands through the seam which could cause a scatter of readings greater than the inter-axis values.

CONCLUSIONS

This preliminary study documents the existence of medium and low-volatile bituminous coals with biaxial reflectance indicatrixes in the Peace River Coalfield. A technique was developed to accurately determine the character and dimension of reflectance indicatrixes from standard particle samples.

Significant problems were realized in trying to calculate indicatrix dimensions from oriented sections but the oriented section method does provide excellent information regarding the orientation of the indicatrix. A combination of the two methods used here provides an excellent description of the reflectance indicatrix characteristics. The coal particle examination technique described here provides a rapid and accurate technique for identifying and quantifying the reflectance character of biaxial coals.

Future work will concentrate on documenting the biaxial reflecting coals and their use in interpreting the structural and thermal histories of coal deposits.

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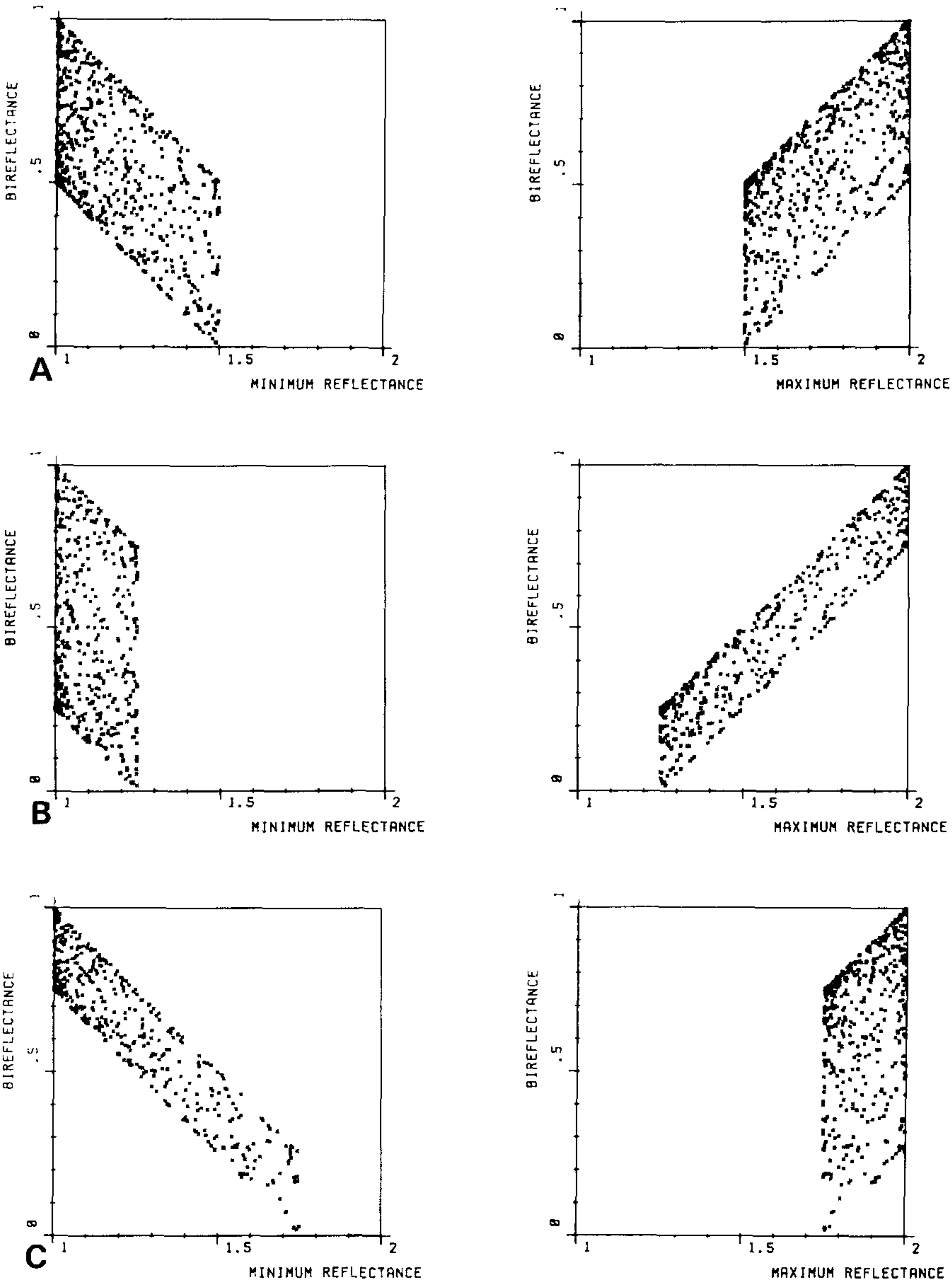

Figure 19-6. Cross-plot displays of three reflectance indicatrixes generated with randomly oriented data populations of 500 points. (a) a = 1.5, b = 2, c = 1, biaxial, standard deviation = 0; (b) a = 1.25, b = 2, c = 1, biaxial (+), standard deviation = 0; (c) a = 1.75, b = 2, c = 1, biaxial (−), standard deviation = 0.

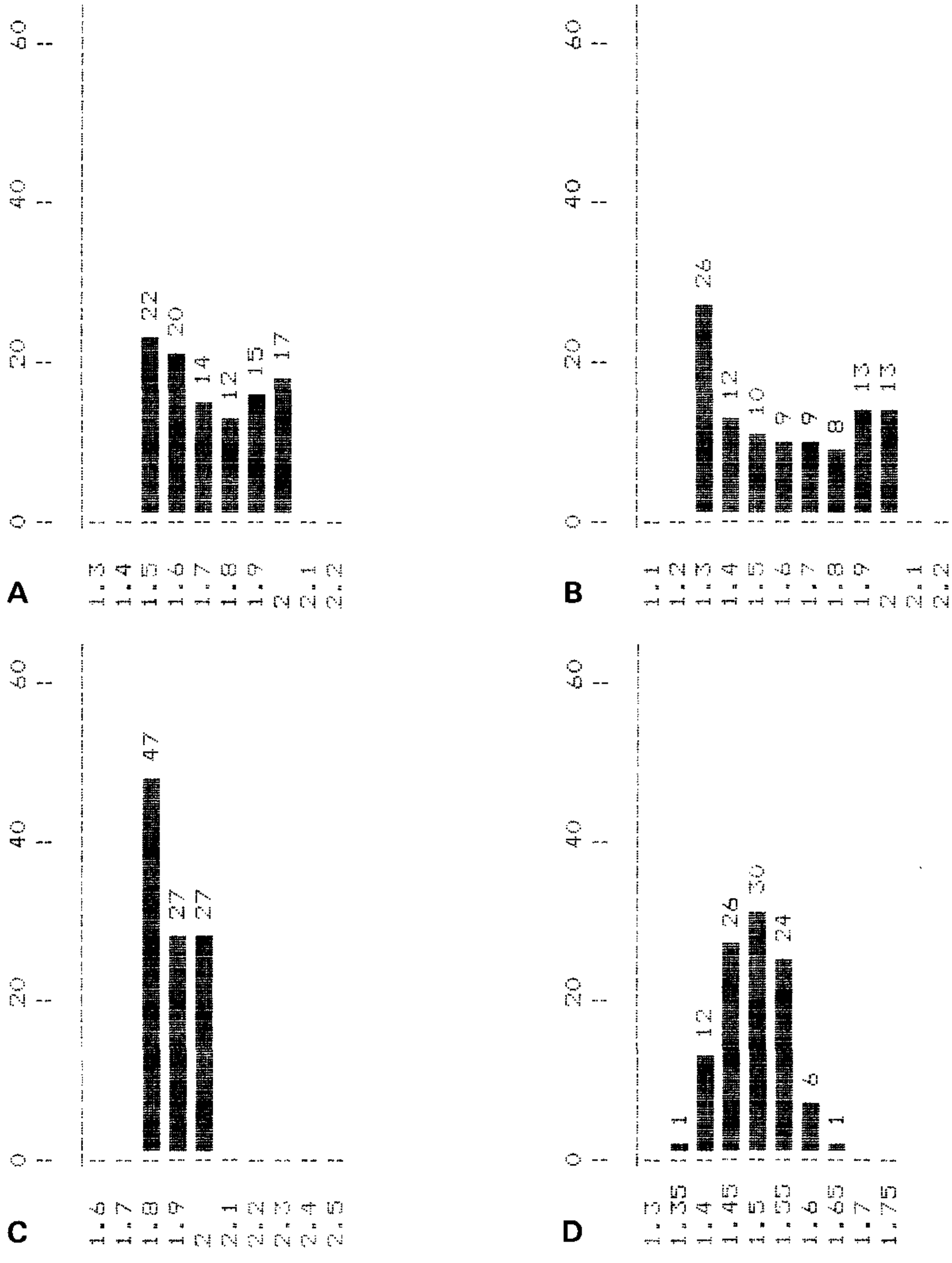

Figure 19-7. Histograms of generated data. (a) a = 1.5, b = 2, c = 1, biaxial, standard deviation = 0, 500 points; (b) a = 1.25, b = 2, c = 1, biaxial (+), standard deviation = 0, 500 points; (c) a = 1.75, b = 2, c = 1, biaxial (−), standard deviation = 0, 500 points; (d) a = 1.5, b = 1.5, c = 1, unaxial (−), standard deviation = 0.05%, 100 points.

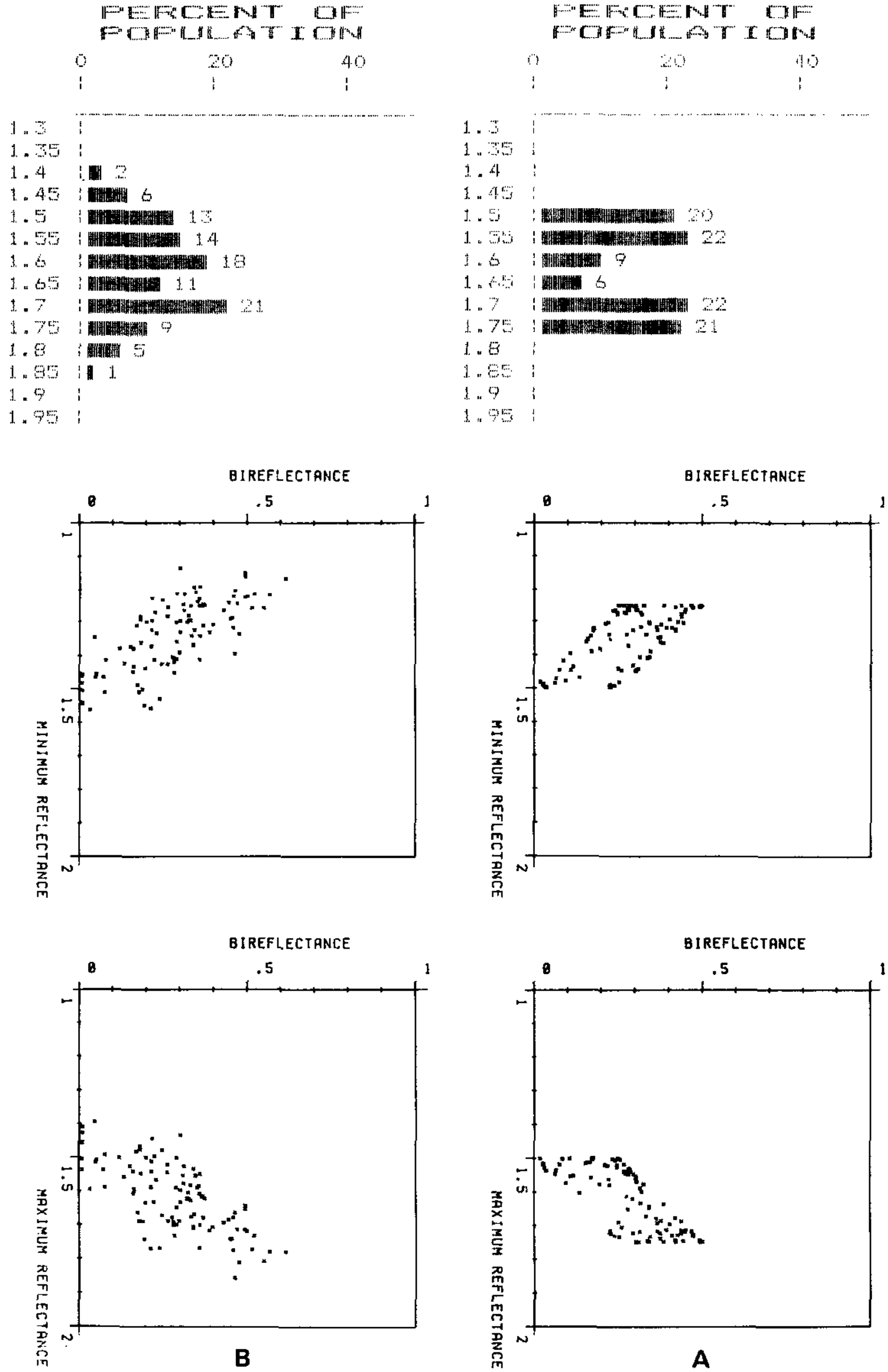

Figure 19-8. Histograms and cross-plots for biaxial reflectance distribution (a = 1.5, b = 1.75, c = 1.25). One with no variance (a) and the other with 0.05% standard deviation (b).

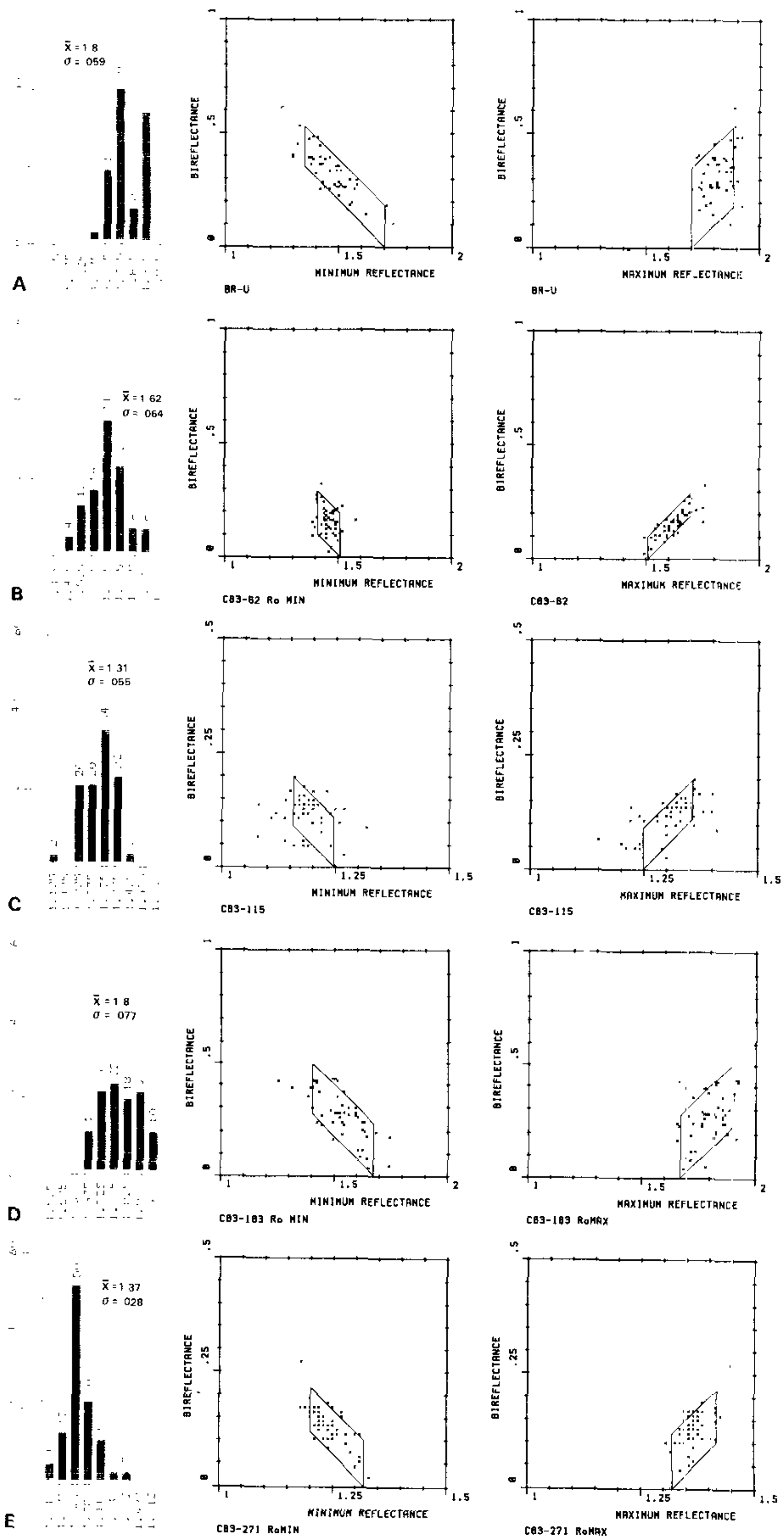

Figure 19-9. Histograms and cross-plots of particle samples. (a) BR-U, (b) C83-62, (c) C83-115, (d) C83-183, (e) C83-271.

SOME CHEMICAL AND MINERALOGICAL CHARACTERISTICS OF TONSTEINS AND BENTONITES IN NORTHEAST BRITISH COLUMBIA (93O, P, I; 94A)

By W. E. Kilby

INTRODUCTION

Tonsteins and bentonites were first reported from the Peace River Coalfield by Duff and Gilchrist (1983) who demonstrated that these altered volcanic ash bands were laterally continuous. Tonsteins have been used successfully for stratigraphic correlation in several regions of the world, most notably the Westphalian coal measures of western Europe and Britain, because they are deposited so rapidly that they are essentially 'time lines.' It was for the purpose of regional and local correlation that the current tonstein and bentonite study was initiated by the Ministry in 1983. To date some 460 samples have been collected of which 416 have been analysed by X-ray diffraction and 101 chemically. These samples were collected from coal-bearing and contiguous formations of the coalfield. Previous articles have discussed outcrop and thin-section characteristics (Kilby, 1984a) and local to regional correlations based on stratigraphic position and geophysical log signature (Kilby, 1985).

This paper focuses on the chemical and mineralogical characteristics of these ash bands. A method of digitally representing and utilizing X-ray diffractogram data for mineral and chemical quantification has been developed and is presented here. It is essential to gain a firm understanding of these characteristics if any meaningful correlation techniques based on mineral or chemical parameters are to be developed. Tonsteins and bentonites are mineralogically different but have, in some instances, originated from the same ash fall (Kilby, 1984a). Tonsteins are kaolinite rich and occur in or near coal seams, whereas bentonites are smectite rich and associated with marine strata. Late diagenic or tectonic carbonatization has complicated the chemical and mineralogical characteristics of some samples.

Studies this past field season focused on extending the area over which the Fisher Creek tonstein zone could be correlated. Legun (pers. comm.) discovered a surface showing of this zone along Gaylard Creek about 10 kilometres west of the W.A.C. Bennett Dam; the zone was about 20 metres below the Moosebar Formation at this location. A similar tonstein zone was found along the south side of the Murray River about 4 kilometres west of the Quintette plant site. Identification of the stratigraphic interval thought to contain the tonstein zone in this area was made on geophysical logs from rotary borehole QBR-8118 which led to its location in surface exposure. Core searches yielded several occurrences of tonsteins at the suspected stratigraphic horizon from holes on the Monkman property. Proving that these are the Fisher Creek tonstein zone would establish a lateral correlation of approximately 160 kilometres. Isochronous marker horizons on this scale provide an excellent framework on which to base coal rank, stratigraphic, and microfossil studies.

CHEMISTRY

Forty-three new tonstein and bentonite chemical analyses were received during 1985, and P_2O_5 values for 17 of the samples reported in Kilby (1985). Table 20-1 contains the results for all 43 new samples and the other 17 samples for which new information became available. Figure 20-1 shows the correlation matrix of 13

SiO_2	Al_2O_3	Fe_2O_3	MgO	CAO	Na_2O	K_2O	TiO_2	MnO	P_2O_5	Rb	Sr	Zr	
0	.387	-.625	-.797	-.797	.223	.195	.319	-.32	-.416	.065	-.223	-.127	SiO_2
0	0	-.478	-.735	-.69	-.378	-.297	.29	-.216	-.041	-.165	-.262	.132	
0	0	0	.358	.3	-.067	-.038	-.283	.426	.162	.031	.046	.158	•
0	0	0	0	.974	.083	-.03	-.3	.206	.26	-.016	.311	-.081	
0	0	0	0	0	-.003	-.086	-.278	.161	.358	-.062	.346	-.076	
0	0	0	0	0	0	.362	-.19	.075	-.341	.242	.014	-.029	
0	0	0	0	0	0	0	-.399	0	-.342	.745	-.022	.047	•
0	0	0	0	0	0	0	0	-.103	-.049	-.515	-.029	-.113	
0	0	0	0	0	0	0	0	0	-.015	.087	0	.01	
0	0	0	0	0	0	0	0	0	0	-.247	.415	.126	
0	0	0	0	0	0	0	0	0	0	0	.055	.273	•
0	0	0	0	0	0	0	0	0	0	0	0	-.087	
0	0	0	0	0	0	0	0	0	0	0	0	0	Zr

Figure 20-1. Chemical correlation matrix for 13 elements determined for 101 samples.

British Columbia Ministry of Energy, Mines and Petroleum Resources, Geological Fieldwork, 1985, Paper 1986-1.

TABLE 20-1. CHEMICAL ANALYSES OF TONSTEINS AND BENTONITES, PEACE RIVER COALFIELD

SAMPLE	FORMATION	SIO2	AL2O3	FE2O3	MGO	CAO	NA2O	K2O	TIO2	MNO	P2O5	Rb	Sr	Zr
R83-2	GETH	45.82	35.65	.1	.07	.28	.08	.08	.45	<.003	.13	10	15	270
R83-3	GETH	43.24	36.48	.15	<.06	.91	.09	.24	.84	<.003	.38	10	27	138
R83-5	GETH	39.71	26.71	16.07	.26	.35	.16	.27	.59	.085	.08	<10	32	185
R83-6	GETH	36.75	26.19	4.51	2.93	7.83	.06	.38	.6	.031	.51	14	320	160
R83-7	GETH	38.44	25.26	16.55	.16	.08	.1	.27	.68	.038	.27	15	27	185
R83-8	GETH	48.53	34.1	.74	.16	.32	.38	.77	1.27	.004	.04	15	30	312
R83-9	GETH	49.8	33.31	.78	.1	.37	.06	.54	.85	.006	.33	13	33	152
R83-10	GETH	51.07	33.41	.12	.07	.13	.06	1.08	1.07	<.003	.04	13	22	312
R83-11	GETH	45.77	29.93	8.36	.18	.27	.08	.35	.82	.058	.34	15	32	200
R83-13	GETH	49.3	33.72	.26	.1	.45	.04	.37	.68	<.003	.31	10	95	200
R83-14	GETH	45.01	31.34	7.54	.2	.28	.04	.34	.85	.4	.1	13	21	223
R83-15	GETH	48.23	35.25	.36	.07	.64	.06	.38	.83	.004	.37	10	30	138
R83-20	GETH	46.14	32.48	3.58	.2	.79	.06	.28	1.01	.028	.42	11	100	152
R83-24	GETH	37.05	24.8	4.75	3.6	6.25	.2	.28	.83	.041	.27	15	63	132
R83-25	GETH	51.7	27.91	1.44	.79	1.08	.33	2.64	.62	.007	.01	32	100	127
R83-26	GETH	50.18	24.78	2.58	.81	1.37	.64	1.24	.68	.009	.02	31	132	177
R83-27	GETH	47.41	30.36	8.52	.24	.26	.08	.35	.83	.061	.03	14	45	135
R83-33	GETH	45.23	35.29	.24	.07	.33	.024	.265	1.05	.003	.16	12	30	200
R83-35	GETH	47.28	32.62	2.77	.7	.76	.008	.083	.9	.015	.45	11	70	233
R83-38	GETH	44.15	30.46	8.45	.16	.26	.016	.341	.81	.050	.19	5	20	208
R83-39	GETH	45.2	31.56	6.9	.1	.46	.022	.229	.79	.047	.4	21	40	224
R83-43	GETH	49.0	32.7	.95	.12	.31	.185	1.165	1.13	.005	.29	22	130	235
R83-44	GETH	47.18	33.39	.64	.15	.35	.128	.682	1.02	.003	.21	19	110	223
R83-45	GETH	50.36	32.95	1.06	.05	.11	.044	.105	.77	.004	.05	2	70	216
R83-46	GETH	46.4	32.93	3.77	.25	.78	.034	.197	1.1	.029	.49	12	120	271
R83-52	GETH	47.39	33.21	.61	.12	.08	.054	.635	.87	<.002	.02	33	120	275
R83-58	GETH	53.98	26.63	2.65	.19	.88	1.432	.803	.696	.025	.2	32	20	194
R83-60	GETH	50.26	31.46	2.47	.12	.21	.202	2.26	1.01	.021	.04	32	40	230
R83-64	GETH	50.87	29.78	1.95	.14	.21	.182	2.27	1.02	.012	.07	39	30	244
R83-65	GETH	44.29	33.76	8.0	<.03	<.07	.209	.086	1.46	.003	.02	5	<10	237
R83-69	GETH	47.51	32.85	1.21	.19	.08	.277	.840	.92	.006	.02	39	<10	279
R83-71	GETH	48.26	33.54	.37	.05	.34	.037	.16	1.05	<.002	.24	<15	30	249
R83-73	MOOS	44.46	32.73	2.87	.6	.34	.292	1.89	.213	.002	.04	51	190	163
R83-74	MOOS	45.37	31.99	2.91	.75	.41	.168	2.42	.425	.095	.09	60	160	376
R83-75	MOOS	45.56	33.39	1.93	.59	.31	.124	1.72	.17	.04	.01	38	110	196
R83-76	MOOS	46.57	29.53	4.42	.87	.47	.117	2.27	.488	.121	.11	75	270	282
R83-80	GETH	46.0	32.51	.96	.07	.11	.186	.175	.552	.006	.02	<15	20	223
R83-83	GETH	48.18	27.22	1.53	.97	1.78	.543	.558	.87	.013	.07	13	120	184
R83-84	GETH	48.69	30.82	1.33	.17	.15	.035	.184	.677	.009	.04	<15	20	195
R83-89	GETH	51.8	32.74	.2	.05	.56	.02	.214	.435	<.002	.45	18	70	230
R83-90	GETH	54.36	19.02	3.12	1.59	4.72	.311	2.56	.495	.02	.22	72	210	119
R83-94	GETH	48.39	32.13	.62	.23	.27	.128	.587	1.12	.005	.07	23	30	272
R83-97	GETH	48.77	33.61	.47	.06	.59	.015	.136	1.1	.002	.5	<15	125	224
R83-98	GETH	49.22	33.22	.54	.09	.1	.031	.195	1.0	<.002	.09	2	80	252
R83-105	GETH	32.62	23.62	16.92	2.79	.9	.123	.170	.89	.141	.08	13	30	247
R83-108	GETH	46.6	33.19	.94	.47	.88	.112	.389	1.1	.007	.11	6	40	265
R83-109	GETH	48.56	33.71	.62	.14	.81	.028	.258	1.15	.004	.49	4	150	268
R83-114	GETH	44.44	35.9	.26	.07	<.04	.06	.18	1.09	<.004	.03	<15	20	243
R83-115	GETH	46.11	36.1	.17	.06	.15	.19	.08	.94	<.004	.08	4	20	207
R83-121	MOOS	18.03	9.4	6.83	10.26	21.36	.21	.45	.28	.056	.27	25	250	67
R83-122	MOOS	29.74	23.32	4.87	5.19	11.83	.12	.26	.56	.020	.57	24	450	164
R83-134	GETH	36.42	25.24	5.24	3.75	6.55	.17	.25	.97	.047	.24	13	120	162
R83-151	MOOS	48.65	30.12	2.72	1.17	1.58	.73	2.83	.4	.079	.08	71	340	360
R83-156	MOOS	47.92	34.71	1.47	.6	.25	.63	1.72	.18	.02	.06	59	370	186
R83-159	BLUE	35.0	22.2	18.42	.62	.1	.54	2.02	.27	<.003	<.02	29	150	561
R83-174	GETH	49.04	31.72	1.06	.14	.13	.07	1.02	.84	.008	.05	8	25	218
R83-194	MOOS	47.42	29.33	4.67	1.23	.42	.94	2.89	.2	.013	.02	79	120	329
R83-205	GETH	48.02	34.74	.36	.08	.37	<.03	.12	.98	<.004	.26	<15	65	238
R83-207	MOOS	45.99	30.87	2.04	.83	2.45	1.11	3.32	.47	.015	.06	81	180	545
R83-208	MOOS	46.84	34.5	1.0	.53	.21	.98	1.97	.17	<.003	.03	41	140	195

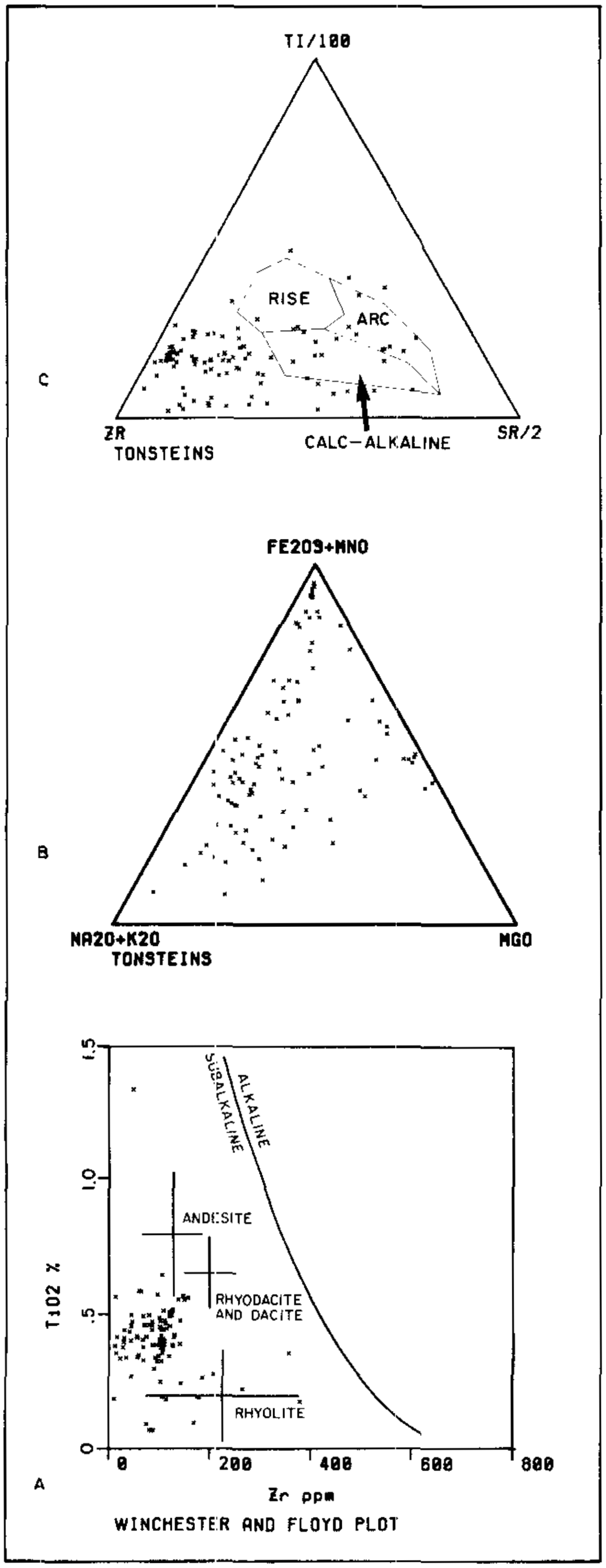

Figure 20-2. Diagnostic plots of chemical values. (a) AFM diagram. (b) Zr:Ti:Sr diagram. (c) TiO_2:Zr diagram.

elements from the total population of 101 samples analysed to date. There are no significant differences between this matrix and the one reported in Kilby (1985). A significant value in this matrix would have a correlation value greater than 0.26 or less than −0.26 at the 99 per cent confidence level. A series of plots were prepared from the chemical data in an attempt to predict the general original composition of these rocks and to determine the presence of any natural groupings (Fig. 20-2). The Ti:Zr plot suggests an original composition in the rhyolite to andesite range. The ternary plot of Ti:Zr:Sr shows the majority of the strata falling outside common zones. This may suggest a general depletion of Sr. If strontium were added to the samples, the majority would fall in the calc-alkaline zone. Strontium tends to substitute for calcium due to similar ionic size and charge. It will be shown following that ankerite contains a significant portion of the total strontium. It is felt that strontium was mobile and tended to be lost from the original minerals although some was retained in the post-deposition mineral ankerite.

The AFM diagram shows widely scattered data. This scatter is due in part to the late introduction of MgO in the form of ankerite (discussion following).

Early attempts at correlation based on chemical values proved encouraging on a local scale (Kilby, 1985). For regional correlations it is important to consider only the elements or ratios of elements that are not affected by diagenesis. It was suggested (Kilby, 1985) that calcium and magnesium in the form of ankerite had been introduced in a significant number of the samples. It is felt that although these elements and strontium were useful in local correlations where similar burial histories could account for their introduction, their effects should be removed before any regional correlations are attempted.

The resources required to chemically analyse all samples collected in this study could not be justified. Consequently an X-ray diffraction procedure was devised as an alternative, more cost-effective comparison method.

X-RAY MINERALOGY

X-ray diffraction analysis was performed on all samples collected during this study. Mineral identification and relative abundances were determined by J. Kwong in the Ministry Laboratory. To quantify the X-ray diffractogram chart information for comparative purposes a system was developed to digitally record the curve shapes and store this information for subsequent analysis. Digitization of X-ray diffractograms provides the facility to compare the shapes of the diffractogram curves and compare peak intensities for specific minerals, enabling prediction of chemical composition.

X-RAY DIFFRACTOGRAM DIGITIZING

Kilby (1985) pointed out the visual similarities of X-ray diffractogram curves for samples which had been correlated by both chemical and geophysical means. The first step in utilizing these diffractograms quantitatively was to digitize the curves by means of a digitizing tablet connected to an IBM XT microcomputer. Program CURV-DIG (Kilby, 1984b) was used to collect the digital data. The diffractogram was digitized between the interval 5 to 40 degrees 2θ (Cu kα; Fig. 20-3a). The chart tracing was followed with the digitizer stylus and data points were recorded at 0.127-centimetre spacings along the trace. Typically 1100 to 1200 coordinate pairs were collected for each curve. This raw data was then reduced and standardized with the program CURV-RED (Kilby, 1984b). CURV-RED aligned each curve about the quartz peak at 26.6 degrees 2θ and calculated the height in millimetres of the curve at 0.1 degree 2θ intervals for the 345 points between 5.1 and 39.5 degrees 2θ (Fig. 20-3b). These reduced data were stored in Data Handler format to be accessed by the analysis programs of the Cal Data Geological Analysis package. The reduced data were then used to plot a curve at the same scale as the original for verification. Any deviations

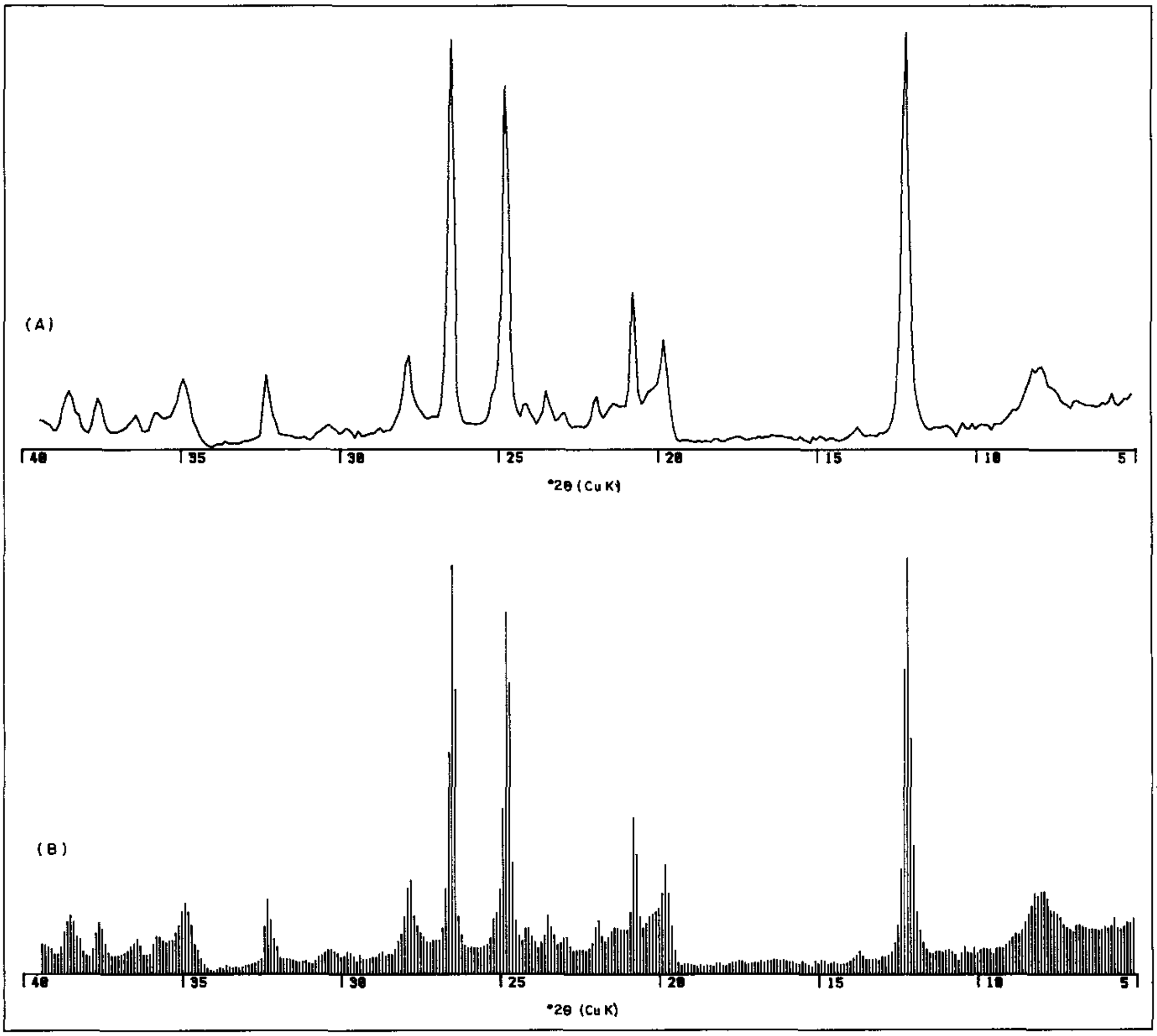

Figure 20-3. (a) Example of an X-ray diffractogram. (b) Positions and heights of points saved for each curve. Heights range from 0 to 2 500 millimetres.

between the two curves were easily identified by overlaying them. Corrections were made to the pertinent data point with the editor of the Data Handler.

The X-ray diffractogram was divided into 17 zones of 0.4 degree 2θ width which corresponded to prominent peaks on the curve which represent common tonstein and bentonite minerals (Table 20-2); each zone, therefore, is treated as a 'pseudomineral.' The total of the four curve point heights above background within these zones were used to quantify the abundance of the pseudominerals. Background was defined by two straight lines; one running from the curve height at 10 degrees 2θ to 15 degrees 2θ, the other from 15 degrees 2θ to 34 degrees 2θ. The absolute values of the areas under the portion of the curve assigned to each pseudomineral do not directly correspond to the abundances of real minerals because of varying absorption coefficients and other factors. The pseudomineral zones do, however, provide a means of examining relative changes in mineral abundances.

A variety of correlation procedures are possible with the pseudomineral data but present work is concentrating on determining which pseudominerals or which portions of the X-ray diffractogram are most diagnostic for a variety of purposes such as: *regional correlation, identifying secondary carbonatization, identifying* secondary silicification, distinguishing weathered samples, and tonstein and bentonite differentiation.

PSEUDOMINERAL EXAMINATION

An initial examination employing the pseudomineral method was carried out on the 101 chemically analysed samples. Figure 20-4 displays the correlation matrix for the 17 pseudominerals. Any correlation coefficient greater than 0.26 or less than −0.26 is significant at the 99 per cent confidence level. High correlation coefficients between adjacent pseudomineral zones are suspect and likely due to overlapping of peaks or wide peaks sampled by two pseudomineral zones. The usefulness of correlation coefficients is

TABLE 20-2
PSEUDOMINERALS FOR TONSTEINS AND BENTONITES, PEACE RIVER COALFIELD

Pseudomineral	Degree 2θ (Cu kα)
Goethite	33.1 – 33.4
Pyrite	32.8 – 33.1
Siderite	31.9 – 32.2
Ankerite	30.7 – 31.0
Calcite	29.3 – 29.6
Barite	28.6 – 28.9
Feldspar	27.7 – 28.0
Quartz	26.4 – 26.7
Septechlorite	18.5 – 18.8
Gorceixite	15.3 – 15.6
Harmotome	13.6 – 13.9
Kaolinite	12.1 – 12.4
Gypsum	11.4 – 11.7
Illite	8.6 – 8.9
Montmorillonitic mixed-layer clay	7.9 – 8.2
Illitic mixed-layer clay	7.4 – 7.7
Chlorite	5.6 – 5.9

not affected by the fact that the pseudomineral values do not represent true mineral abundances — so long as the zones reasonably represent specific minerals, the correlation coefficients will be similar to the values obtained for true mineral quantitites.

Several pseudomineral abundance relationships are apparent from the correlation matrix tabulation. The diffractogram results for the pseudomineral goethite correlates strongly with those for pyrite and ankerite. This suggests an alteration of pyrite to goethite, however, the diagnostic X-ray peaks for these minerals are close together, and may overlap to some extent, causing spuriously high correlation values. The ankerite-goethite peaks are well separated so the high correlation is real and due to the introduction of secondary carbonate (discussed later). Siderite does not significantly correlate with any other pseudomineral. Ankerite has a strong positive correlation with goethite, discussed previously, and a signficant negative correlation with kaolinite. Calcite and barite are strongly correlated but this may be due to the closeness of the peaks. Calcite has strong positive correlations with illite and the mixed-clay minerals but a strong negative correlation with kaolinite. This suggests that the presence of calcite is related to the same processes which lead to formation of smectite-rich bentonites rather than kaolinite-rich tonsteins. The marine affinity of bentonites is consistent with the presence of calcite in this type of alteration. Feldspar has strong positive correlations with the mixed-layer clays and a negative correlation with kaolinite. Kaolinization strongly affects feldspar while the processes that create smectite clays appear to affect it less. Feldspar and harmotome have a strong correlation but this is likely due to the fact that some feldspars have secondary peaks which coincide with the harmotome zone. Quartz has significant positive correlations with feldspar and illite. Quartz and feldspar peaks are well separated so their correlation is significant. The correlation with illite suggests that silica is released during diagenesis as smectite is converted to illite. Septechlorite and gorceixite are not positively or negatively correlated with any of the other pseudominerals. Kaolinite has a strong correlation with gypsum but this is almost certainly due to the proximity of the two diffraction peaks. Kaolinite displays strong negative correlations with the minerals that characterize bentonites—illite, montmorillonitic mixed-layer clay, illitic mixed-layer clay, and chlorite. Kaolinite also has strong negative correlations with calcite, ankerite, and goethite. Gypsum has negative correlations with virtually all of the pseudominerals except kaolinite, as discussed previously. Field examination of some gypsum-rich samples revealed gypsum rosettes on fracture surfaces.

Illite has three previously discussed positive correlations — with calcite, barite, and quartz. In addition it has strong positive correlations with the mixed-layer clays. Illite commonly forms from the collapse of interlayer spaces in mixed-layer clays; thus the more smectite the more potential for illite formation. Montmorillonitic mixed-layer clay has a very high correlation with illitic mixed-layer clay which is in part due to the broadness and nearness of their respective peaks. Chlorite has strong negative correlations with kaolinite and gypsum.

Several significant trends in mineralogy are indicated by the correlation matrix. Ankerite and goethite exist in samples at the expense of all other minerals, which suggests they formed later. Siderite is unrelated to all other minerals and is likely a weathering product. Calcite and barite are strongly correlated and preferentially concentrated in the environment which produces illite and smectite. Feldspar, which is believed to be primary, survives in the bentonite-producing environment but is altered to kaolinite in the tonstein-producing environment. Quartz content is closely correlated with feldspar; it also is likely predominantly primary; however, a strong

GEOTHITE	PYRITE	SIDERITE	ANKERITE	CALCITE	BARITE	FELDSPAR	QUARTZ	SEPTOCHLORITE	GORCEIXITE	HARMOTOME	KAOLINITE	GYPSUM	ILLITE	MONT. M/C	ILLITIC M/C	CHLORITE	
0	.673	-.091	.5	.148	.047	-.252	-.132	-.115	-.05	-.151	-.354	-.279	.196	0	-.064	-.055	Geothite
0	0	-.023	.012	.05	.17	-.077	-.105	-.069	-.094	-.099	-.195	-.101	0	.051	.05	-.055	
0	0	0	-.042	-.022	0	-.01	-.117	-.079	.068	-.074	.054	-.039	-.054	.102	0	-.134	
0	0	0	0	.122	-.313	-.129	-.168	-.161	-.014	-.093	-.357	-.329	-.039	-.068	-.116	-.056	
0	0	0	0	0	.474	.147	.089	0	-.065	-.081	-.48	-.27	.345	.471	.304	.089	•
0	0	0	0	0	0	.275	.232	.252	-.026	-.044	-.243	.062	.518	.6	.481	.078	
0	0	0	0	0	0	0	.272	.059	0	.556	-.212	-.114	.112	.5	.472	.106	
0	0	0	0	0	0	0	0	-.014	-.033	.142	-.012	-.015	.275	.078	-.003	-.079	
0	0	0	0	0	0	0	0	0	.101	.073	.003	.224	.046	.064	.055	0	•
0	0	0	0	0	0	0	0	0	0	.244	.121	.147	-.151	-.143	-.193	-.204	
0	0	0	0	0	0	0	0	0	0	0	.094	.038	-.07[illegible]	.065	.135	.106	
0	0	0	0	0	0	0	0	0	0	0	0	.704	-.302	-.527	-.543	-.41	
0	0	0	0	0	0	0	0	0	0	0	0	0	-.198	-.314	-.374	-.409	•
0	0	0	0	0	0	0	0	0	0	0	0	0	0	.435	.309	.243	
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	.811	.396	
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	.681	
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	Chlorite

Figure 20-4. Correlation matrix of 17 pseudominerals calculated for 101 samples.

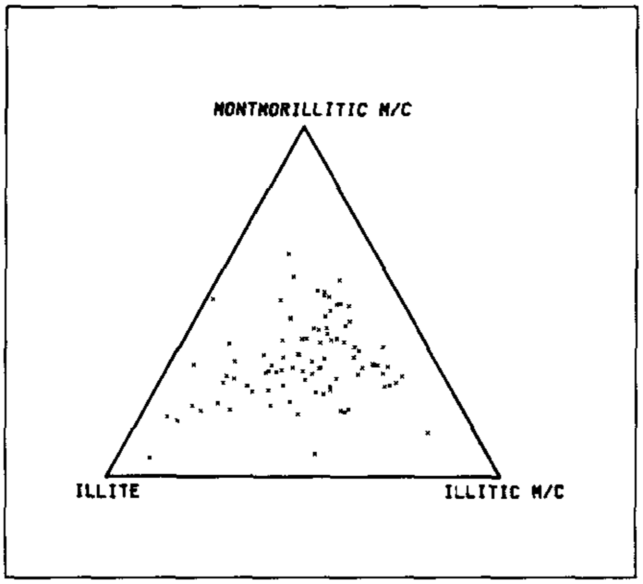

Figure 20-5. Ternary plot showing the relationship between the pseudominerals illite, montmorillonitic mixed-layer clay, and illitic mixed-layer clay.

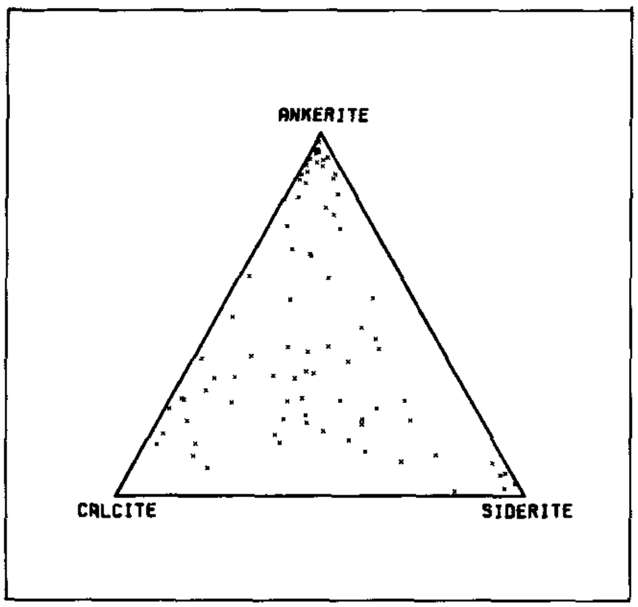

Figure 20-6. Ternary plot of the relative quantities of the major carbonate pseudominerals.

positive correlation with illite suggests some is secondary. Kaolinite, which characterizes tonsteins, apparently replaces all other minerals. Illite, chlorite, and the mixed-layer clays correlate in a similar manner to virtually all other minerals; these clay minerals characterize bentonites.

The ternary plot of illite and the two mixed-layer clays (Fig. 20-5) shows a relatively constant ratio (1:1 ±) between the mixed-layer clays as the illite content varies. The ternary plot of the carbonate minerals calcite, ankerite, and siderite for the 101 samples shows a relatively even distribution of the three minerals, although some samples have high concentrations of ankerite and siderite (Fig. 20-6). In this data, points which plot in the centre of the diagram generally represent samples with little or very low amounts of these carbonates.

CORRELATION OF CHEMICAL AND X-RAY ANALYTICAL RESULTS

The digitized X-ray diffractorgram data allowed a correlation study between the diffractogram curves and the chemical analyses of the 101 samples. Each of the 345 curve-defining points were correlated with each of the 13 elements analysed for each sample. The result was 345 correlation coefficients which covered the full length of the digitized diffractograms for each element based on 101 samples. The correlation coefficients then were plotted against the 2θ angles. The resultant plots (Fig. 20-7) show the correlation between elements and minerals within the 101 samples. By examining the 2θ angles which correspond to a specific mineral, elemental relationships for that mineral can be determined. Also the plots

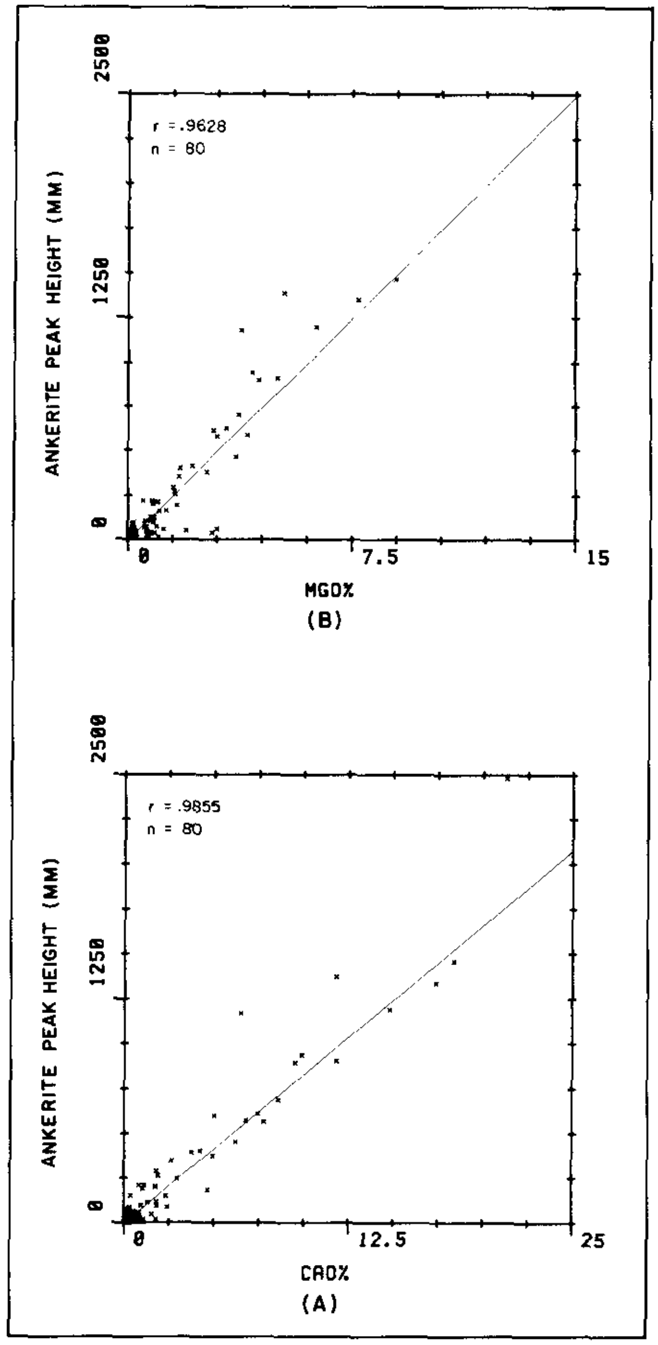

Figure 20-8. Cross-plots showing the relationship between the mineral ankerite (30.8 degrees 2θ on X-ray diffractograms) and (a) CaO per cent and (b) MgO per cent.

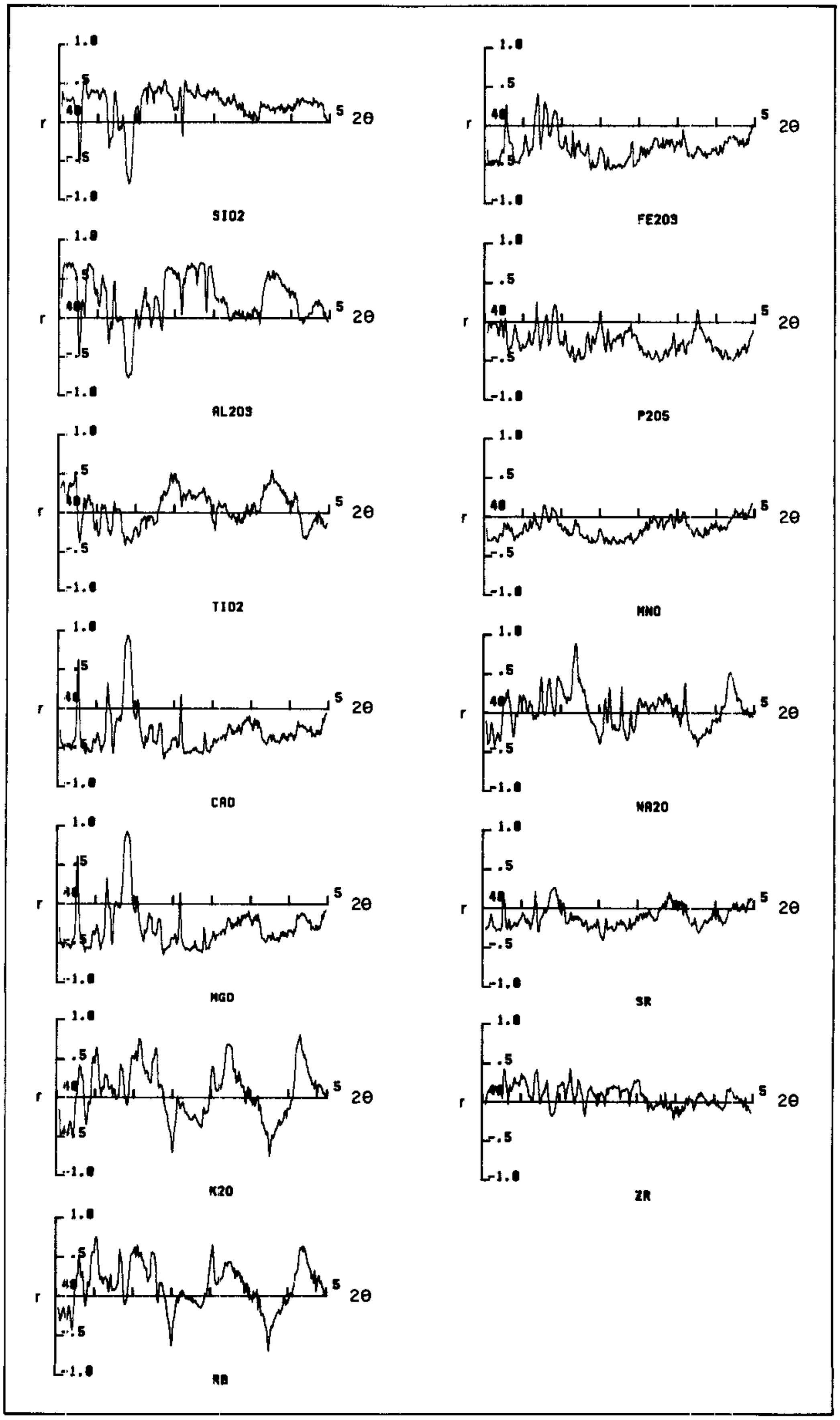

Figure 20-7. Correlation coefficent plots of X-ray diffractogram relationships with chemical abundances for 13 elements based on 101 samples.

illustrate which minerals contain the various elements. Significant correlations correspond to coefficients greater than 0.26 or less than −0.26.

Comparison of CaO and MgO correlation curves show the two elements to have virtually identical correlation coefficients throughout the range of minerals covered by the diffractogram. The prominent peak at 30.8 degrees 2θ corresponds to ankerite. The extremely high correlation coefficients of 0.986 and 0.963 (Fig. 20-7) for calcium and magnesium imply that virtually all of these two elements occur in the same mineral — ankerite — which is an alteration mineral.

Figure 20-8 shows the relationships between calcium and magnesium with respect to the height of the ankerite peak at 30.8 degrees 2θ. From these plots it is also a simple matter to calculate the magnesium to calcium ratios found in ankerite. Based on the linear regression equations the ratio of MgO to CaO in ankerite is 0.475. The ankerite:magnesium plot shows some samples with MgO around 2 to 3 per cent with no ankerite peak, which suggests the presence of some other magnesium-bearing mineral.

Potassium and rubidium have similar correlation curves (Fig. 20-7). Strong correlations in the 26.7 to 30.5-degree 2θ range imply significant correlation of potassium and rubidium with the feldspars. A sharp decrease at 28 degrees 2θ (sodic feldspars) corresponds to a strong positive correlation in the sodium curve. Both potassium and sodium also correlate well with the smectite peak around 8 degrees 2θ, suggesting alteration of feldspars to these clays. The relationship between potassium and rubidium does not change between feldspar and smectite. Rubidium commonly substitutes for potassium; it has the same charge and a similar ionic radius. The substitution of rubidium for potassium may be one of the reasons for the high gamma log responses often seen for bentonites. Taking into account the respective half lives and the percentage of radioactive isotopes of each element, rubidium is about 3.46 times as radioactive as potassium. Potassium, rubidium, and sodium show strong negative correlations with kaolinite (25 and 12.3 degrees 2θ). This negative correlation explains why, in contrast to the strong gamma log responses noted for smectite-rich bentonite, kaolinite-rich tonsteins have very weak responses. The close association of potassium and rubidium may proved useful in correlating bentonites with similar Rb/K ratios; Figure 20-9 contains a cross-plot showing the relationship of these two elements.

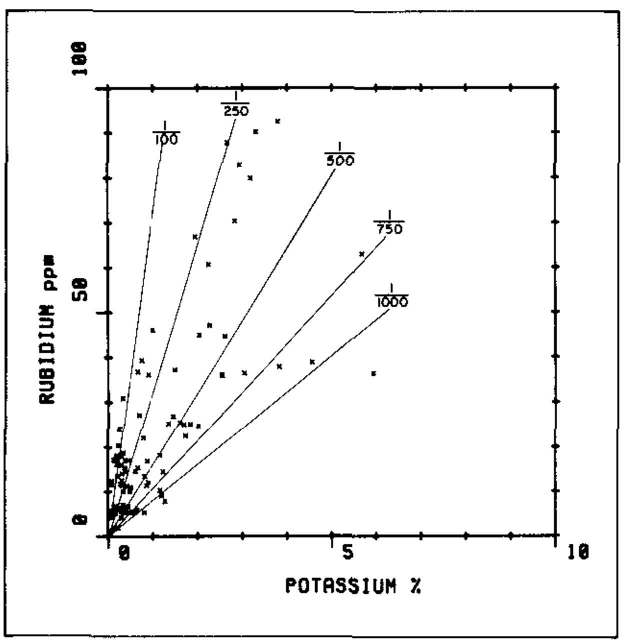

Figure 20-9. Cross-plot showing the relationship between Rb and K_2O content. Rubidium/potassium ratios are also displayed.

Alumina and silica have similar correlation curves which are nearly mirror images of the calcium and magnesium curves, suggesting these two sets of elements tend to be mutually exclusive in these samples. Titanium has a curve which shows correlations similar to those of alumina and silica with respect to the various minerals. Titanium and alumina have similar correlations with respect to kaolinite at 12.5 and 25 degrees 2θ.

Managanese and strontium have very few significant correlations but their general traces are similar. Both are negatively correlated with kaolinite. Strontium has a low positive correlation with ankerite at 31 degrees 2θ. This results from strontium substituting for calcium as discussed previously.

Iron and phosphorous have similarly shaped curves in the 30 to 35-degree 2θ range; there are many overlapping mineral peaks in this interval, such as ankerite and apatite. Phosphorous shows slight positive correlation with kaolinite.

CHEMICAL ESTIMATES FROM X-RAY CURVES

The correlation curves (Fig. 20-7) show which minerals contain various elements. Both positive and negative correlations provide useful information about elemental abundances in given minerals. If an element is found exclusively in a single mineral then a simple cross-plot (Fig. 20-8) will show the relationship and provide a predictive tool for element contents. However if an element occurs in several minerals or is negatively affected by the presence of some other mineral, then a slightly more complicated technique such as multiple linear regression must be employed.

Multiple linear regression proved successful in determining which peaks most accurately described the abundances of various elements and at arriving at a predictor equation. All multiple linear correlations were based on only 80 samples, due to limited memory capacity of the available microcomputers. Plots of the results of the derived equations contain all 101 samples.

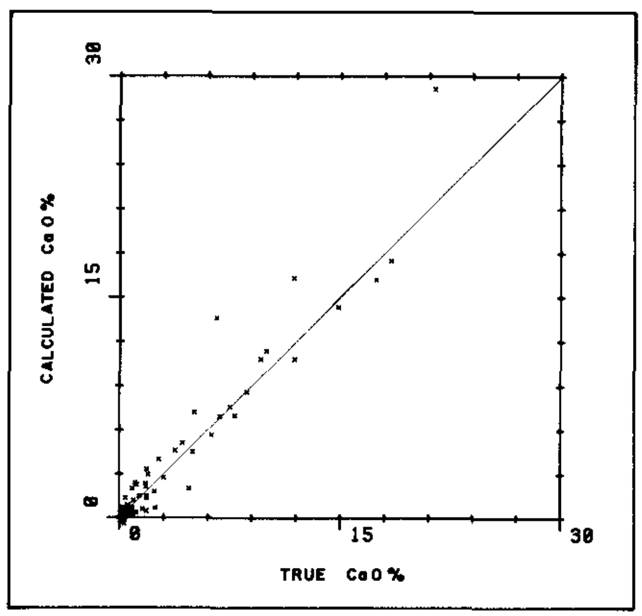

Figure 20-10. Comparison of X-ray calculated CaO content from multiple linear regression and chemical analysis. Regression based on 80 samples, 101 plotted.

Calcium was shown previously (Fig. 20-8a) to have a very strong correlation with the X-ray curve at 30.8 degrees 2θ. Examination of the correlation curve for calcium (Fig. 20-7) shows that a strong negative correlation occurs at 26.1 degrees 2θ, which is an area influenced by both quartz and kaolinite. Utilization of both the curve positions, 30.8 and 26.1 degrees, provided only marginally better definition of the calcium content than the 30.8-degree peak alone ($R = 0.9855$ to $R = 0.9876$). Figure 20-10 contains a comparison of the chemical analysis values with those predicted from ankerite and the quartz-kaolinite peaks. The extremely small increase in resolution does not justify inclusion of the second peak in the predictor equation. CaO per cent values are adequately described by the linear regression equation:

$CaO\% = -0.159928 + 0.012078$ (peak height at 30.8° 2θ)

This equation explains 97 per cent of the calcium variance in the samples. The similarity of the correlation curves suggest that a similar equation would provide an equally good estimate of magnesium content. Based solely on the ankerite peak at 30.8 degrees 2θ, 92.7 per cent of the magnesium variance is explained by the following equation:

$MgO\% = 0.0898353 + 0.00534672$ (peak height at 30.8° 2θ)

In this case the multiple linear regression technique showed that a single mineral was the best estimator of two elements, CaO and MgO.

Potassium content was found to be predicted best by a combination of three curve positions. The curve positions at 29.1, 12.3, and 8.4 degrees correspond to the minerals potassium feldspar, kaolinite, and illite, respectively. The respective correlation coefficients of each of these positions with K_2O content was +0.7957, −0.6738, and +0.8569. Figure 20-11 contains the true and calculated results of predicator equations based on several combinations of these minerals. It is interesting that the two positively correlated minerals (Fig. 20-11a) do not predict K_2O content as well as a combination of a positively and negatively correlated mineral (Fig. 20-11b); the best predictor utilized all three minerals. This equation, which explained 89 per cent of the K_2O variance was:

$K_2O\% = 0.0775335 + 0.00809$ (peak height at 29.1°) + 0.009951 (peak at 8.4°) + −0.000594 (peak height at 12.3°)

The fact that both feldspar and illite give good estimates of K_2O content but when combined do not greatly improve the estimate of K_2O content suggests these minerals are directly related. This relationship is the result of concordant increases in feldspar and illite peaks; illite is an alteration product of feldspar. Rubidium content would be accurately predicted by a similar equation due to the similarity between the Rb and K_2O correlation curves.

The sodium correlation curve (Fig. 20-7) showed a strong positive correlation with sodium feldspar at 28 degrees 2θ. A significant negative correlation occurs with kaolinite at 12.4 degrees 2θ, and a moderate positive correlation is present with illite at 7.9 degrees 2θ. Individual correlations with these three peaks were 0.9202, 0.2201, and 0.5774 for feldspar, kaolinite, and illite, respectively. The combination of feldspar and kaolinite at $R = 0.9314$ proved a better estimate than feldspar and illite at $R = 0.9205$ (Fig. 20-12). Inclusion of the illite peak did not significantly improve the predictability of NaO content so only two peaks were used in the following equation, which explains 86.7 per cent of the variance of sodium:

$NaO\% = -0.00420716 + 0.00559678$ (peak height at 28.2°) + −0.0000779881 (peak height at 12.4°)

The correlation curve for Al_2O_3 content (Fig. 20-7) has a large range of positively correlation points on the X-ray curve and one strong negative correlation. The negative correlation coincides with ankerite and has a value of −0.7727. Points which corresponded to feldspar and kaolinite, 21.3 and 12.2 degrees, were selected arbitrarily from the myriad of positive correlations. Correlation co-

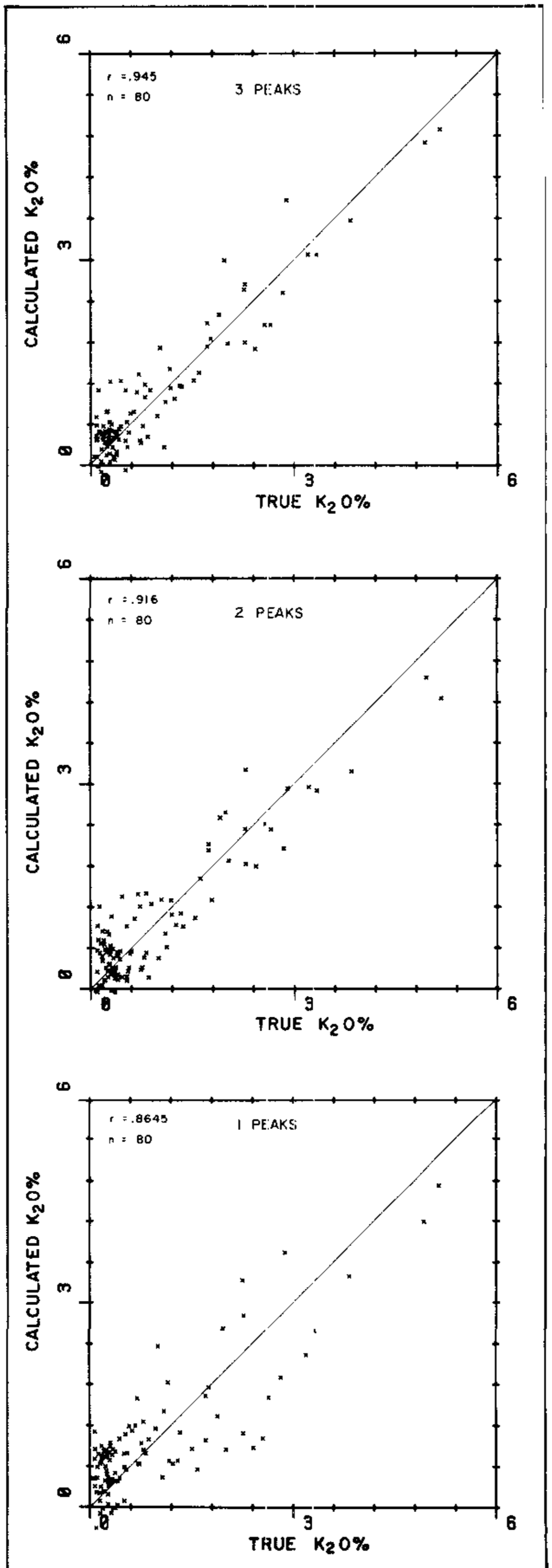

Figure 20-11. Examples of predictive regression equations for K_2O content based on up to three points on the diffractograms.

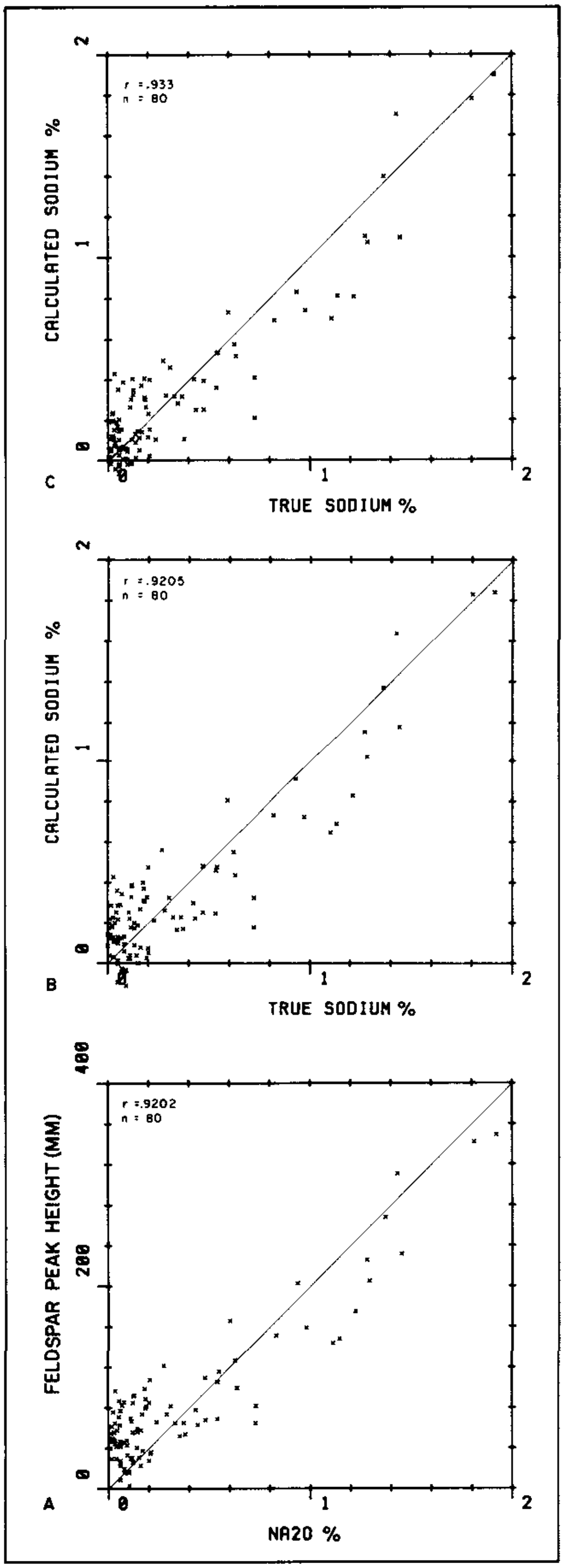

Figure 20-12. Na_2O% predictability (a) based on one curve point, (b) based on two curve points, and (c) based on three curve points.

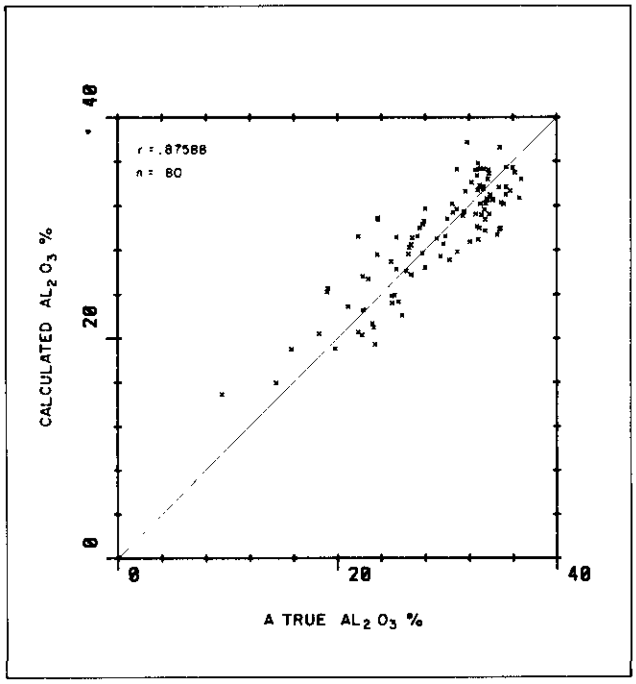

Figure 20-13. Predictability of Al_2O_3 content based on three X-ray curve positions.

efficients of 0.7176 and 0.6885 were obtained for feldspar and kaolinite. A predictor equation based on all three peaks explained 77 per cent of the variance of Al_2O_3. Figure 20-13 contains the true values and those calculated using the following equation:

$Al_2O_3\% = 23.6822 + -0.008284$ (peak height at 30.9°) + 0.017914 (peak height at 21.3°) + 0.002358 (peak height at 12.2°)

In this case ankerite, a mineral containing no aluminum, proved to be the best single predictor. This is due to the dilution effect of late ankerite mineralization, which simply reduces the percentage of aluminum-bearing minerals. Ankerite and kaolinite mineral peaks explained 73 per cent of the Al_2O_3 variance; the addition of feldspar brought this value up to 77 per cent.

CONCLUSIONS

This article has shown the viability of using X-ray diffractograms to accurately predict sample chemistry. In some aspects the diffractograms are superior correlation tools because they not only provide mineralogical information but also many of the same correlation properties as chemical data. The objective of this part of the study was to find an alternative to chemical analysis; X-ray diffraction provides one.

Techniques developed for this study provide insight into the various styles of alteration affecting volcanic ash falls in and around coal swamps. The chemical-diffractogram correlation curves also provide a means of examining the chemical characteristics of individual minerals within a sample. Certain elements, such as calcium and magnesium, can be shown to have been introduced largely with one mineral, ankerite, at a late date. These elements are obviously of no use for regional correlation of an ash band on the basis of common source chemistry.

Future work will concentrate on applying the knowledge of chemical behaviour of these rocks to their regional correlations. Comparisons of altered samples with similar mineralogy (that is, ankerite rich) may give insight into the causes or mechanisms of the alteration. Comparisons of coal rank and mixed-layer clay abundances may aid the understanding of clay diagenesis.

ACKNOWLEDGMENT

All X-ray diffraction analyses were performed by Dr. J. Kwong of the Ministry Laboratory and his efforts are greatly appreciated.

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WAPITI SYNCLINE PHOSPHATE POTENTIAL (93J/10, 7)

By A. Legun and P. Elkins

INTRODUCTION

The Wapiti syncline area, which is located 70 kilometres south-southeast of Tumbler Ridge, extends for 10 kilometres between Wapiti Lake and Red Deer Creek (Fig. 21-1). Access is by helicopter or by four-wheel drive along the Red Deer Creek trail which leads to the back of the ridge at the south end of the syncline; the ridge must then be climbed. Floatplanes also may land at Wapiti Lake to the north; from there the syncline is reached by foot along the valley bottom.

The writers spent eight field days sampling and tracing Triassic and Permian phosphate units along the limbs of the Wapiti syncline from a base camp at Two-Lake Cirque (Fig. 21-2).

Previous work includes Gibson (1972, 1975), McGugan and Rapson (1964), and personnel of Esso Resources Canada Ltd. (1980, Assessment Report 8 407, Mineral Resources Division). In addition, stratigraphic sections of the Permian and Triassic rocks are presented in Assessment Report 1 870 (Petroleum Resources Division).

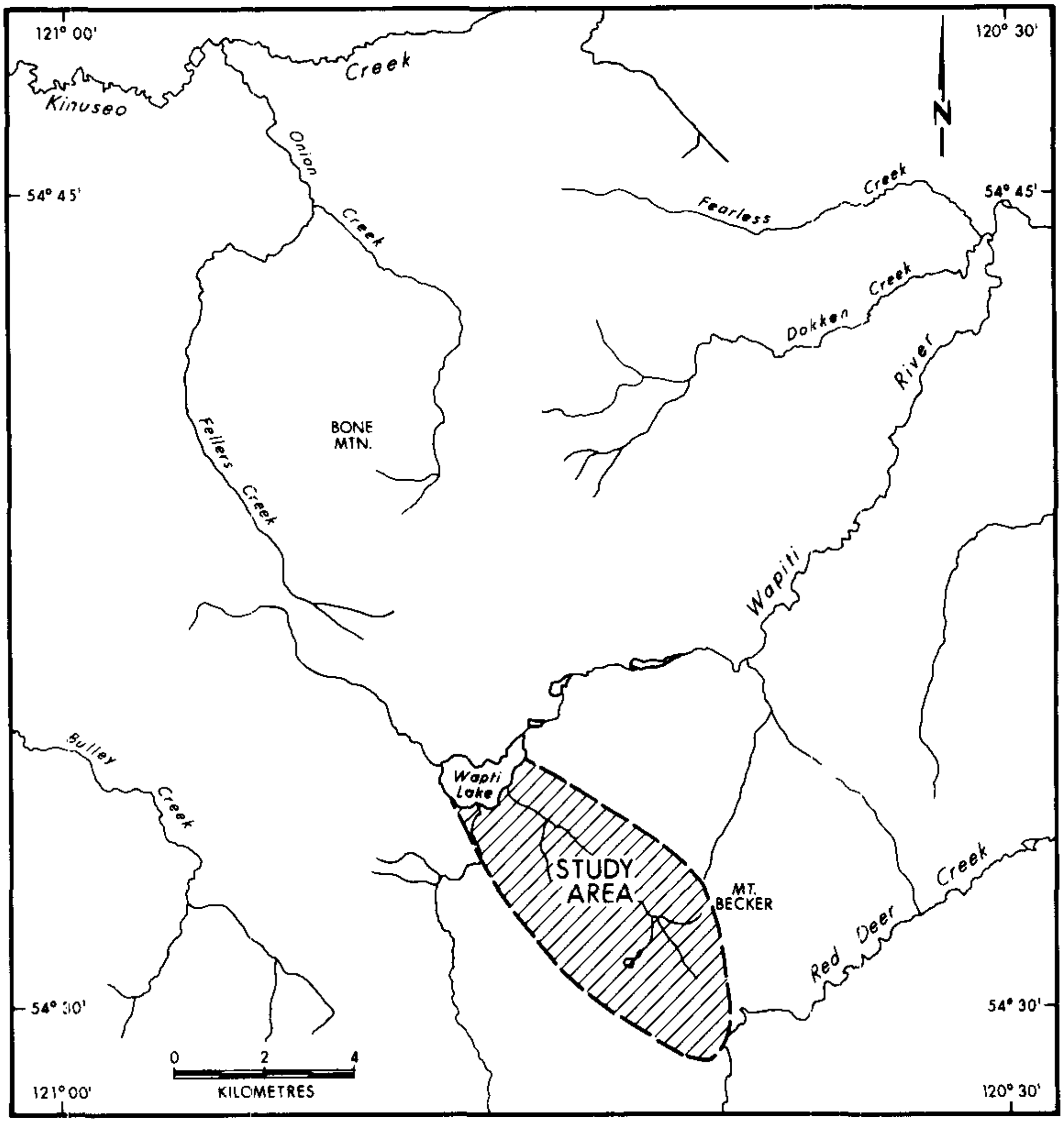

Figure 21-1. Location of study area, Wapiti Lake phosphate project.

British Columbia Ministry of Energy, Mines and Petroleum Resources, Geological Fieldwork, 1985, Paper 1986-1.

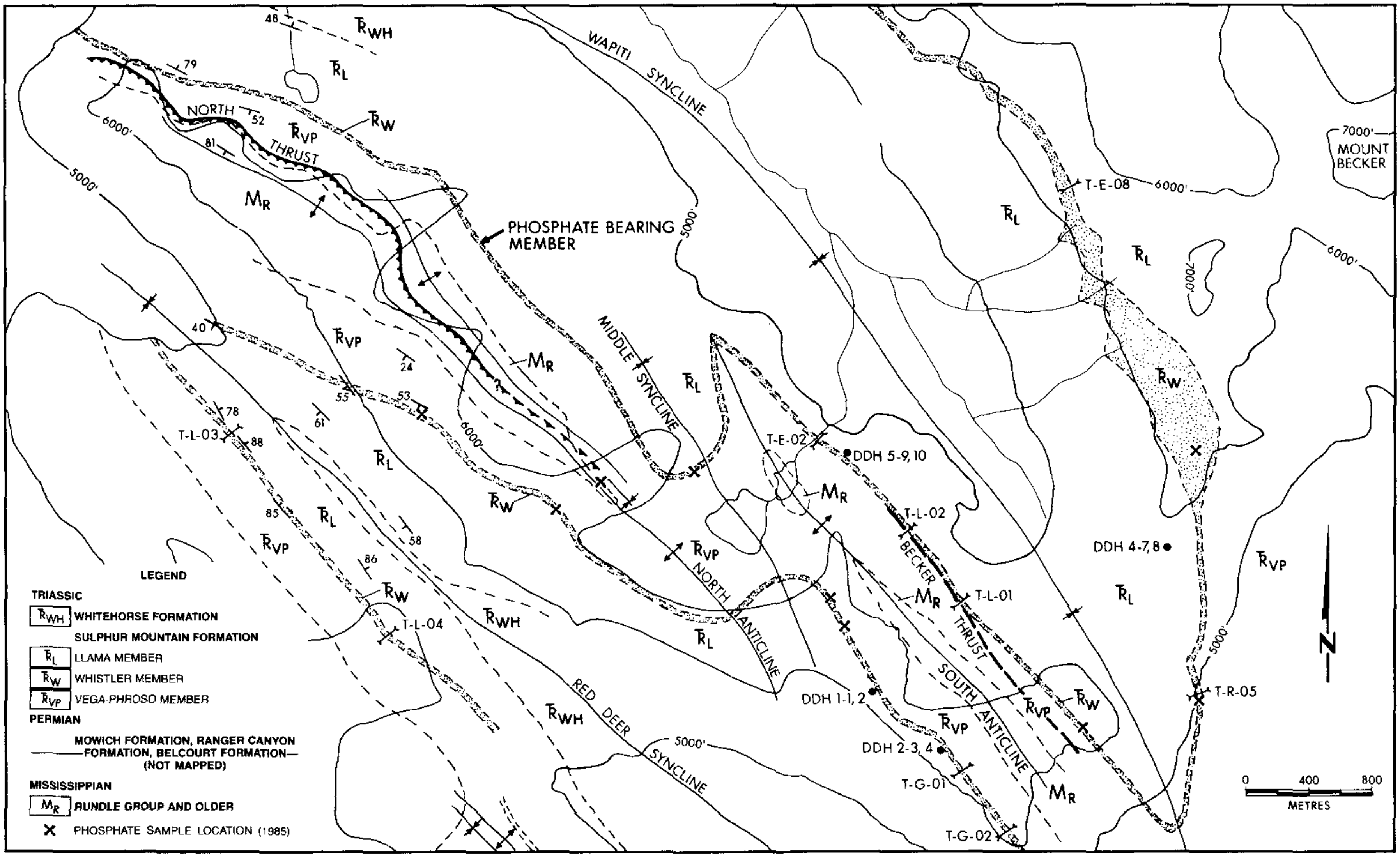

Figure 21-2. Wapiti phosphate (93I/7, 10).

OBJECTIVES OF THE STUDY

This study is designed as part of a larger effort that is directed toward locating areas of high phosphate potential in northeastern British Columbia. A large number of individual references to phosphate occurrences in northeastern British Columbia exist in the literature but, publically, little attempt has been made to synthesize the data. No general synthesis exists that identifies what stratigraphic intervals and what areas are worthy of follow-up. An exception to this is the work of Esso Resources Canada Ltd. south of the Pine River; eventually Esso Resources focused on the Whistler Member of the Triassic Sulphur Mountain Formation in the Wapiti syncline area. Although Esso Resources dropped the Wapiti claims, phosphate grades up to 29.7 per cent over 1.01 metres, which are encouraging when compared with analytical results in other studies (*see* MacDonald, 1985), were reported.

This study was initiated to evaluate Esso Resources's work, to carry out follow-up analyses, and to trace phosphatic intervals in the area.

METHOD OF STUDY

The geology map for the Wapiti claims of Esso Minerals Canada was used as a guide in locating the phosphatic unit at the base of the Whistler Member. Old trenches were found and in some cases resampled. New exposures were located and channel sampled. In this regard a portable scintillometer proved useful in prospecting. In old trenches, the variation in total counts per second of combined uranium and thorium radiation roughly matched the variation in P_2O_5 grades for the intervals; higher counts correlated with higher grades. Consequently the scintillometer was used in combination with visual recognition of phosphorite to determine sampling cutoff widths. A total of 11 locations were sampled; these included 2 samples of the Mowich Formation sandstone of Permian age which outcrops in the area and is a known phosphatic interval (MacDonald, 1985). Fourteen samples were submitted to the Ministry of Energy, Mines and Petroleum Resources' laboratory in Victoria for whole rock oxide analysis and 30-element semi-quantitative emission spectrographic analysis. The results will identify P_2O_5 grade, chemical impurities such as calcium, toxic adulterants such as cadmium and lead, or valuable byproducts such as fluorine, rare earths (yttrium, europium, neodymium), or uranium, which are are known to be associated with phosphate.

RESULTS

Analytical results were not available at time of writing; the thickest uninterrupted interval of phosphorite found during the field reconnaissance was 1.1 metres; within it the maximum scintillometer count was 50 000, which is 100 times background. Phosphate occurs as pelletal phosphorite and minor phosphate pebble conglomerate. In some locales thin beds of bivalve and belemnite shell hash and vertebrate bones are present with visible purplish thorite. The bottom contact of the phosphate zone consists of mottles of pelletal phosphorite in a siltstone background. The origin of these mottles is unknown. It may be diagenetic; it could represent burrow fillings; it may even be of clastic, soft sediment rip-up origin.

The trace of the Whistler Member on Esso Minerals' map is essentially correct. The only geology that we added on Figure 21-2 is the 'V' trace of the Whistler unit about the axis of the south anticline. The Whistler unit could not be located to the north because the anticline has a considerable northward plunge.

Tracing the Triassic phosphate interval in reasonably well-exposed alpine terrain showed that the phosphatic units lense out over short lateral distances into more barren siltstones. Considerable variation in grade might be expected and this is supported by known analytical data, which indicates grades ranging from approximately 10 to 30 per cent P_2O_5 across a 1-metre-wide phosphatic interval.

According to Gibson (1975, Fig. 10, p. 13) outcrop sections containing good phosphatic sandstone with conglomerate interbeds at the base of the Whistler Member generally are associated with 'shelf' or thinning trends illustrated on his isopach maps. The thinning trend continues from the area of the Wapiti syncline southeastward to the Peak of Muinok Mountain. The thickness of the phosphate interval at Muinok Mountain is not known but could be significant. Once available the analytical data may suggest other trend directions that are worthy of pursuit.

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GEOLOGY OF THE CARBON CREEK AREA (93O/15)

By A. Legun

INTRODUCTION

The Carbon Creek area is located 30 kilometres west of the W.A.C. Bennett Dam in northeastern British Columbia (Fig. 22-1). Fieldwork in 1985 was directed toward compilation of the geology of the east half of the map sheet and integrating it with 1984 work in the west (Legun, 1985b). The focus of 1985 work was the Carbon Creek syncline which contains more than 70 million tonnes of mineable coal. Previous work in the area includes that of Matthews (1947), Hughes (1964), Stott and Gibson (1980), Stott (1983), Legun (1983, 1984, 1985), Gibson (1985), and personnel of Utah Mines Ltd. and Gulf Canada Resources Inc. (1980-1983 assessment reports). The area includes the Carbon Creek licences of Utah Mines Ltd. as well as the former licenses of West Carbon Creek (Utah Mines Ltd.) and Whiterabbit (Gulf Canada Resources Inc.).

Previous work has not adequately resolved the geology or the stratigraphy of the area; particularly areas bounding the two major coal-bearing synclines of Carbon Creek and West Carbon Creek. Figure 22-2 shows the geology based on a 1983 1:125 000 compilation map of NTS 93O by the Geological Survey of Canada (Open File 925). This can be compared to the first draft of a detailed compilation by the writer (Fig. 22-3).

METHOD OF STUDY

The writer, assisted alternately by Pat Desjardins, Paul Elkins, and Hugh Christie, spent 32 field days tracing and mapping geologic units on the periphery of the Carbon Creek syncline. Some work was also done in West Carbon Creek and outside the map-area to the east to solve specific problems of mapping and correlation. Air photographs were used to plot stations as well as to extrapolate geologic contacts between traverses. Fieldwork data was integrated with data from previous maps. In areas of poor exposure, outcrop pattern was predicted by the method of structure contours intersecting topography between two points where the attitude of the geologic contact is known.

Thickness of formations was calculated from air photographs. Scale and adjustments for change in scale with elevation were calculated using the centre areas of air photographs. Further corrections were made for slope and obliqueness to strike of ridges being traversed. Relevant formulas are found in Ragan (1985, p. 22) and Compton (1962, p. 84). Stratigraphic thickness data are presented in Table 22-1.

STRUCTURE

The structure of the map-area consists essentially of a pair of broad synclines separated by a box-like anticlinal structure (Fig. 22-3). This fold sequence is bounded by major faults. To the west the West Carbon Creek syncline is faulted against Triassic limestones on the Pardonet thrust. To the east Fernie shale on the east limb of the Carbon Creek syncline is faulted against Fort St. John Group shales on the Carbon thrust. Both major synclines tighten to the southeast with subsidiary folding and faulting. Both are doubly plunging forming a canoe shape modified by topography. Results of structural and stratigraphic mapping are best discussed in the context of a comparison of old and new maps (Figs. 22-2 and 22-3). The salient changes are as follows:

(1) Extension of Gething Formation coal measures from Carbon Creek to the Beattie Peaks area where they pinch out in a series of tight, faulted folds. The synclinal extension is broader than shown on the Geological Survey of Canada map and additional faults are present.

(2) More extensive distribution of the Bickford Formation in the area of Mount Monach (The Monach).

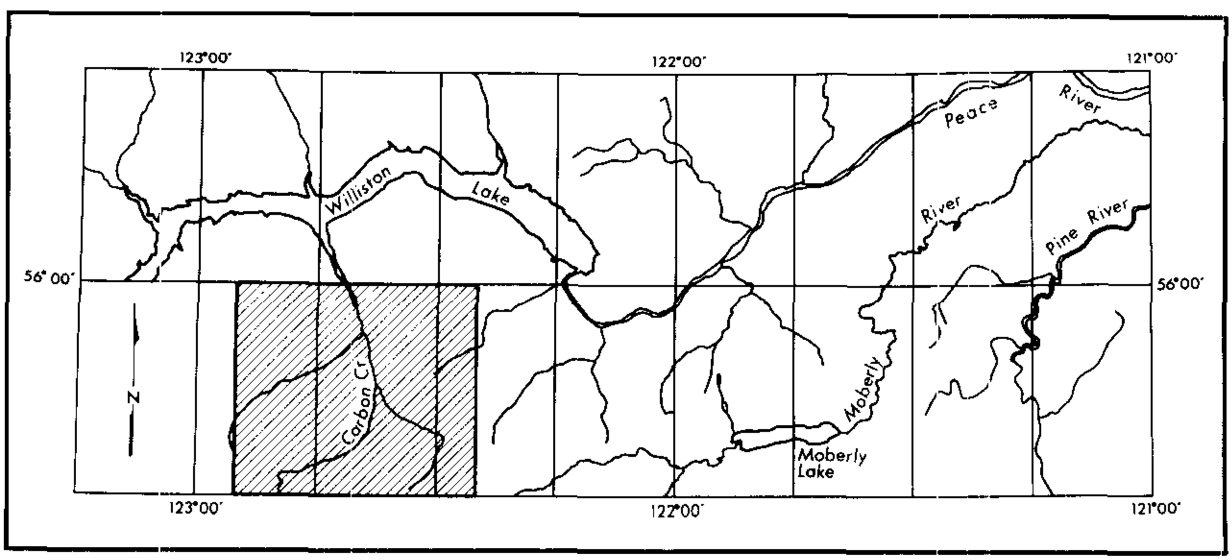

Figure 22-1. Location of the West Carbon Creek map-area.

British Columbia Ministry of Energy, Mines and Petroleum Resources, Geological Fieldwork, 1985, Paper 1986-1.

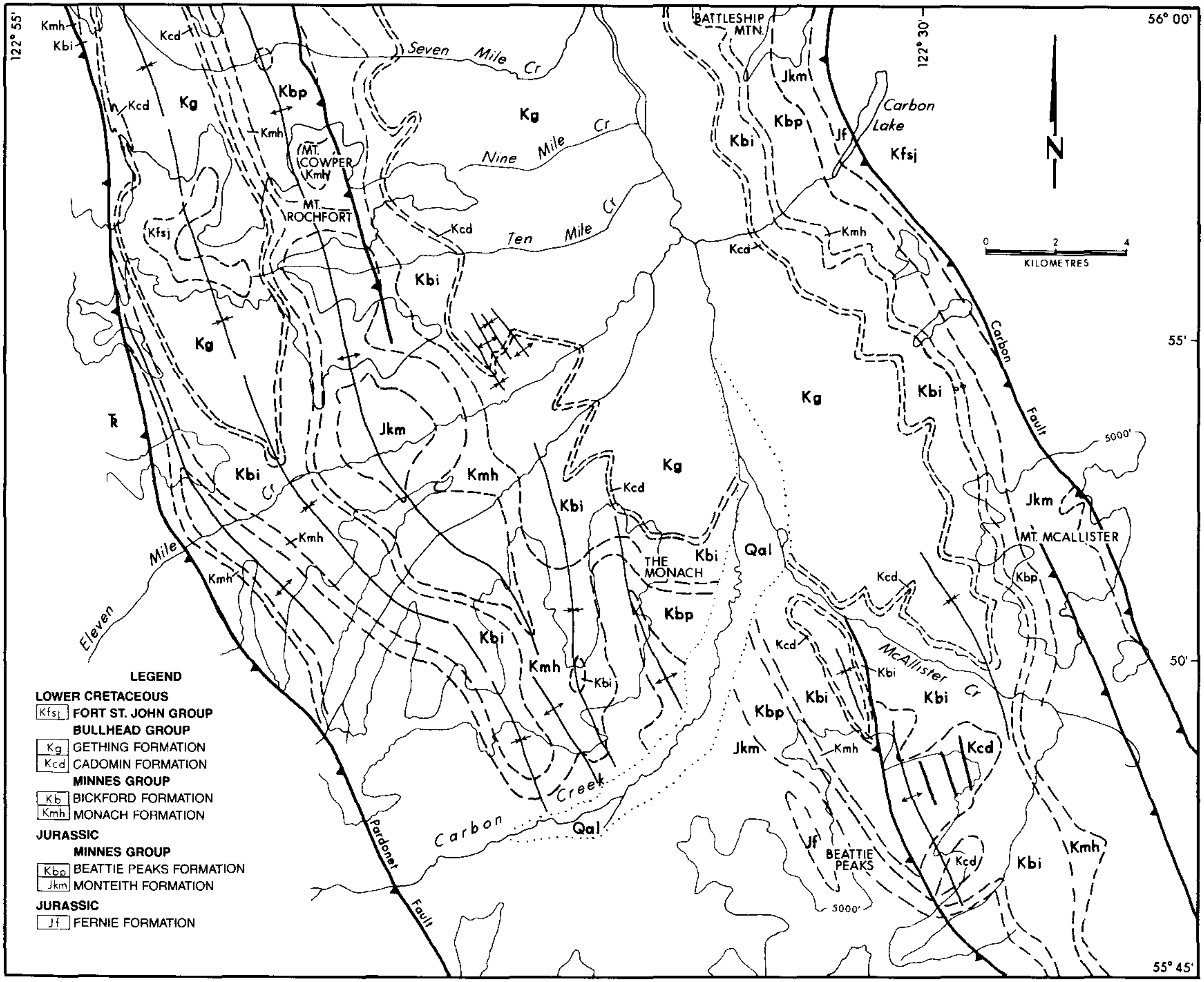

Figure 22-2. Geology of the Carbon Creek map-area (from Geological Survey of Canada Open File 925).

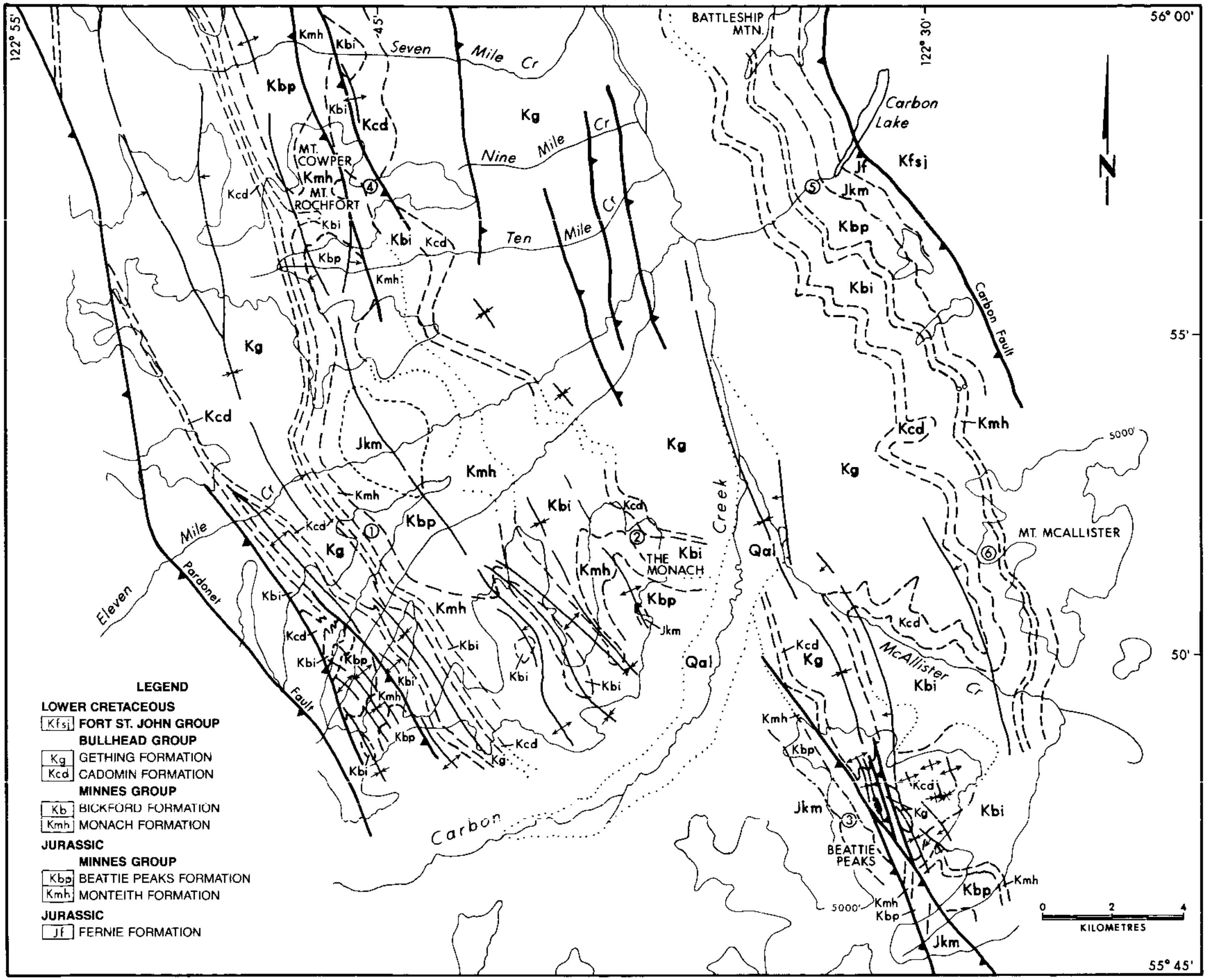

Figure 22-3. Preliminary compilation geology of the Carbon Creek map-area (93O/15).

TABLE 22-1. FORMATION THICKNESS DATA
(*See* Fig. 22-3 for locations.)

Area	Monteith Formation	Beattie Peaks Formation	Monach Formation	Bickford Formation	Cadomin Formation
	Metres	Metres	Metres	Metres	Metres
Ridge south of Mount Wrigley	—	400	442	148	268
Mount Monach	—	—	336	210	—
Beattie Peaks	564	394	—	—	—
Mount Rochfort	—	—	289	349	—
Carbon Lake	612	284	129	331	284
Mount McAllister	—	272	122	256	—
Mount Gething (Interpretation 1)	>626	>119	—	—	—
Mount Gething (Interpretation 2)	>446	90±	90±	>119	—

(3) A fault structure on the west limb of the Carbon Creek syncline near Mount Rochfort and Mount Cowper.

(4) A much greater southern extent of Gething coal measures in the West Carbon Creek syncline and a very different synclinal configuration.

MINNES GROUP

MONTEITH FORMATION

The Monteith Formation consists of two lithofacies:

(1) Clean arenites and quartz arenites that are massive to crossbedded.

(2) Clean to dirty arenites (quartz arenite to wacke) interbedded with siltstone and shale.

In the Carbon Creek area lithofacies (1) is dominant in the upper half of the Monteith and lithofacies (2) is common in the lower half of the Monteith. Shaly recessive intervals in the Monteith can be 50 or more metres thick. The base of the Monteith is transitional into shales of the Fernie Formation. The Monteith Formation is estimated to be 612 metres thick near Carbon Lake.

BEATTIE PEAKS FORMATION

The Beattie Peaks Formation is dominated by dark grey and brown shale with interbeds of siltstone and arenite. Arenite units are fissile and increase in thickness and number toward the top of the Formation. Burrowing is common and bedding surfaces are marked by trace fossils of unknown type. The lower contact of the Beattie Peaks shale with Monteith quartz arenites is sharp and unconformable, easily traced on air photographs. The upper contact with the Monach Formation is gradational. The thickness of the Beattie Peaks is calculated to be 392 metres at Beattie Peaks and 272 metres at Mount McAllister.

MONACH FORMATION

The Monach Formation is typified by units of flaggy, planar to shallow crossbedded arenites, massive arenite, and lesser quartz arenite. The units, which can be 10 metres or more thick, are separated by much thinner intervals of non-carbonaceous shale. Quartz arenites, which may be gritty, form local marker units. The Monach Formation forms the top of a coarsening upward sequence that begins in shales of the Beattie Peaks Formation. The contact between the two formations is arbitrarily placed where arenite units become prominent. Arenite units are thin toward the base of the formation and dominated by horizontal laminations. Units thicken up section and exhibit shallow-angle planar crossbedding, trough crossbedding, and uncommon hummocky cross-stratification. Some arenites show the peculiar feature of grading over a few decimetres into quartz arenite that forms either a cap on the unit or a lens within it.

The fossil bivalve *Buchia* is very common in some locales and less so in others. It may occur as discrete coquina 'beds' within the arenites or as dispersed single shells; the degree of shell fragmentation varies considerably from one bed to another. The thickness of the Monach Formation varies more than previously reported (Legun, 1985b). It is thick in the anticlinal area between Mount Cowper and Mount Monach, reaching 400 metres or more; in addition there is a thick transition zone from the Beattie Peaks Formation. Thickness trends west of the anticlinal structure are uncertain. However, to the east at Mount McAllister or Carbon Lake the Monach Formation is much thinner (120 metres); there is virtually no underlying transition zone and individual arenite units are thinner. The Monach Formation forms a thick, east-tapering lens in the Carbon Creek area.

BICKFORD FORMATION

The Bickford Formation is a sequence of interbedded arenites and shales. The arenites include salt and pepper lithic varieties as well as quartz arenites. The shales include carbonaceous shale, dark grey siltstones, and mudstones. Beds of grit and thin coals are present in some areas. Sedimentary structures include low-angle crossbedding in the arenites, flaser bedding in the shales, symmetric ripples, and vertical and U-shaped burrows *(Diplocriterion)*. Plant debris as well as root casts occur. These features indicate depositional environments ranging from marginal marine to marginal continental; marginal marine is more evident in the east, for example, near Carbon Lake.

The Bickford Formation shows a weak tendency to coarsen upward and thick arenites may directly underlie the Cadomin Formation. The contact with the Cadomin Formation is placed with the appearance of successive units of pebbly arenite, an increase in carbonaceous content, and the general disappearance of flaggy (low-angle crossbedded) and dark coloured lithic arenites. In some locales, such as the east flank of Mount Rochfort, one or more isolated pebbly arenite units, which may be channel deposits, occur below this defined contact; perhaps there is a gradational and continuous change in sedimentation between Bickford and Cadomin deposition. In other areas, for example the Carbon Creek road, the contact is sharp, and burrowed siltstone (marine) and quartz arenite are in contact with pebbly arenite full of log casts (alluvial channel).

The lower contact of the Bickford Formation is placed where interbedded arenite and shale pass into thick successive units of arenite of the Monach Formation with a loss of carbonaceous content. This change can be abrupt or gradual. Where flaggy arenites of the Bickford are exposed and shaly recessive units are covered it is particularly difficult to distinguish the Monach from the Bickford. Careful tracing on air photographs of the lower contact of the Bickford suggests that the lower contact is at the top of different arenite units from place to place, therefore, Bickford lithologies pass laterally into Monach arenites. As a result calculated thickness for the Bickford is variable. In this context the thickest section of Bickford Formation is found at Mount Rochfort (349 metres); both upper and lower contacts are gradational.

BULLHEAD GROUP

CADOMIN FORMATION

The Cadomin Formation is characterized by up to 10-metre-thick arenite to pebbly arenite units separated by thinner recessive intervals that include siltstone, carbonaceous shale, fine-grained arenite, and coal. The proportion of resistant pebbly arenite units to recessive intervals varies laterally and vertically within the formation. This results in prominent ribbed ridges in some areas and subdued topography in others. On the west side of Mount Wrigley, a lateral facies change occurs and pebbly arenites of the Cadomin pass laterally into coal measures which, lithologically, are basal Gething Formation. The Cadomin Formation thus thins between Mount Wrigley and Mount Rochfort. The impression from mapping throughout the region is that the Cadomin is not a thick continuous sheet deposit but consists of lenticular 'leaves' that are vertically stacked to overlapping. Observed lateral variation in number of 'leaves' suggests that they represent a series of coalescing fluvial fans with preservation of some interfan areas.

Generally, as a geologic unit, the Cadomin Formation maintains a thickness of 200 to 275 metres in the map-area. This value is rather artificial in the west where upper and lower contacts are gradational.

GETHING FORMATION

The Gething Formation is a coal measure sequence consisting of interbedded arenite, siltstone, mudstone, carbonaceous shale, and coal. Some beds are calcareous or ferruginous. In the Carbon Creek syncline over 100 diamond-drill holes (ddh) and a number of rotary drill holes (rdh) have been drilled by Utah Mines Ltd. in the Gething Formation. Only two penetrated the underlying Cadomin Formation (ddh 75-41, ddh 72-17). Correlation of holes indicates a total Gething thickness of 1 067 metres. There are more than 100 coal seams *in this stratigraphic interval; most are lenticular and thin.* Less than 10 seams are of economic interest and their individual average thicknesses do not exceed 2 metres. The thickest intersection is 3.5 metres (ddh 71-8). The coals in the Gething Formation are concentrated in the upper half of the stratigraphic interval, particularly the top 200 metres. They range from medium volatile to high volatile bituminous A in rank.

The thickness of the Gething in West Carbon Creek area is comparable to that in the Carbon Creek syncline. Only eight holes have been drilled by Utah Mines Ltd. and no correlation with Carbon Creek coals has been attempted. Seams are even more numerous in West Carbon Creek, but thinner. Utah Mines Ltd.'s thickest coal intersection was 1.8 metres; however, Gulf Canada Resources Inc. trenched a 3-metre seam in the south half of the syncline.

It may be possible to correlate the Gething section at Carbon Creek with that of the Adam property (formerly held by Crows Nest Resources Ltd.) east of the fault. A thick sandstone unit (40 metres) found in both properties may be equivalent (Fig. 22-4). On the Adam property the top of this sandstone is 150 metres below the Moosebar in rdh 79-5, while at Carbon Creek it is 105 metres below the top of the exposed Gething in ddh 81-88. These data suggest that the top of ddh 81-88 is near the Moosebar-Gething contact (Fig. 22-4).

Gibson (1985) argues that strata of the Gething Formation in the Carbon Creek coal basin were deposited in two major deltaic environments; the lower half of the Gething has characteristics of an upper delta plain; the upper half has characteristics of a lower delta plain. Work by Kilby and Oppelt (1985) on volcanic ash bands (tonsteins and bentonites) just east of the study area suggests that coal measure sedimentation continued in the Carbon Creek area at the same time as the Moosebar sea was transgressing in the east.

Utah Mines Ltd. defined three reserve areas on east-facing slopes on the west limb of the Carbon Creek syncline. These lie north of Seven Mile, Ten Mile, and Eleven Mile Creeks respectively (Fig. 22-3). Total mineable reserves are on the order of 70 million tonnes which can be mined by a combination of underground and open-pit methods.

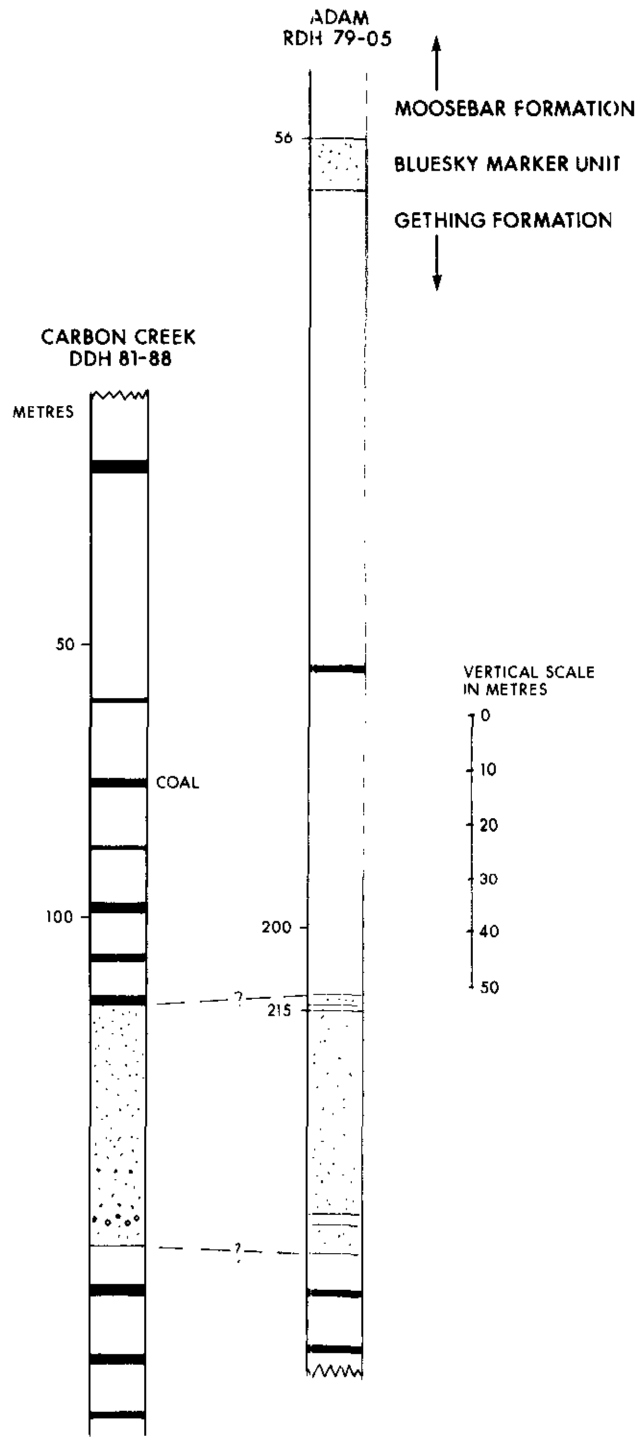

Figure 22-4. Correlation of the Gething Formation.

DISCUSSION OF REGIONAL STRATIGRAPHY

The thickness between the top of the Monteith Formation and base of the Cadomin Formation decreases from more than 1 200 metres in the West Carbon Creek area to 774 metres at Carbon Lake to 650 metres at Mount McAllister on the eastern edge of the map-area (Table 22-1). This appears to be largely due to thinning of the Beattie Peaks and Monach Formations. East of the Carbon fault at South Mount Gething the interval has apparently shrunk to 224 metres with the disappearance of the Bickford Formation. This drastic thinning of the Bickford Formation occurs over a few kilometres and is based on designation of 600 metres of strata below as Monteith Formation by Utah Mines Ltd. (South Mount Gething 1982 assessment report) and Legun (1985a). This thickness of the Monteith Formation is virtually the same as that at Carbon Lake. It is possible that this interval actually comprises the Monteith, Beattie Peaks, and Monach Formation; if this is true, then the overlying unit — mapped as Beattie Peaks — is actually the Bickford Formation; the problem is deciding which shale interval represents the Beattie Peaks. Is it the shale mapped as a recessive internal in Monteith Formation quartzites or the shale that overlies these quartzites? If it is the latter, then east of the Carbon fault the Bickford was probably eroded prior to deposition of the Cadomin Formation. If it is the former, then the Bickford Formation is preserved east of the Carbon fault and some changes are required to Stott's concept of a regional unconformity at the base of the Cadomin and to the interpretations on the preliminary map of the Butler Ridge area (Legun, 1985a). Though not conclusive the stratigraphic position of the bivalve *Buchia inflata* sp. in a measured section at Mount Gething (Petroleum Resources Division, Assessment Report 1870) suggests that the overlying shales are Bickford Formation and that the Beattie Peaks shale is a recessive unit within Monteith quartzites (Table 22-1).

CONCLUSIONS

The geology of the Carbon Creek map sheet is different in detail from that shown on previous maps, particularly in the southern extension of Gething Coal measures in West Carbon Creek and at Beattie Peaks. The maximum thickness of Gething Formation in the Carbon Creek and West Carbon Creek synclines is approximately the same at about 1 100 metres; coal seams are numerous but thin in both synclines. Based on a thick sandstone unit, correlation of Carbon Creek coals with those on the Adam property east of the Carbon fault may be possible. A correlation between Carbon Creek and West Carbon Creek coals has yet to be attempted. The Gething Formation thins eastward to Peace River Canyon where only 550 metres are recognized.

In the study area the Minnes Group consists of two upward-coarsening cycles between the Monteith and Cadomin Formations; the first cycle is more prominent than the second. The first cycle begins with marine shales of the Beattie Peaks and ends with nearshore arenites of the Monach Formation; the second starts with marginal marine arenites and shales of the Bickford Formation and ends with coarse alluvial arenites of the Cadomin Formation.

Formations of the Minnes Group thin eastward. The Monach forms a thick lens in the Carbon Creek area and its upper contact with the Bickford varies in stratigraphic position.

East of the Carbon fault Minnes Group stratigraphy is unresolved in spite of previous work; uncertainty has arisen as to which of two shale intervals correspond to the Beattie Peaks. If it is the upper shale then Bickford has probably been eroded east of the fault. If it is the lower, then the Bickford is preserved and the stratigraphy of Stott (1981) and Legun (1985a) east of the Carbon fault requires revision. Critical sections of the Minnes Group at South Mount Gething and Mount Gething will be re-examined during the 1986 field season.

ACKNOWLEDGMENTS

The writer was assisted alternately during the course of the field season by Patrick Desjardins, Paul Elkins, and Hugh Christie. Each provided cheerful assistance and worked capably and safely.

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British Columbia Geological Survey
Geological Fieldwork 1985

STRATIGRAPHY AND CHARACTER OF THE BLUESKY FORMATION (94A, B, H, G; 93I, O, P)

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INTRODUCTION

Lower Cretaceous Bluesky sediments found in the Northern Rocky Mountain foothills can be traced into the subsurface of the plains of northeastern British Columbia. In the plains region, the unit produces significant quantities of oil and gas from a series of structural-stratigraphic traps; equivalent strata in northwestern Alberta also contain large hydrocarbon reserves. The Bluesky Formation is used as a lithostratigraphic datum in the correlation of coal seams in the Peace River Coalfield. Despite economic interest in the succession, no detailed investigation of its distribution or character in northeastern British Columbia has been published.

This paper is a preliminary account of the distribution, stratigraphy, and lithology of the Bluesky Formation. Much of the information is based on drill core, outcrop, and geophysical log examinations. A petrographic study has not yet been completed. The recognition of several major environments is based on comparison with modern environments.

From previous work on the Bluesky Formation, it is evident that discrepancies as to its stratigraphy, regional relationships, and interpretations of depositional environments still exist. Traditionally, the Bluesky has been considered a nearshore lag deposit formed during the early transgressive stage of the Moosebar/Clearwater Sea (Pugh, 1960; Rudkin, 1964; White, 1983). Stott (1968) considered the unit to be a lateral facies equivalent of the uppermost Gething Formation. In the Sukunka-Wolverine area, Duff and Gilchrist (1983) documented the presence of a marine tongue which divides the Gething Formation into two coal-bearing zones — the lower Gething, and the upper Chamberlain members. The marine tongue and Chamberlain member were considered to be lateral equivalents of the Bluesky in the plains regions. Southeast of the Wolverine River, where the Gething marine tongue is thought to pinch out, the upper Chamberlain member merges with the lower Gething Formation. This then suggested that south of the Wolverine River the Bluesky, which overlies the lower Gething Formation, was not present. However, from boreholes logged as part of this study: (1) only the marine tongue and not the Chamberlain member should be considered part of the Bluesky, (2) the marine incursion can be traced as far south as the Belcourt River, and (3) the continental Chamberlain member was deposited at the same time as active Bluesky deposition in the plains, but in different environments. Kilby (1985) documented the presence of two prominent bentonite bands in the Moosebar Formation. These volcanic ash 'time lines' can be used to establish the complex sequence of events for Bluesky deposition.

METHODOLOGY

Oil and gas well core and coal exploration diamond-drill core were examined during the 1985 field season at the British Columbia Ministry of Energy, Mines and Petroleum Resources core storage facility in Charlie Lake. Core from 88 petroleum wells and 41 diamond-drill cores were examined; a total of 1490 discrete rock units were measured. Information from the drill holes was entered into a computer data base system using the CAL DATA LTD. Geological Analysis Package and a Kaypro II 64K microcomputer.

LITHOFACIES DESCRIPTIONS

The Bluesky Formation is a lithologically diverse unit containing three major lithofacies; all are distinct but genetically related. It includes: (1) basal chert pebble conglomerates and conglomeratic to coarse-grained sandstones ('C' facies); (2) middle bioturbated, interbedded siltstones and mudstones ('B' facies); and (3) upper glauconitic argillaceous sandstones, siltstones, or mudstones ('A' facies; Fig. 23-1).

The chert pebble conglomerate/sandstone or C facies unit contains three distinct subfacies: 'C1,' chert pebble conglomerate with mud matrix; 'C2,' medium to coarse-grained sandstone of three varieties: bioturbated, glauconitic sandstone; micaceous quartzose sandstone; planar crossbedded sandstone; and 'C3,' chert pebble conglomerate with coarse sand matrix.

Subfacies C1: Chert pebble conglomerate with mud matrix, is generally confined to the uppermost beds of the Bluesky throughout the study region. The clasts are composed predominantly of chert or quartzite; most of the chert is black, white, grey, or pale green. The clasts vary from subangular to well rounded with most being subrounded. The pebble-size clasts are embedded in a dark grey to black mudstone matrix. Larger clasts may be found at the top as well as the bottom of the unit; sorting is generally poor. In some beds, the mud merely fills the space between touching pebbles, whereas in others the pebbles are matrix supported. In most units stratification is fairly obscure. Glauconite content can vary up to 60 per cent but averages 15 per cent.

Subfacies C2: Three types of medium to coarse-grained sandstones are common in the Bluesky. The first type is a highly bioturbated, glauconitic sand where bedding is destroyed. Burrows are mainly round, vertical tubes averaging 1 centimetre in diameter and 2 to 15 centimetres in length. Burrow orientations range from subvertical to subhorizontal. Those burrows, which are mud-lined and infilled with a similar material to the surrounding matrix, are the trace fossils *palaeophycus*, which are considered to be open burrows occupied by suspension feeders which were infilled by passive sedimentation after desertion (Pemberton and Frey, 1982). Burrows that are subvertical shafts are the trace fossil *skolithos*. Bioturbation gives the unit a distinct mottled appearance. Composition of the sand averages 80 per cent quartz plus chert, 10 per cent dark fines, and 10 per cent glauconite. Contacts are generally gradational. Burrowing activity decreases as the contacts are approached. Beds may range up to 10 metres in thickness. Porosity is fair to good. This rock type is only found in the plains, especially in 94H and the eastern portion of the 94A block.

The micaceous quartzose sandstone in C2 is composed of clear, subangular to subrounded quartz grains; glauconite is sparse. Authigenic white kaolinite platelets commonly occupy the pore spaces.

British Columbia Ministry of Energy, Mines and Petroleum Resources, Geological Fieldwork, 1985, Paper 1986-1.

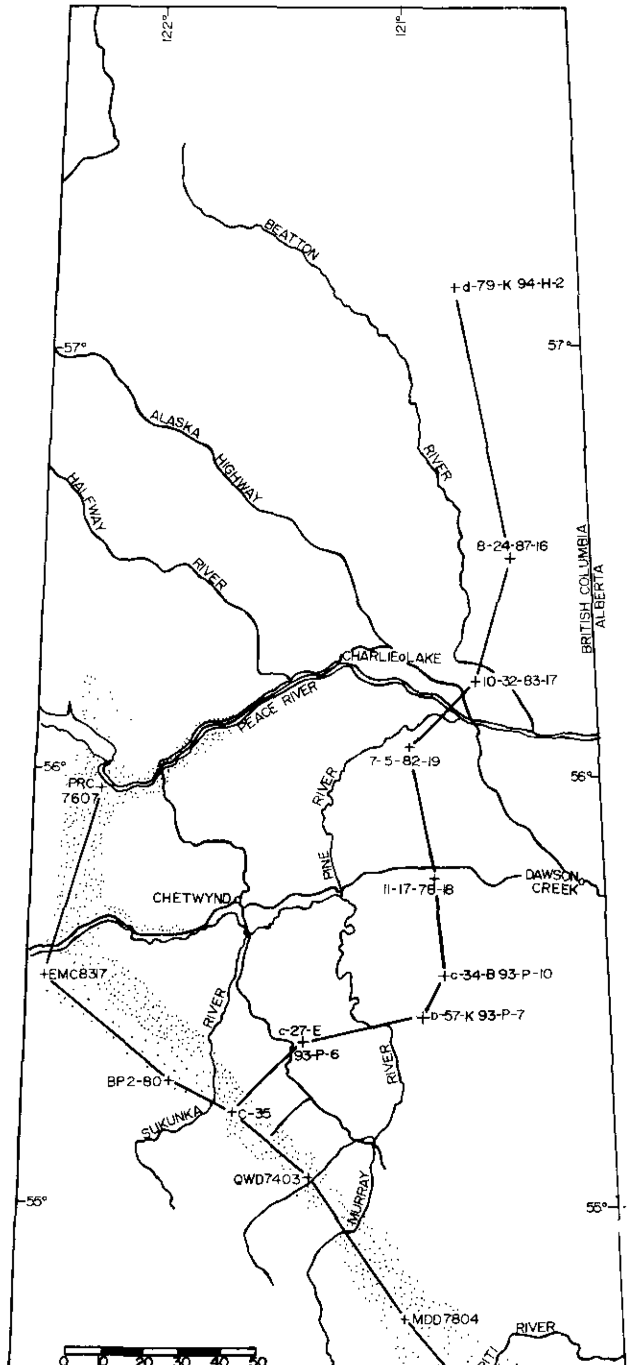


Figure 23-1. Generalized sequence of Bluesky facies in the back barrier section of the formation.

The unit is always tan-brown in colour, non-bioturbated, and poorly cemented. Porosity is good to excellent. Bedding is faint to massive.

The third and most common variety of sand in C2 is a planar crossbedded sandstone. Crossbeds are generally low angle and thinly laminated. Glauconite, if present, occurs along the basal planes of crossbeds. The sand is generally clean, non-bioturbated, well sorted, and tightly packed. Porosity ranges from fair to good. Crossbeds, generally small scale, range from weakly to well developed. Occasional dark laminae are composed of silt or concentrated finely macerated carbonaceous debris. Trough crossbedding was found in only two wells (d33J-94H7 and d59L-94A13).

Subfacies C3: Chert pebble conglomerate beds with a sand matrix, occur sporadically throughout the formation in the plains region but are confined to the lowermost beds in the Peace River foothills. Clast size and composition are generally identical to those in facies C1; however, in the Crassier Creek area boulders to 20 centimetres in diameter were noted. Pebbles are embedded in a medium to coarse-grained sandstone matrix composed mainly of chert or quartz grains. Some of the conglomerates have a strong bimodal grain size distribution, the chief mode being pebble size material, and the secondary mode being coarse grain sand. An interesting feature of the Bluesky unit is that although the sand matrix conglomerate may grade vertically upward into the mud matrix conglomerate type, there is no decrease in pebble size.

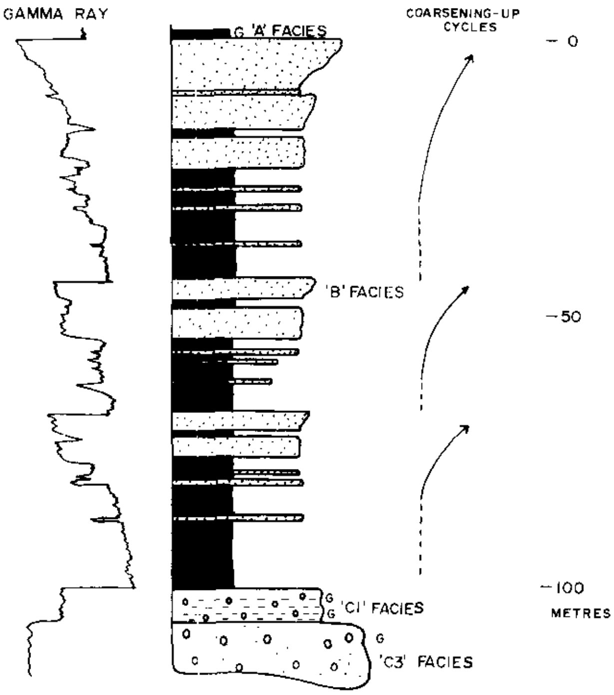
Packing of the clasts becomes very tight with many sutured clast contacts. This tight packing decreases the porosity of the unit. The conglomerates generally exhibit some cross-stratification, although bedding is faint to fairly obscure. Prominent low-angle, planar crossbedding was noted in the Willow Creek area. Planar crossbeds are more common than trough crossbeds. Glauconite content averages 5 per cent. The bases of many beds are scoured; they are sharply discordant and appear to be lensoidal. Beds occur in 0.1 to 2-metre units.

Marine mudstone and siltstone/sandstone interbeds (B facies) lie conformably above the basal C conglomeratic facies. A rhythmic or cyclic development occurs within this unit; mudstones grade upward into siltstone-sandstone-mudstone interbeds. This coarsening upward sequence is also reflected in geophysical logs (Kilby, 1984). The cycle may be repeated several times in the section. Thick accumulations of this unit occur in the Falls Mountain to Sukunka area but rarely in the plains region. Sandstones of this facies are fine grained, commonly with well-developed, low-angle laminations, and often have scoured bases with abundant load casts. Individual sand beds show distinct grading upward to clay size material. The mud beds show varying degrees of bioturbation. Burrows which are mainly horizontal, unlined, and infilled with sand are the trace fossil *planolites*. In places the burrows are pyritized; they are usually 2 to 4 millimetres across and oval in cross-section. Small (1 to 2-millimetre), subhorizontal burrows with tight meanders, and composed of the same mud as the surrounding host, are the trace fossils *helminthopsis*. Laminations in the mudstones are virtually absent and stratification is indicated only by thin silty streaks. The mudstones are similar to the Moosebar/Wilrich mudstones which resemble Recent offshore clays. The mudstones weather to rusty, small blocky pieces. The siltstones/sandstones are platy to blocky weathering. Marine fossils have been documented in this horizon by Duff and Gilchrist (1983).

Extremely glauconitic mudstone to sandstone (A facies) forms a diagnostic unit at the top of the formation. The unit ranges from 0.1 to 2.0 metres in thickness. In most places the contact with the overlying Moosebar shale is abrupt. Glauconite content varies from scattered grains to about 60 per cent where the unit forms a coarse gritty sand. Bioturbation was not seen in the cores. In some places there are a few scattered floating pebbles; they are usually black or white chert.

REGIONAL RELATIONSHIPS

The regional stratigraphic variations within the Bluesky Formation are illustrated in a series of columnar sections (Figs. 23-2 to 23-4). The main datum used is the base of the Bluesky Formation. Figures 23-3a and 23-3b depict the vertical stacking of Bluesky and Chamberlain member sequences in the Sukunka-Wolverine area.



GENERALIZED SECTION OF BACK-BARRIER DEPOSITS BLUESKY FORMATION

Figure 23-2. Well location map and outline of study area in northeastern British Columbia. Shaded area outlines Lower Cretaceous outcrop.

Although the diagram suggests high relief in this area compared to adjacent areas, the reader should note the vertical exaggeration incorporated in the diagram. The paleoslope is estimated to be less than one degree.

The three lithofacies described previously can be found throughout most of the foothills belt. The unit ranges in thickness from 5 to 85 metres. It is conformably overlain by the Moosebar Formation in the Peace River region and to the south in the Sukunka-Wolverine-Belcourt areas by the Chamberlain member of the Gething Formation. From the foothills toward the plains this tripartite division is replaced laterally by a succession of thick sandstone or conglomerate beds. Two prominent bentonite horizons distinctly 'frame' the Bluesky throughout the region. One bentonite occurs in the Moosebar and the other in the lower Gething Formation. Kilby (1985) correlated these over considerable distances in which the lower bentonites maintained a parallel relationship with the top of the lower Gething. This implies that at the close of lower Gething time the entire area was a continuous coastal swamp of very little relief (Kilby, 1985). As the source area for Gething sediments was reduced in elevation, less material was contributed to the continually subsiding basin which eventually led to rapid flooding of the upper Gething delta by the Clearwater Sea. Bluesky deposition marks the early stages of this transgression.

ENVIRONMENTS

The sandstone facies of the Bluesky Formation are mainly shallow marine in origin. The presence of glauconite, good sorting, uniform grain size, and *skolithos* and *palaeophycus* trace fossils all point to an offshore to nearshore environment. Although much of the sandstone appears to be sheet-like, it may be a composite of smaller sand bodies. Correlation of any one bed between neighbouring wells is difficult. Such shallow marine deposits are similar to Recent tidal/barrier island sand bodies or areally extensive offshore bars. The occurrence of the severely bioturbated sandstone unit may represent the lower to middle shoreface facies during fair weather, when biogenic activity is allowed to proceed. However, with storm activity, large clouds of sand are put into suspension and redeposited along the shoreface. The quartzose sandstone unit, with very low glauconite content, may represent this type of deposit. The cross-stratified, coarse-grained sandstone with good glauconite development may indicate tidal inlet channels. The unit has large to small-scale planar crossbeds, no bioturbation, erosional bases, and is often overlain by a coarse lag deposit.

In a westward direction, the sands pass into marine siltstones with intercalated beds of marine shale (B facies) over a conglomeratic base. This characteristic coarsening upward sequence may represent part of the back barrier facies bordering a pebble beach strandline. Typically lagoonal sediments consist of coarsening upward sequences of clays and silts complicated by influxing channel fill detritus from a tidal delta on the landward side (Reinson, 1984). This may result in brackish water conditions for the lagoon and a regressive sequence in the section. The individual sand beds of the back barrier zone may represent washover storm deposits from the barrier side into the lagoon. This is evidenced by the fining upward cycle in which the size of material in suspension changes from coarse to mud-sized particles, and also by the occurrence of a scour base. With the return of fair weather, biogenic activity returns, along with normal mud deposition. As the flood-tidal delta matured and stabilized, peat marshes developed. The Moosebar Sea by this time had begun to encroach landward toward this delta complex. Evidence of periodic flooding of the delta is found in the Chamberlain member. The glauconite or A facies found in the Peace River region may mark rapid incursion of the Moosebar Sea where flooding conditions brought about chemico-physico conditions to favour glauconite development.

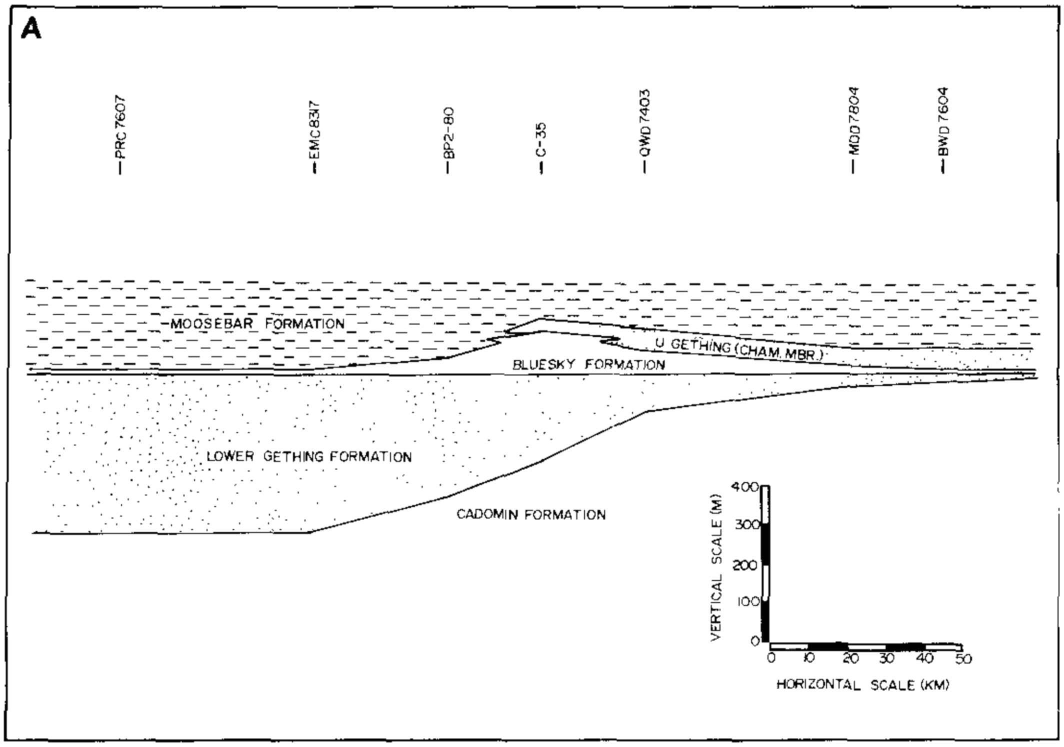
The final episode was the complete and rapid flooding of the entire study area by the Clearwater Sea forming a deep quiet basin into which the Moosebar bentonite was deposited.

PETROLEUM OCCURRENCES

Oil and gas accumulations in the Bluesky Formation occur in well-sorted, clean, porous sandstone units. The deposits are found in both stratigraphic and stratigraphic/structural traps. Suitable source beds are present in the Jurassic and Cretaceous marine shales and Gething Formation coal beds. Marine Moosebar shales cap the Bluesky sands, forming an effective seal for hydrocarbon entrapment.

Yield from the sandstone reservoirs will undoubtedly vary as the permeability changes with the type of sandstone. The severely bioturbated sandstone has high glauconite and fine sediment content which reduces the intergranular and dissolution porosity significantly. Extensive cementation occurs in this and the crossbedded sandstone unit lowering their permeabilities. The third type of sandstone, the poorly cemented, quartzose sandstone, should have a higher primary porosity and permeability than the bioturbated and crossbedded units. Porosities up to 15 per cent and permeabilities to 1 darcy can be expected. A complete petrophysical examination of the sandstone units would reveal their ratings and diagenetic history.

The conglomeratic facies may also contain hydrocarbons, depending upon their diagenetic history. Compression and local recrystallization structures have been noted in some cores, especially in zones with a low sand content matrix. Sutured contacts and quartz overgrowths effectively cut off the pore throat apertures, thereby



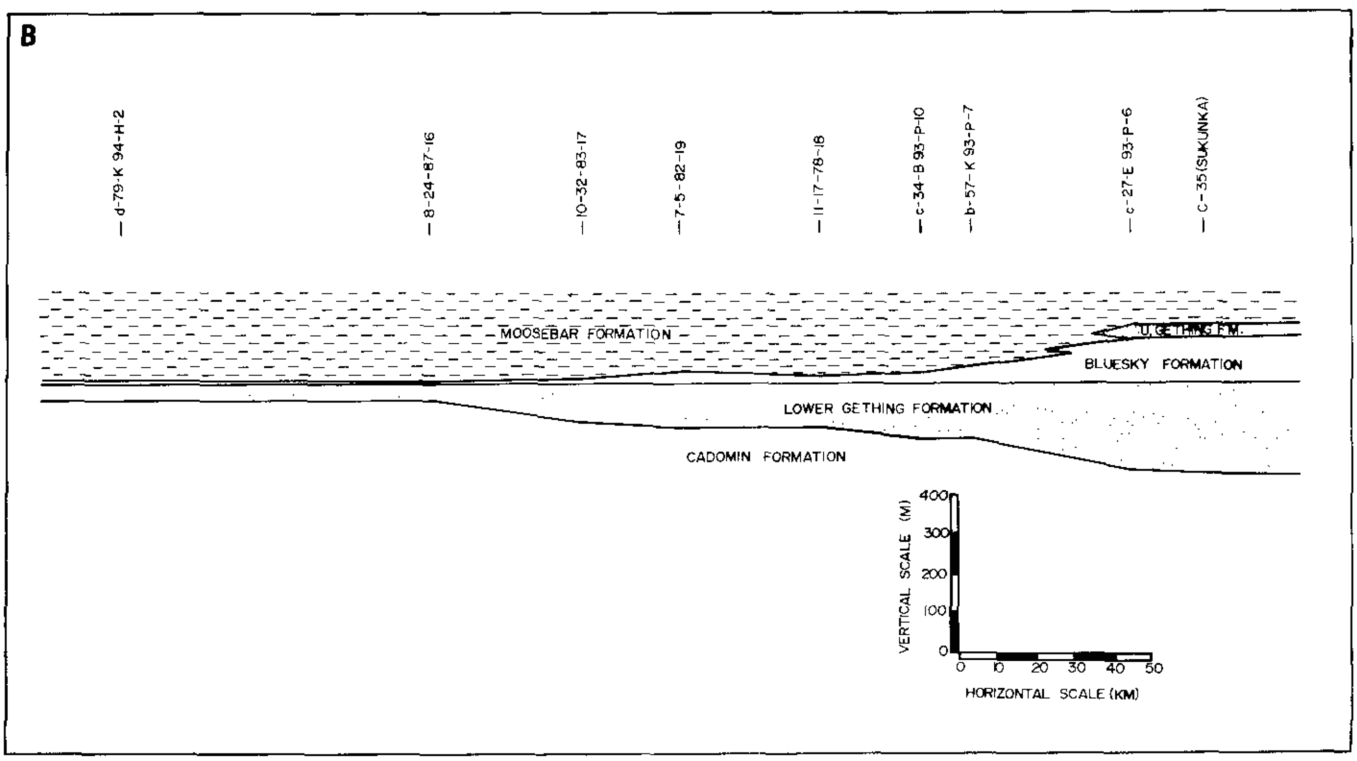


Figure 23-3. (a) Stratigraphic relationships of Bluesky sediments along a northwest-southeast section line. *See* Figure 23-1 for borehole locations. (b) Stratigraphic relationships of Bluesky sediments along a northeast-southwest section line.

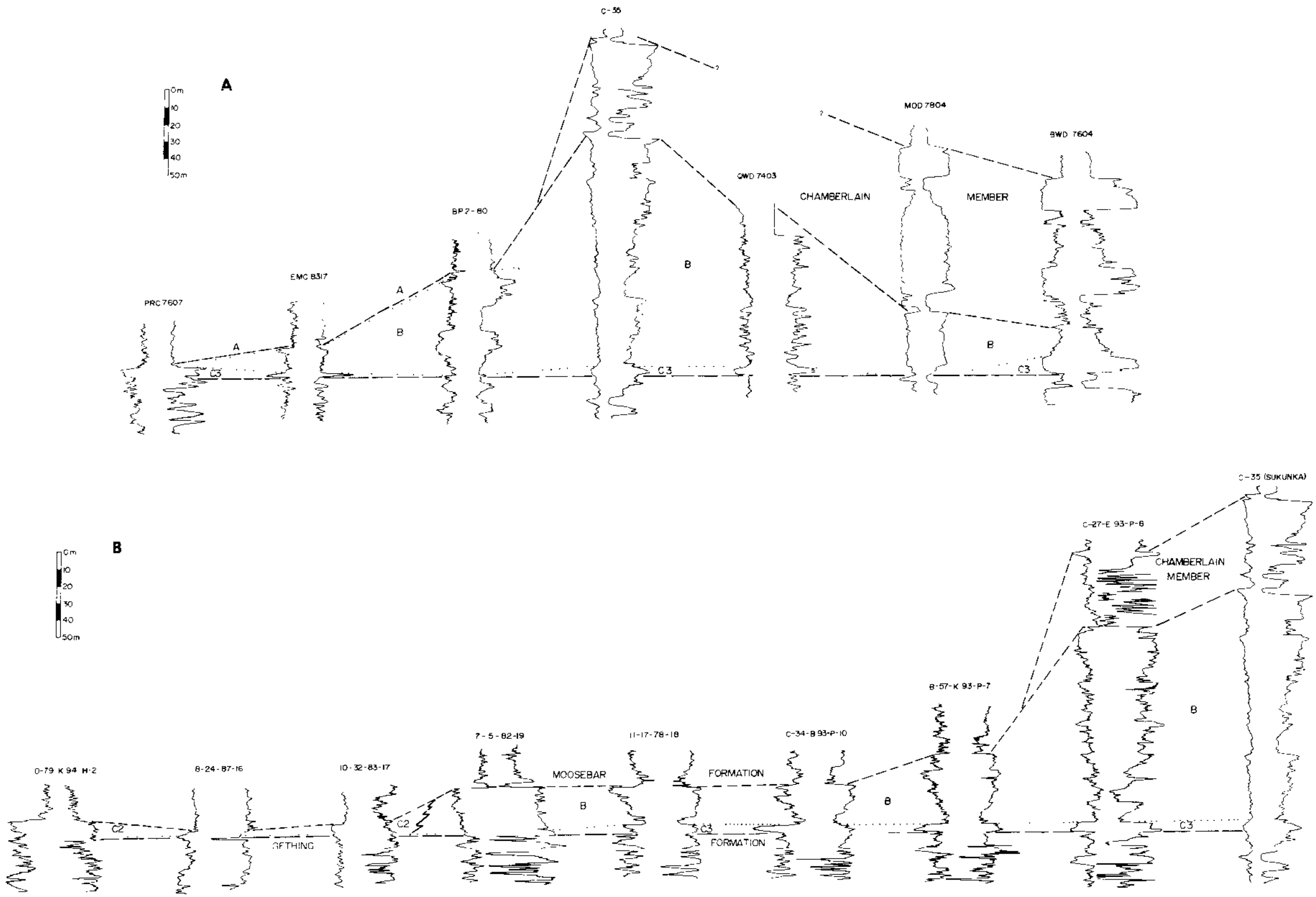


Figure 23-4. (a) Gamma and neutron geophysical log correlation of Bluesky Formation along a northwest-southeast section line. *See* text for explanation of facies codes. (b) Gamma and sonic geophysical log correlation of Bluesky Formation along a northeast-southwest section line. *See* text for explanation of codes. *See* Figure 23-2 for well locations.

reducing porosity and permeability. These deposits are also complicated by irregular thicknesses and lateral extent and thus, would be difficult to predict with any certainty.

The geometry of the quartzose sandstone units should be easier to predict. Being storm generated, their outlines will be elongate normal to shoreline. Therefore, as a storm wanes, the sediments are deposited seaward. These deposits should be sizeable but still limited in extent. Trapped gas or oil reserves could be found near their pinch-out points. A regional hydrodynamic study would probably uncover several pressure systems influenced by these facies variations.

CONCLUSIONS

Investigation into the Bluesky stratigraphy is at a preliminary stage. Further work into the time relationship of the Gething-Bluesky-Moosebar contacts is needed to sort out the sequence. Detailed petrographic studies and ichnofacies correlations for the units should reveal a more definitive answer for the depositional history. To date the study has shown (1) that the occurrence of the Bluesky can be extended southeastward to the Wapiti River; (2) the formation can be subdivided into three distinct facies; (3) the Bluesky is a barrier island/offshore bar complex with back barrier deposits; and (4) a close genetic relationship exists between the back barrier deposits and the emerging Chamberlain delta.

ACKNOWLEDGMENTS

The author would like to thank Ward Kilby of the Ministry of Energy, Mines and Petroleum Resources for his suggestions, support, and discussions during the field season. Sincere thanks is extended to Sylvia Chicorelli and Steve Larson, also of the Ministry, for their valuable assistance. Excellent service at the Charlie Lake core facility was provided by K. Clark and E. Meeks.

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TOODOGGONE RIVER AREA*
(94E)

By T. G. Schroeter, L. J. Diakow, and A. Panteleyev

INTRODUCTION

The writers continued to examine and keep abreast of ongoing mineral exploration in the Toodoggone gold-silver 'camp', located approximately 300 kilometres north of Smithers. In August 1985, British Columbia Ministry of Energy, Mines and Petroleum Resources' *Preliminary Map 61, at a scale of 1:50 000, Geology of the* Toodoggone River Area, NTS 94E by L. A. Diakow, A. Panteleyev, and T. G. Schroeter, was released. The map includes a detailed geological subdivision of the 'Toodoggone Volcanics' (Carter, 1972), age dates obtained by the authors and the Geological Survey of Canada, the location and minerals present for mineral occurrences and prospects (with Mineral Inventory File Number where present), and types of hydrothermal alteration. Major faults (predominantly with a northwesterly trend) are located on the map.

*The level of exploration and development activity in the Toodog*gone area during 1985 was the highest ever recorded; an estimated $6 million was spent.

ACCESS

Access into the area continued to be by means of fixed-wing aircraft to the Sturdee Airstrip from Smithers (approximately 1.1-hour flight). From Sturdee Airstrip road access exists to the Lawyers property (approximately 26 kilometres) and an additional 4 kilometres was added to access the Silver Pond property (Fig. 24-1). Elsewhere access is by foot or helicopter.

In the spring of 1985 a preliminary agreement was reached by SEREM Inc. and the province of British Columbia to share in the cost of upgrading and extending the Omineca Resource Road from its present terminus at Moosevale Flats to the Sturdee Airstrip, a distance of approximately 71 kilometres. The final decision and plans for this resource access road are contingent on SEREM Inc.'s submittal of a Stage 1 Report and commitment to a production decision to the province of British Columbia; this decision is expected some time in early 1986. Such improved access will no doubt enhance and stimulate further exploration and development activity in the Toodoggone area.

REGIONAL GEOLOGY

The regional geology of the Toodoggone area is described in several publications including Barr (1978), Schroeter (1981-1985), Panteleyev (1982-1984), and Diakow (1983-1985). British Columbia Ministry of Energy, Mines and Petroleum Resources' Preliminary Map No. 61 (Geology of the Toodoggone River Area, NTS 94E) incorporates field mapping by Ministry staff (mainly between 1980-1983), data from ministry assessment reports, plus data supplied by various companies.

NEW AGE DATES

Diakow (1984) reported published and new K/Ar age determinations of 204 to 182 Ma from volcanic rocks in Toodoggone River map-area, and Schroeter (1982) reported a single hydrothermal alunite date of 190 ± 7 Ma.

New dates for three hydrothermal adularia samples from Lawyers AGB deposit, Golden Lion prospect, and Metsantan prospect are: 180 ± 6, 176 ± 6, and 168 ± 6 Ma, respectively (Table 24-1). A specimen of hornblende basalt from Takla rocks underlying Toodoggone volcanics was determined to be 210 ± 8 Ma. A whole rock sample of volcanic glass from a rhyolite flow was analysed but was not suitable for dating.

The 180 and 176 hydrothermal dates are from relatively pure adularia from vein selvages at the Lawyers and Golden Lion deposits. The Metsantan sample was a mixture of adularia with fine-grained quartz; the indicated 168 Ma age of mineralization might be low due to some loss of argon. The hydrothermal events and related gold-silver mineralization apparently postdate the youngest volcanism in the map-area by two to six, and possibly as much as 14 million years. This is similar to the 2 to 17-million-year interval between volcanism and mineralizing hydrothermal activity reported from southwestern United States Tertiary epithermal deposits.

CLAIM STATUS

The unofficial status of claim holdings within the Toodoggone area to September 1985 is shown on Figure 24-1. Table 24-2 lists current operators, where they are known.

TABLE 24-1
K/Ar AGE DETERMINATIONS FROM ADULARIA AND HORNBLENDE, 1985

SAMPLE NO.	LOCATION UTM COORDINATES		MINERALS	%K	Ar40* $\times 10^{-10}$ mol/g	%AR40	APPARENT AGE (Ma)
82AP-T107A	609560E	6356420N	Adularia	7.68	25.249	95.0	180 ± 6
LD84-Golden Lion	602550E	6381430N	Adularia	10.38	33.189	97.9	176 ± 6
LD84-Metsantan	601900E	6365270N	Adularia-quartz	8.09	24.666	96.4	168 ± 6
LJD84-Hb (Adoogacho Creek)	591400E	6380750N	Hornblende	0.696	2.696	93.7	210 ± 8

* Radiogenic Ar
Constants: $\lambda^{40}K_{\varepsilon} = 0.581 \times 10^{-10} yr^{-1}$ $\lambda^{40}K_{\beta} = 4.96 \times 10^{-10} yr^{-1}$; $^{40}K/K = 1.167 \times 10^{-4}$
%K determined by the Analytical Laboratory, British Columbia Ministry of Energy, Mines and Petroleum Resources, Victoria
Ar determination and age calculation by *J. E. Harakal, University of British Columbia*

British Columbia Ministry of Energy, Mines and Petroleum Resources, Geological Fieldwork, 1985, Paper 1986-1.
* This project is a contribution to the Canada/British Columbia Mineral Development Agreement.

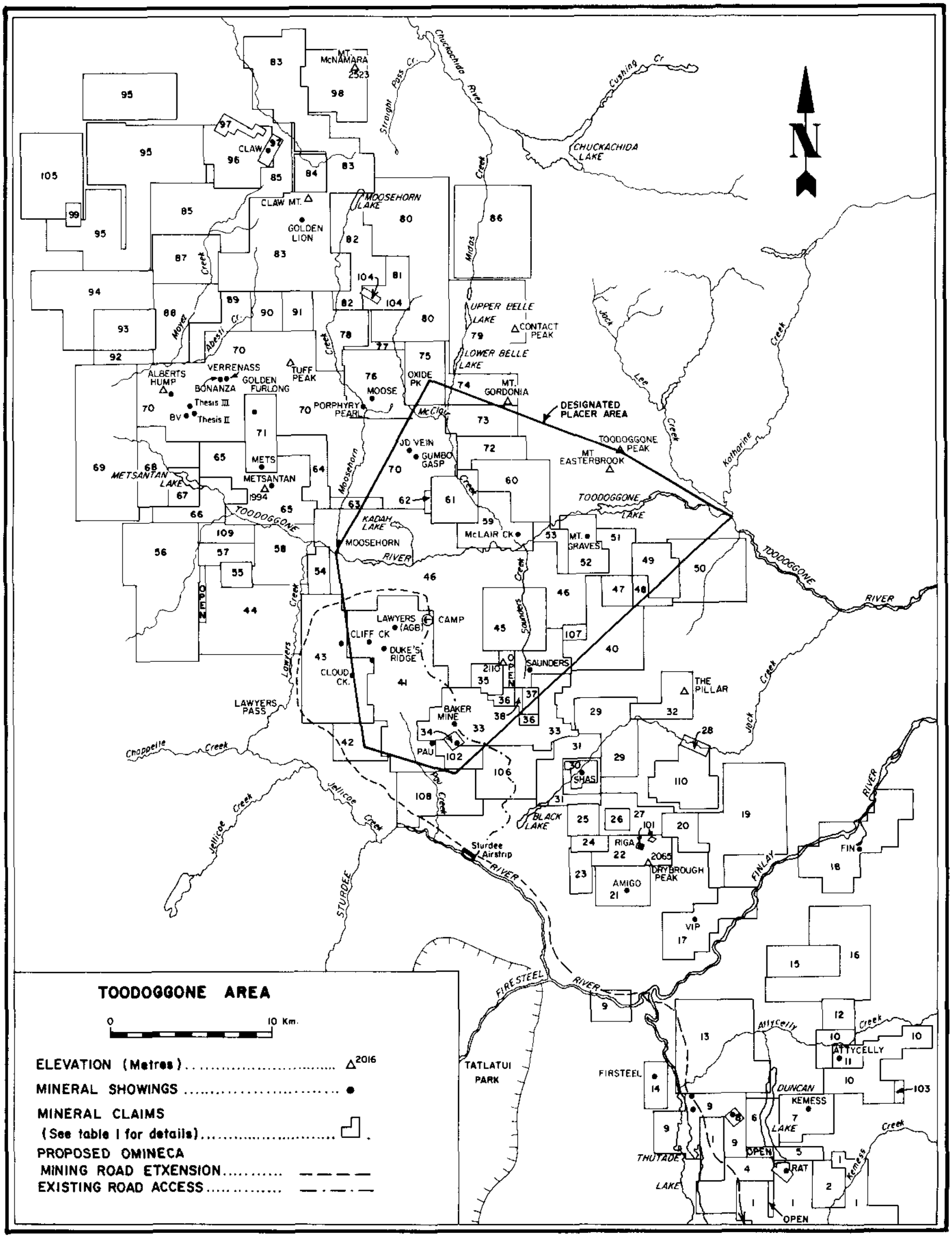

Figure 24-1. Claims in the Toodoggone River area (94E).

TABLE 24-2
TOODOGGONE RIVER AREA MINERAL PROPERTIES

NO.	CLAIMS	MINERAL INVENTORY NUMBER (94E)	OPERATOR
1	RON 1-11	13, 14, 15	Pacific Ridge Res.
2	DU, DU 2	—	Pacific Ridge Res.
3	RAT	25	Cominco
4	TUT 1, 2	—	Univex Mining
5	DU 1, 2	—	Pacific Ridge Res.
6	DUNCAN 1-4	—	Asitka Res.
7	NEW KEMESS 1, 2	21	Kennco
8	CROWN-GRANTED CLAIMS	12	Cominco
9	LAKE 1-5	—	Pacific Ridge Res.
10	KEM 1-9	—	Inca Res.
11	AUDREY WEST, AUDREY EAST	22	ABM Mining Group
12	AWESOME	81	Inca Res.
13	ARK 1-7	—	Ark Energy
14	FIRESTEEL	2	SEREM
15	WRICH 1-3	82	SEREM
16	RICH 1-5	—	Golden Rule Res.
17	GRACE 1-5	48	Asitka Res.
18	FIN 1-9	16	B. Pearson
19	JOCK 4, 6-12	—	Golden Rule Res.
20	GOLDEN RING, GOLDEN RING 2	—	Newmont Expl.
21	STAR, PULL, SUN	58	SEREM
22	PARADISE 3, 4	—	Phillip Res.
23	DALE	—	M. Bell
24	LEGHORN	—	Kidd Creek Mines
25	JERRY	—	Phillip Res.
26	DAWN	—	Newmont Expl.
27	SHASTEX, PARADISE 2	—	Alexim
28	BRENDA 1-8	8	Camine Dev.
29	JK 1-5	39	Golden Rule Res.
30	SHAS, SHA 1-2	50	International Shasta, Newmont
31	SHASTA 3-5, SILVERREEF 3	—	Arctic Red Res.
32	ATLAS, HERCULES	42, 83	SEREM
33	CHAPPELLE	26, 71	Multinational Res.
34	CROWN-GRANTED CLAIMS	27	O. McDonald
35	PEL	—	Multinational Res.
36	XT 1, 3	—	D. Stecyk
37	DAVE PRICE	—	Western Horizons
38	XT 2	—	Golden Rule Res.
39	GOLDEN NEIGHBOUR 1-4	37	Alban Expl., Lacana
40	IAN, ADRIAN, PAUL, OTTO	—	Rhyolite Res.
41	NEW LAWYERS 1-4, LAW 1-3, BREEZE, ROAD 1-3, PERRY 1, 2, MASON 1, 2, GTW 1-3, ATTORNEY 2	66, 67, 74, 72, 73	SEREM
42	ATTORNEY 1, 2	—	Alexim
43	SILVER POND, ASAP, SILVER SUN, SILVER CLOUD 1-3, SILVER CREEK	69, 75	St. Joe
44	PC 1-4, MM 1-4	—	Tanker Oil and Gas
45	SAUNDERS 1-4	40	Golden Rule Res.
46	GWP 1, 10-30, 34, 40, 41, 43, 200	86	Cassidy Res., Western Pacific Energy, Imperial Metals
47	DEBRA LYNN	—	Kelley-Kerr Energy
48	MARKER	28	Kelley-Kerr Energy
49	SAMMY, SUN	89	Newmont Expl.
50	KNIGHT, KEVIN, BISHOP, CASTLE	—	Hi-Tec Res.
51	GRAVY II, IV	—	Hemlo Expl.
52	GRAVES 1, 2	7, 87	Miramar
53	GRAVY I, II, TODD	—	Kelley-Kerr Energy
54	KODAH 1-2	68	SEREM
55	GOLDEN STRANGER, GOLDEN STRANGER 2	76	Western Horizons
56	LASSIE 1-4, LADD 1-4	—	Alexim
57	SB 3, 4	—	S. Young
58	LAINEY 1-4	—	Deep South Pet.
59	MAC III, HYFLY I, II	1	C. Ashworth
60	MAC I, II, IV	—	Hi-Tec Res.
61	BELLE 1, 2, 4	—	Manson Creek Res.
62	*BIG LODE*	—	*Alexim*
63	KEY	—	Duke Minerals
64	LEXIM 1-3, GWP 42	—	Mandusa Res.
65	METSANTAN 1-9	64	Bart Res.
66	SY 2-4	—	A. L. Constantine
67	DISCOVERY 4	—	Black Diamond Res.
68	DISCOVERY 1-3	—	Duke Minerals
69	INDIAN GOLD 1-4, TOODOGGONE 1-4	—	Alexim
70	AL 1-8, BERT, ERNIE, WINKLE, BULL, CHUTE, SURPRISE, GEROME, CALF MOOSE, ANTOINE LOUIS, TOUR, COW MOOSE, STURDEE, JM, JS, KADAH 1-2, BIG BIRD, GAS 1, JR, JB, JD	66, 65, 80, 78, 85, 84, 79, 91, 32	Energex
71	METS 1, 2	—	Manson Creek Res.
72	PEREGRINE, FALCON A	—	C. Ashworth
73	JOANNA III, JOANNA IV	—	International Westward Dev.
74	JOANNA I, II	36	Armour Res.
75	AMETHYST, KIDVIEW	—	Geostar
76	SCREE 1-3, MOOSE 1-3, BULLMOOSE, GAS 2	31	New Ridge Res.
77	*OXIDE I*	—	*Alexim*
78	HORN 1-5	20	Norman Res.
79	LAKE I-IV, MAGIC I, II	23	Hi-Tec Res.
80	CAT 1-4, MID 1-3, BELL 1-3	59	A. L. Constantine
81	GORD DAVIES, GORDON DAVIES 2	53	Lacana
82	HORN 1-4, AS 1-3	—	Deep South Pet.
83	GUARD, LYNX 1-8, GOLDEN LION 1-11, HUMP 1-2	77, 19	Newmont Expl.
84	SPAR MOUNTAIN	—	C. Kowall
85	PAW, PIKA, CAL 1, YET 1, SUET, GACHO	—	Hi-Tec Res.
86	ORO I, II, URUS I-IV	—	Hi-Tec Res.
87	RANGER 1-4	—	Cusac Industries
88	MOYEZ 1, 2, 4	—	Geostar
89	SPIKE, WOLF I	—	Duke Minerals
90	WOLF II	—	Texpez Oil and Gas
91	WOLF III	—	Skeena Res.
92	CHUCK 1, 2	—	Miramar
93	MOYTAN I, II	—	Yukon Gold Placers
94	ADOOG 1-5, STIK 1-4	—	Delaware Res.
95	GACHO 1-3, WILDCAT 1-3, HEAVY METAL 1-8, SHEEP ROCK 1, 2	54, 62	Alexim
96	*COPPERKING 1-5 NAMERA IV*	—	Western Horizons
97	CLAW	45	Umex
98	WOLVERINE I-IV	—	Hi-Tec Res.
99	DAR	93	Newmont Expl.
100	SILVER REEF	—	Newmont Expl.
101	RN	3	Windarra
102	CASTLE MT. 1	—	Dynamic Oil
103	MESS 4	70	SEREM
104	HAR	53	Kennco Expl.
105	STIK 1-4	—	Delaware Res.
106	BLACK	—	Hi-Tec Res.
107	ARGUS 2 plus?	—	Rhyolite Res.
108	HECKLE, JECKLE, TITAN	—	M. Bell
109	SB 1, 2	—	P. Crook

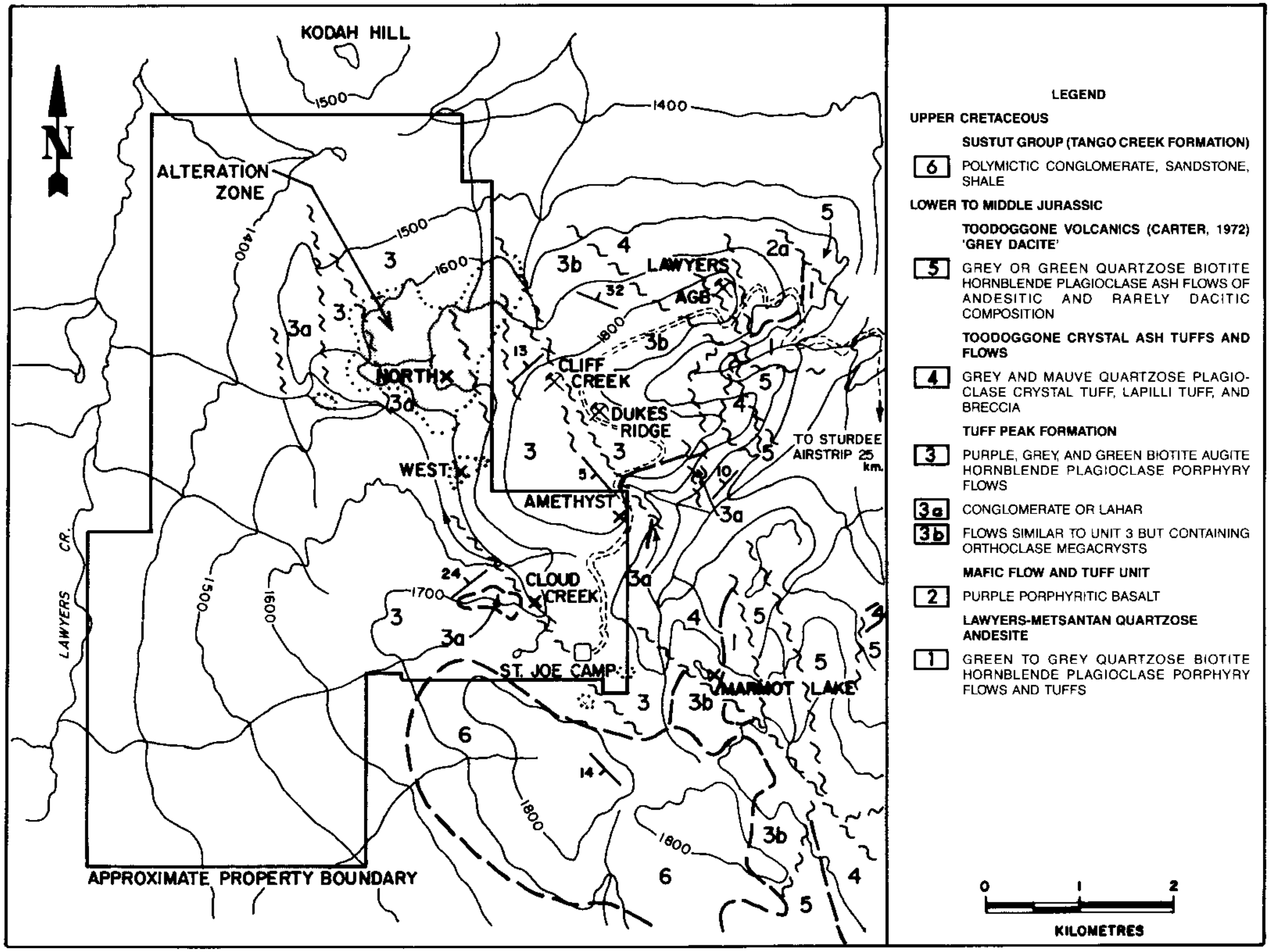

Figure 24-2. Geology of the Silver Pond property and area (based on Preliminary Map 61).

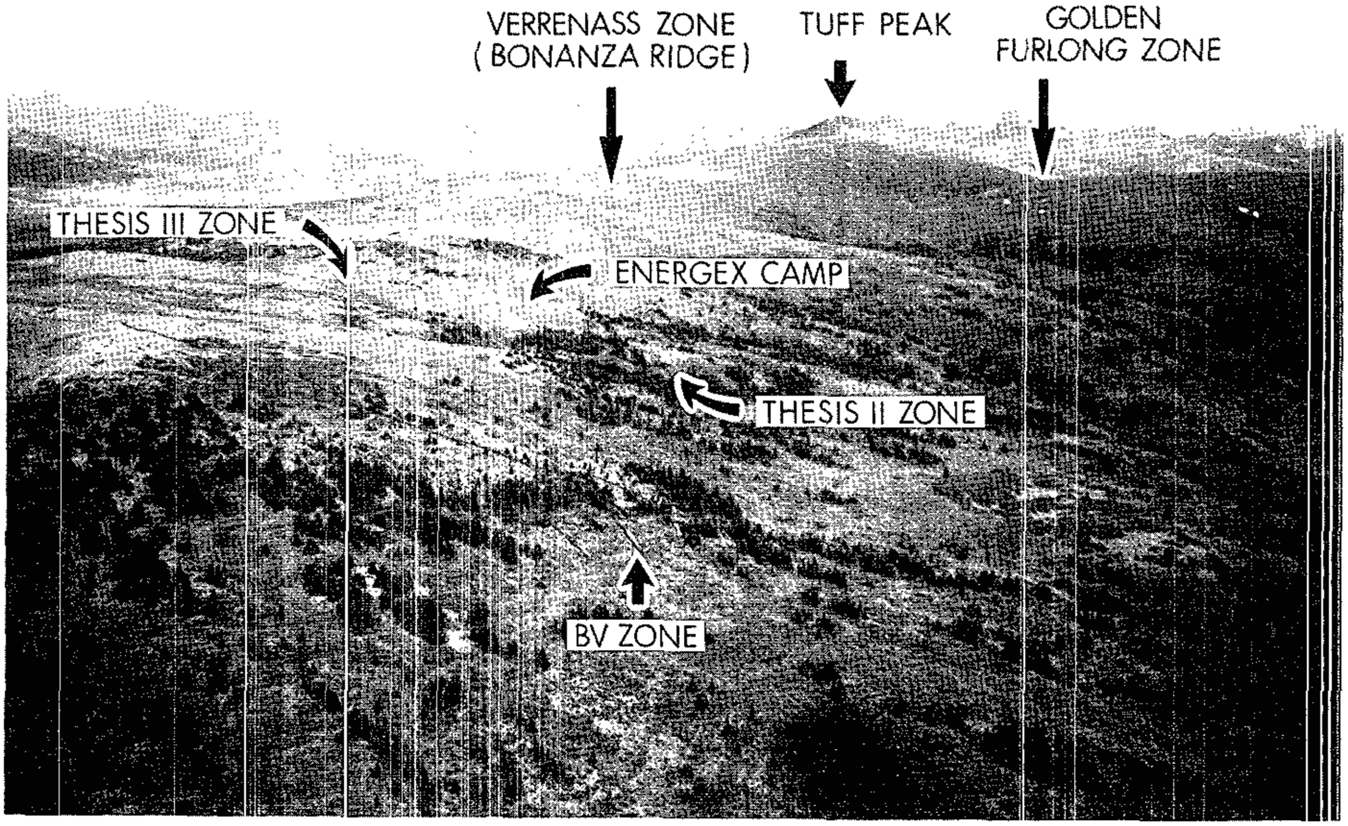

Plate 24-1. Looking northeasterly over A1 property.

PROPERTY UPDATES

Very brief visits were made to several properties within the Toodoggone area and only highlights of ongoing activity are described here.

LAWYERS (MI 94E-66) — SEREM INC.

The largest and most significant progam in the Toodoggone "camp" during 1985 cost an estimated $2.4 million and involved development, environmental studies, and road design. It was carried out by SEREM Inc. on their Lawyers property (*see* Fig. 24-2). Two new adits were completed on the Amethyst gold breccia zone, one from the 1 760-metre level and the other from the 1 800-metre level. Together with the previously completed 1 750-metre level adit consisting of 762 metres of advance and slash, these three adits have enabled the sampling, correlation, and delineation of ore reserves, now estimated at 509 600 tonnes grading 7.2 grams per tonne gold and 260 grams per tonne silver over a vertical range in excess of 150 metres on the Amethyst gold breccia zone. The 1 700 level adit consists of a 250-metre crosscut plus drifts, 50 metres north and 45 metres south. The ore shoot intersected on the 1 700 level was well mineralized with electrum, native gold, and argentite. Slickensiding observed near the 1 700 level portal indicated a strong left lateral movement which appears to be typical in the Toodoggone area. The 1 800 level consists of a 107-metre crosscut plus drifts 60 metres north and 68 metres south. In addition, 178.6 metres of raising was completed, connecting all levels to the surface.

In addition to the development program, SEREM Inc. contracted out environmental studies and an on-site investigation of the proposed extension of the Omineca Resource Road from Moosevale Flats to link up with the Sturdee Airstrip.

PAU CREEK (MI 94E-72) — SEREM INC.

Exploration during 1985 on the Pau Creek showing by SEREM Inc. revealed some significant assays for gold and silver. On the property Takla Group andesites are in structural contact with Permian limestones.

AL — ENERGEX MINERALS LTD.

The Al property, located approximately 40 kilometres north of the Sturdee Airstrip, is owned and operated by Energex Minerals Ltd. It is a very large property, consisting of 565 claim units and fractional claims (*see* Plate 24-1 and Fig. 24-3). During 1985, Energex Minerals Ltd. completed a diamond-drilling program totalling approximately 1 690 metres in 35 short holes as well as surface trenching, geophysics, and prospecting at an estimated cost of nearly $1 million. Three areas of gold mineralization were tested:

(1) **Thesis III (MI 94E-91)** — 17 short HQ holes totalling approximately 969 metres tested a steeply plunging quartz-barite-native gold zone in clay altered (mainly dickite) hornblende-feldspar andesitic tuffs ('Toodoggone volcanics'). The central part of the altered zone was drilled along a strike length of 120 metres, a width ranging from 12 to 22 metres, and a maximum vertical depth of approximately 60 metres. Native gold is primarily associated with replacement barite

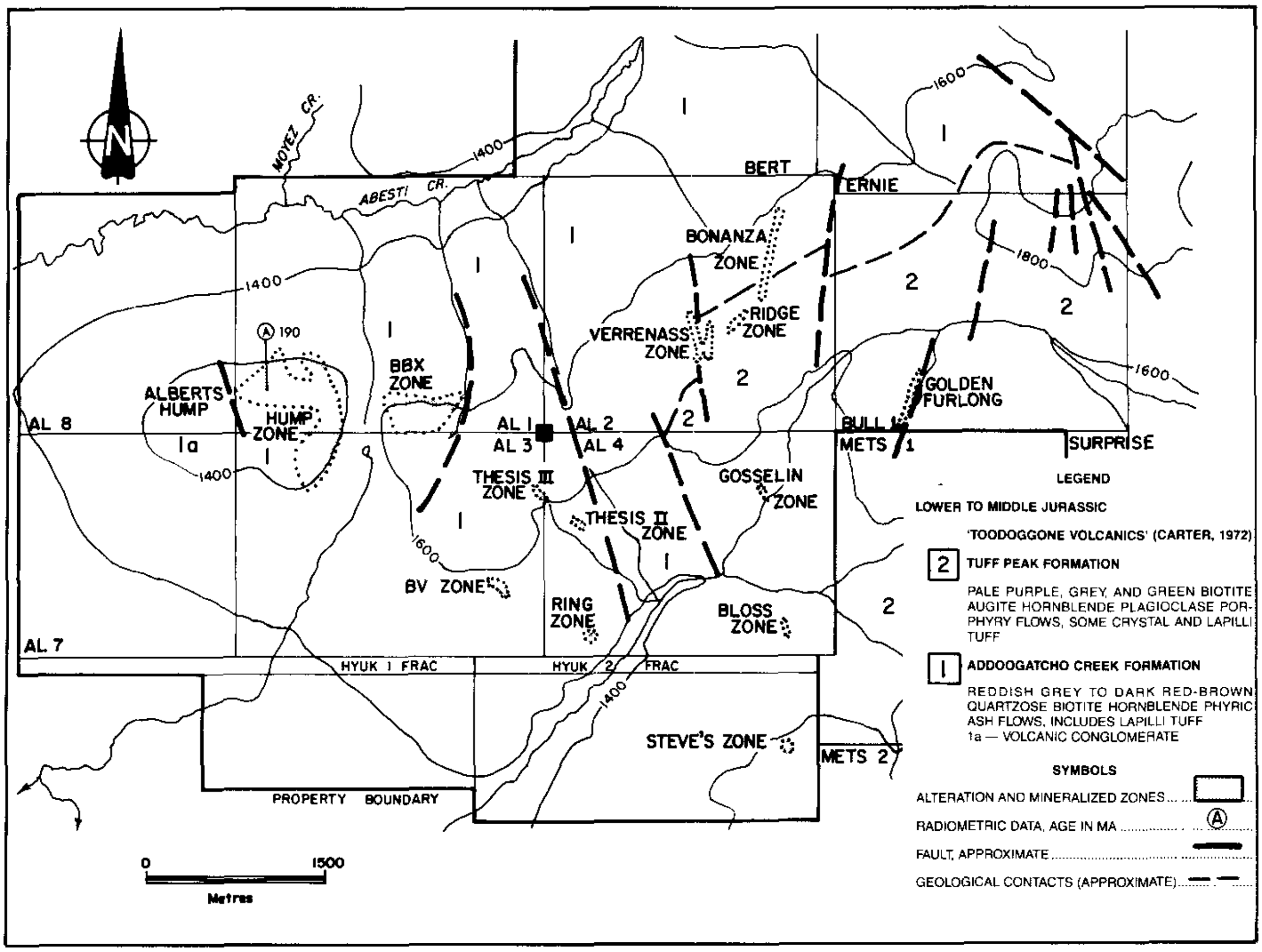

Figure 24-3. Geology of the Al property.

which averages 2 to 5 per cent. Locally, at depth, pyrite is abundant and trace amounts of native gold were observed. There are trace amounts of chalcopyrite, and galena, and corkite [$PbFe_3(PO_4)(SO_4)(OH)_6$] was identified by X-ray analysis of samples from DDH-85-02 at 61.1 metres. Some spectacular grades related to native gold were intersected in drilling holes like 85-10 and 85-30.

(2) **BV (MI 94E-91)** — 11 short HQ holes totalling approximately 450 metres were drilled along a zone exposed by trenching and drilling for more than 500 metres; alteration widths are up to 15 metres. Native gold is intimately associated with barite-filled fractures within a silicified, pyritic, clay alteration zone. The fractures appear to have a predominant west-northwest trend.

(3) **BONANZA RIDGE (MI 94E-78, 79)** — 7 short HQ holes totalling approximately 271 metres were drilled to test the small, high-grade, structurally complex Verrenass zone, and the Ghost zone, which may have potential for a near-surface bulk mining operation. Both areas are similar to the Thesis III zone. A chemical analysis of typical quartz-barite altered rock from the Verrenass zone yielded the following results: SiO_2, 64.21 per cent; Al_2O_3, 1.53 per cent; Fe_2O_3, 0.19 per cent; MgO, <0.02 per cent; CaO, <0.03 per cent; Na_2O, 0.011 per cent; K_2O, 0.048 per cent; TiO_2, 0.48 per cent; MnO, <0.002 per cent; Ba, 18.5%; S, 4.17%; CO_2, <0.07%; LOI, 2.2%; and H_2O-, 0.11%.

The total is apparently low because barium is present as barite (barium sulphate). The pattern represented here is characteristic of alteration zones on the Al property, with a gain in silica and barite and net losses of iron, manganese, potassium, sodium, cadmium, and aluminum.

For a more complete description of geology, alteration, and mineralization on the Al property the reader is referred to Schroeter (1985).

Overall mineralization on the Al property is suggested to have occurred in a high level, epithermal setting that included local hot spring discharge sites where boiling created porosity in the volcanic rocks and subsequent mineralization. There is a strong structural control involving intersections of small, local northeast-southwest faults with large, regional northwest-southeast faults. An anomalous heat flow regime and possibly some of the fluid component of the system may have been provided by hypabyssal felsic intrusions at depth. Hydrothermal alteration is widespread in structurally favourable zones; locally it is superimposed on diagenetic hematitization.

A thesis study by J. R. Clark underway at McGill University is aimed at defining the environment of formation of the mineralization and alteration.

SILVER POND (MI 94E-69) —
ST. JOE CANADA INC./
IMPERIAL METALS CORP.
CASSIDY RESOURCES LTD.

During 1985 St. Joe Canada Inc. (operator) completed 33 diamond-drill holes totalling approximately 3 000 metres on the Silver Pond property (*see* Fig. 24-2). Four main zones of mineralization were tested:

(1) **Cloud Creek (or Silver Creek)** — two holes were drilled on the old Kennco showing which consists of a northwesterly trending zone of silicification in 'Toodoggone' andesitic tuffs.
(2) **Amethyst zone** — a northwesterly trending silicified zone (minor quartz-amethyst veinlets) on strike with SEREM Inc.'s Cliff Creek breccia zone. The host rock is andesitic crystal tuff, similar to the host rock at the Lawyers AGM zone.
(3) **North zone** — a large pyritic, silicified ± clay (predominantly illite) altered zone with minor quartz veinlets containing trace sphalerite and pyrite.
(4) **West zone** — green andesitic tuff with quartz veinlets carrying minor chalcopyrite and pyrite. Illite is the predominant clay mineral present.

MOOSE (MI 94E-31, 81) —
NEW RIDGE RESOURCES LTD.

During 1985, New Ridge Resources Ltd., under an option agreement with Energex Minerals Ltd., completed approximately 915 metres of diamond drilling in 20 holes (including two on the Porphyry Pearl zone) on the Moose property. The main zone was drill tested along a length of approximately 550 metres in a northwesterly direction. Galena, sphalerite, pyrite, barite, hematite, chlorite, and quartz with minor chalcopyrite and trace amethyst occur as vein-type occurrences in altered hornblende-feldspar crystal and crystal-lapilli tuffs and tuff breccias. Local minor brecciation and shearing are found near the break in slope, which is presumed to be related to a regional fault that extends from McClair Creek northwest up to Moosehorn Creek.

Silver is the main target; the company reports assays of up to 6 600 grams per tonne. Acanthite is suspected but has not yet been verified. Secondary minerals identified include anglesite and cerussite.

METS (NO MI) —
MANSON CREEK RESOURCES LTD.

During 1985, Manson Creek Resources Ltd., under an option agreement with Golden Rule Resources Ltd., completed three short diamond-drill holes on their 'A to E' zone located on the south-eastern portion of the claim group. In all, five northerly trending altered zones, which presumably splay off regional northwesterly faults, have been identified. The 'A to E' zone, consisting of a quartz, barite, clay-altered zone with minor native gold and pyrite, has been traced by 10 surface trenches and 3 short diamond-drill holes along a length of 800 metres and over a maximum width of 11 metres. Locally the zone is brecciated and up to 10 metres in width with a quartz porphyry dyke adjacent to the altered zone. Host rocks are 'Toodoggone' andesitic tuffs.

BAKER (MI 94E-26) —
MULTINATIONAL RESOURCES INC.

During 1985, Multinational Resources Inc., under an option agreement with Du Pont of Canada, completed 11 short holes totalling approximately 610 metres; two were on the West Chappelle vein, one on the D vein, two on the C vein, two on the B vein, and four on the main or A vein and its northeastern extension. The program was designed to re-evaluate known vein systems.

The agreement includes options on the existing mill (90-tonne-per-day-capacity) and the 80-man mining camp.

Between 1980 and 1983 Du Pont of Canada mined 79 580 tonnes from A vien that yielded 1 287 676 grams of gold and 25 446 258 grams of silver.

Bulldozer trenching and an induced polarization survey were also carried out.

METSANTAN (MI 94E-64) —
BART RESOURCES LTD.

Bart Resources Ltd., under an option agreement with Lacana Mining Corp., conducted a small surface program which included resampling of the Lacana Mining Corp. trenches. The program basically confirmed Lacana Mining Corp.'s previous results and located several new anomalies. The main mineralized zone has been traced along a length of nearly 550 metres and across widths of up to 18 metres.

MOOSEHORN (MI 94E-86) —
CASSIDY RESOURCES LTD.
E&B MINES LTD.

During 1985, Cassidy Resources Ltd. (as operator), conducted detailed geological and geochemical surveys in preparation for a diamond drill program. An epithermally altered and weakly mineralized zone has been identified on the surface for a length of 2 200 metres and across widths up to 270 metres.

SHAS (MI 94E-50) —
INTERNATIONAL SHASTA RESOURCES LTD.
NEWMONT EXPLORATION OF CANADA LTD.
ARCTIC RED RESOURCES CORP.

Because of a legal tenure dispute, no work was carried out in 1985 on the Shas prospect, located 16 kilometres southeast of the Lawyers property and 10 kilometres southeast of the Baker property. Arctic Red Resources Ltd. has estimated geologic reserves at several million tonnes grading 2.45 grams per tonne gold equivalent within which there is a higher grade section of 498 850 tonnes grading 5.3 grams per tonne gold equivalent (George Cross Newsletter, July 4, 1985). The main zone is the Creek zone which has a strike length of 370 metres and a width ranging from 2 to 23 metres. Mineralization has been outlined to a depth of 100 metres; it is open to depth and to the north.

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British Columbia Geological Survey
Geological Fieldwork 1985

MUDDY LAKE PROJECT*
(104K/1)

By T. G. Schroeter

INTRODUCTION

Mapping and property investigation were conducted for 12 days in the Tatsamenic Lake-Muddy Lake (Bearskin Lake) area in 1985. The Muddy Lake gold prospect, which consists primarily of the Bear and Totem claims, is located 137 kilometres west of Dease Lake at latitude 58 degrees 13 minutes north and longitude 132 degrees 17 minutes west; it lies approximately 10 kilometres due south of Tatsamenie Lake (Fig. 25-1). Access is by fixed-wing aircraft to Muddy Lake or the Muddy Lake airstrip from Dease Lake, Telegraph Creek, Atlin, or Whitehorse. A winter bulldozer trail to the property exists from Telegraph Creek, located approximately 75 kilometres to the southeast. Helicopter access in the area was kindly provided by Chevron Canada Resources Ltd., the owner/operator of the property. Several other nearby properties, including Nie, Slam, Ram, Tut, Inlaw, Outlaw, Oro, Tan, Misty, and Pole, were also briefly visited by the writer.

During the 1985 season an average of 35 people worked out of the Muddy Lake base camp and two diamond drills were in operation. Drilling during 1985 totalled approximately 4 150 metres in 31 holes; 56 holes totalling approximately 10 000 metres were also drilled in 1984 and 30 holes totalling 5 300 metres in 1983.

LOCAL PHYSIOGRAPHY

Near Tatsamenic Lake the glacial movement was from north to northwest (Souther, 1971). The lake shown on late 1940's air photographs and still shown on the 1:250 000 topographic map (104K), that is located approximately 6 kilometres northwest of Muddy Lake, does not exist today. It apparently drained sometime in the 1960's.

Souther (1971) states that small landslides are found in nearly all major valleys of the Taku-Telsequah map-area. He commented on the 'Bearskin slide', which is located on the south-facing slope above the outlet of Bearskin (Muddy) Lake (Fig. 25-2). There is not much doubt that it formed the barrier behind which the lake is impounded, as suggested by Souther in 1971. The slide appears to be the result of a large single event that came from the north and possibly north-northwest near the top of a 900-metre-high ridge, and swept down the steep slope into the valley and part way up the opposite side. The floor of the valley from the outlet of the lake to more than 1.6 kilometres downstream is strewn with huge boulders of greenstone-metagabbro; many are more than 6 metres in diameter. The cause of the slide has not been determined but its spatial proximity to the Muddy Lake prospect has prompted Chevron to examine it in some detail.

REGIONAL GEOLOGY

Early Geological Survey of Canada workers in the Tatsamenic Lake area included Kerr (1930, 1932) and Souther (1958 to 1960). Their published maps and descriptions remain the best references for regional geology. More recent geological information on the area between Tatsamenie Lake and Bearskin Lake has been compiled from Assessment Reports filed by Chevron (Fig. 25-1). The Tatsamenie Lake area is underlain by intensely folded and regionally metamorphosed Permian, Triassic, and older strata that are separated by a pre-Upper Triassic unconformity from less folded and less metamorphosed Mesozoic sedimentary and volcanic rocks. The Mesozoic strata are overlain unconformably by flat-lying Late Tertiary and Pleistocene plateau basalts of the Level Mountain Group.

Three main episodes of tectonic activity have affected the strata: (1) the Mid-Triassic Tahltanian Orogeny; (2) an Upper Jurassic event, and (3) an Early Tertiary event.

ULTRAMAFIC ROCKS (UNIT 1)

The oldest rocks in the area are small, fault-bounded slices of ultramafic rocks; they are associated with northerly trending faults, especially southeast of Tatsamenie Lake. The rock is a black to greenish black, microcrystalline serpentinite with many slickensided surfaces and trace veinlets of brittle, fibrous serpentine. The proximity of these rocks to beds of dolomitic limestone and to fault zones, the absence of primary minerals, and intense hydrothermal alteration of nearby rocks, including the formation of listwanite, all suggest that these ultramafic bodies are of deep-seated intrusive origin. Their emplacement along fractures that acted as conduits to later gold-bearing fluids is considered structural, not genetic.

PERMIAN LIMESTONE (UNIT 2)

Souther (1971) estimated the Permian section at Tatsamenie Lake to be approximately 760 metres thick. It consists of a succession of limestones and dolomitic limestones, with local chert, shale, and sandstone members. The succession is best exposed in the cores of northerly trending anticlines south and east of Tatsamenie Lake. The limestone is massive to well bedded, usually fine grained, and medium grey in colour. Near intrusions it is a white, medium-grained marble. It contains abundant crinoid and shell debris, as well as poorly preserved fusulinids and corals. The limestones are considered to be part of the Stikine terrane assemblage rather than Cache Creek Group, based primarily on the different faunal content (Monger, 1977). Monger noted that the coeval fusulinid faunas in the Stikine assemblage contain far fewer genera and include forms similar to some in northern California and Nevada, suggesting major transcurrent movements. Schwagerinid fusulinids identified in the Tatsamenie Lake area (Monger, personal communication, 1985) correlate with other 'Stikine Facies' rocks in the Tanzilla-Stikine River area, the Oweegee Peak area, the Terrace area, the Whitesail area, and the Fulton Rivver area. These Permian carbonates on the west side of the Bowser Basin are distinctive in their uniform, presumably sheet-like, character over a north-south distance of 500 kilometres (Monger, 1977). The thick, widespread carbonate sections suggest that stable, shelf conditions existed at their time of formation.

PRE-UPPER TRIASSIC ROCKS (UNIT 3)

Souther (1971) estimated a thickness in excess of 2 620 metres for the Stikine terrane package of fine-grained clastic sedimentary rocks and intercalated volcanic rocks, now mainly altered to phyllite and greenstone, and minor chert, jasper greywacke, and limestone. This package overlies the Permian limestone with apparent conformity. In the Muddy Lake area this contact is often obscured by

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* This project is a contribution to the Canada/British Columbia Mineral Development Agreement.

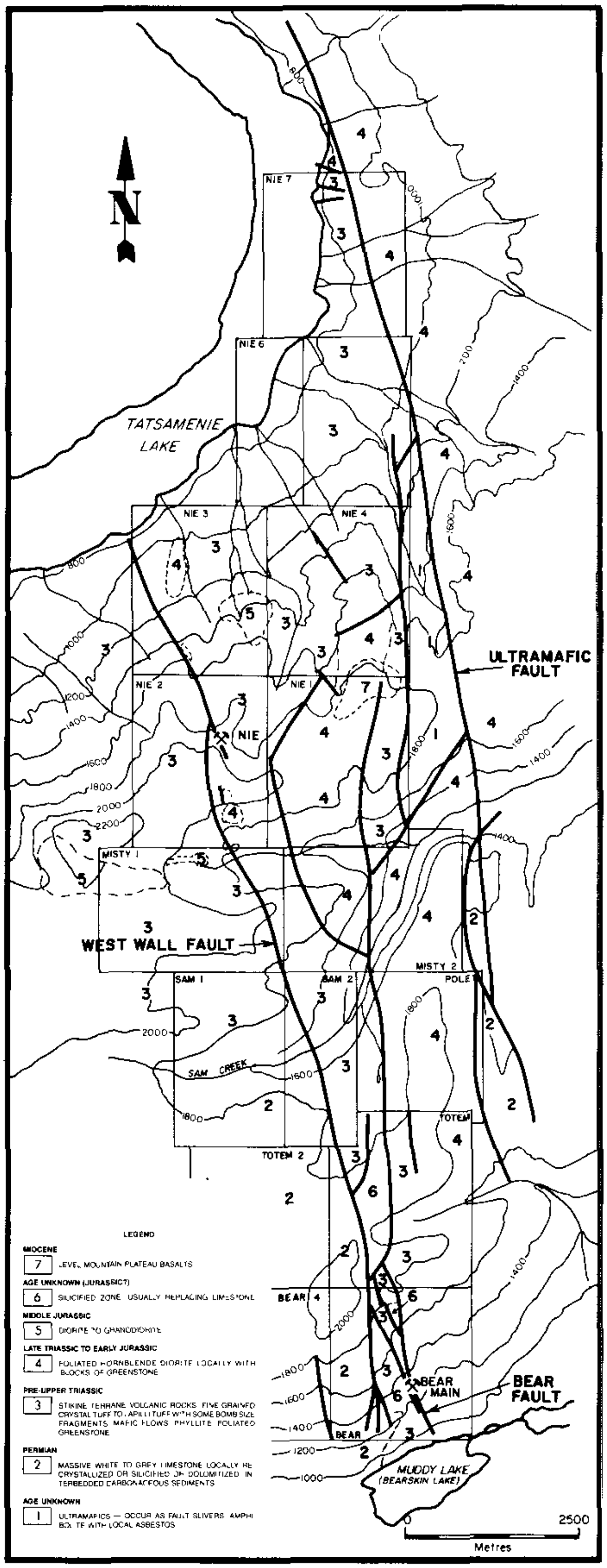

Figure 25-1. Geological plan of the area between Tatsamenie Lake and Muddy Lake. Base map supplied by Chevron Canada Resources Ltd.; compilation in part from British Columbia Ministry of Energy, Mines and Petroleum Resources Assessment Reports.

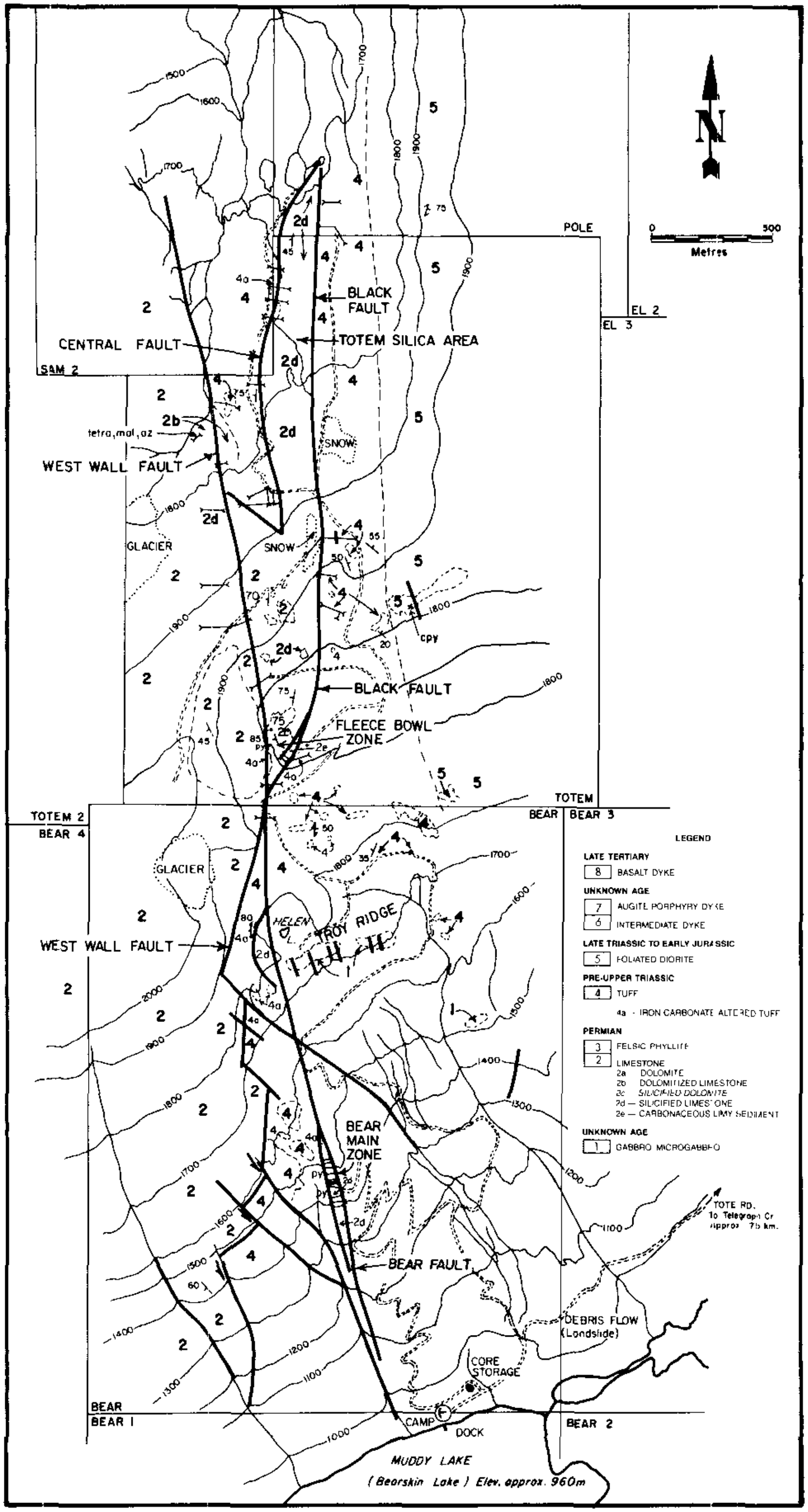

Figure 25-2. Geological plan of the Muddy Lake gold prospect. Base map supplied by Chevron Canada Resources Ltd.

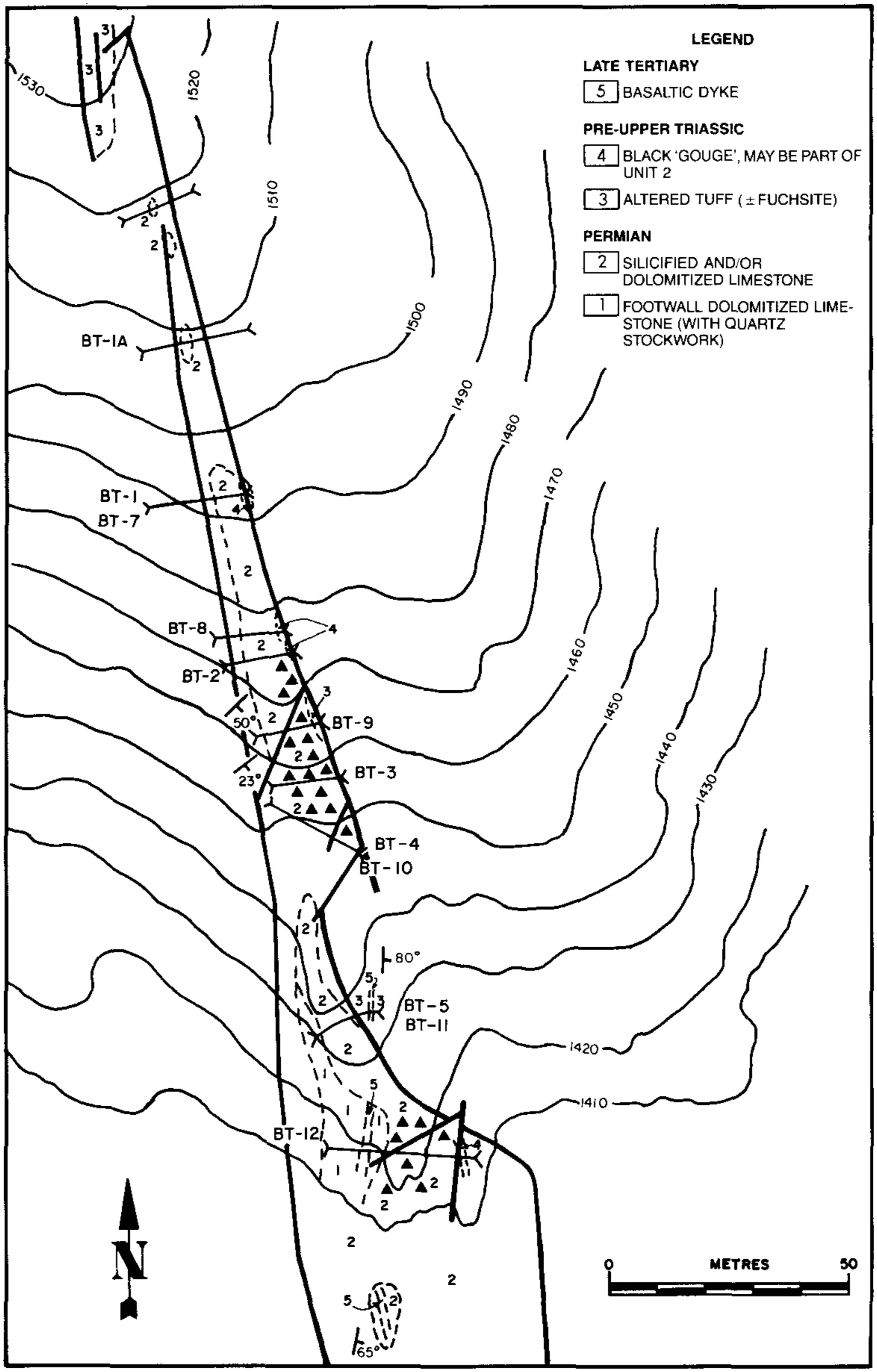

Figure 25-3. Geological plan of Bear Main zone, Muddy Lake.

faulting. The volcanic rocks are intensely folded and sheared; they display a well-developed slaty cleavage and foliation. Regional metamorphism has converted original crystal-lapilli tuffs and mafic flows to greenstone, chlorite-amphibole schist, and phyllite but primary bedding and textural features are preserved locally. Souther (1971) described a relatively undeformed, 610-metre-thick section south of Tatsamenie Lake, consisting of light green, siliceous phyllite interlayered with calcareous and dolomitic phyllite and overlain by more than 500 metres of dark green chloritic phyllite. In general, marker horizons are absent in the greenstone package. Tabular bodies, often dyke swarms, of gabbro (metagabbro) and basic diorite of unknown age are associated with the ultramafic rocks. Zones of intense shearing within these dykes are common. Their spatial relationship to the pre-Upper Triassic volcanic rocks and their chemical similarity suggest that the two correlate. In the Chutine map-area, south of Muddy Lake, black calcareous siltstone occurs more than 100 metres above the Permian limestone. Other banded sediments include shale, siliceous siltstone, and fine-grained greywacke. These rocks correlate with Mid to Upper Triassic rocks.

LATE TRIASSIC TO EARLY JURASSIC (UNIT 4)

Foliated hornblende quartz diorite is the predominant intrusive rock in the eastern portion of the area. The rock is fine to medium grained and ranges in composition from diorite to quartz monzonite. The rock is usually strongly altered with abundant chlorite, epidote, and hematite developed along fractures. The diorite is richer in hornblende near its contacts, and adjacent sedimentary rocks are usually hornfelsed; many contacts are faulted. An Early or Middle Jurassic age is assigned to these rocks on the basis of textural and mineralogical similarity to boulders found in the Lower Jurassic Takwahoni Formation. K/Ar age determinations on two such boulders yielded Late Triassic to Early Jurassic ages of 206 and 227 Ma (Geological Survey of Canada, Age Determinations 62-76 and 62-77). The diorite intrudes pre-Upper Triassic rocks north-northeast of Muddy Lake.

MIDDLE JURASSIC (UNIT 5)

A number of hornblende diorite to granodiorite stocks crop out in the western portion of the region. Contacts with the country rock are sharp and regular; the intrusive rocks are not foliated. Locally, such as at the Nie showing, these bodies occur in fault planes and may have a genetic relationship with mineralization.

An albitized quartz diorite of this suite from the southeast end of Tatsamenie Lake yielded a K/Ar whole rock date of 171 ± 6 Ma (Hewgill, 1985); it probably represents the latest stage of hydrothermal activity associated with Unit 5 rocks.

MIOCENE (UNIT 7)

Flat-lying plateau basalts of the Level Mountain Group are the youngest rocks in the region. They are black, fine-grained basalts with open vesicles along dyke margins, and in flow tops.

PROPERTY GEOLOGY

Remarks on property geology will refer mostly to the Bear and Totem claim groups of the Muddy Lake property (Fig. 25-2), and to specific zones within these claims, such as the Bear Main zone (Fig. 25-3, Plate 25-1).

UNKNOWN AGE (UNIT 1)

A gabbro or metagabbro of unknown age crops out on the eastern portion of the property, particularly on Troy Ridge. It is extensively chloritized and hematized. Its relationship with other rocks is unclear, but it may correlate with the pre-Upper Triassic mafic volcanic rocks. The gabbro appears to be cut by foliated hornblende diorite of the Late Triassic to Early Jurassic age.

PERMIAN (UNIT 2)

The unaltered limestone is massive to well bedded with cherty grey 'boudins' up to 15 centimetres in length. Fossils are not abundant. Local brecciation and sedimentary breccias that occur as conformable layers within the limestone section consist of angular to subangular clasts of limestone in a fine-grained carbonate matrix. Late-stage calcite veins and cavity fillings both crosscut and parallel bedding planes within the limestone. On the bluff above Helen Lake, veins are up to 1 metre in width.

Adjacent to fault contacts, particularly the West Wall fault, the limestone is pink, variably dolomitized, and contorted to isoclinally folded. In altered areas, the limestone is silicified and locally vuggy with the late-stage veinlets of calcite and siderite.

A sedimentary package of siltstone and carbonaceous siltstone lies conformably on the limestone and dips 75 degrees to the east. This unit is invariably strongly faulted and not well exposed. The name 'Black fault' was chosen because it forms a black, carbonaceous zone adjacent to silicified limestone in the hangingwall.

PRE-UPPER TRIASSIC (UNIT 4)

Overlying the limestones with apparent conformity is a thick section of ash, lapilli and crystal andesitic tuffs, and possibly mafic flows. Locally graded beds, flame structures, and rip-up clasts in ash layers give tops. In detail the mafic volcanic rocks grade into tuffs across distances as little as 2 metres. Local coarsening gives the volcanics a dioritic appearance. The sequence has few markers — one being a chalcopyrite-bearing horizon in lapilli tuff. Where altered, mainly in the hangingwall, tuffs are silicified, carbonatized, and contain fuchsite (listwanites). Locally the tuffs are interbedded with black siliceous siltstone and may contain up to 3 volume per cent pyrite. At the Fleece Bowl showing and elsewhere, altered fuchsite-bearing tuffs occur as fault pods or slices.

LATE TRIASSIC TO EARLY JURASSIC (UNIT 5)

Hornblende diorite is strongly foliated and exhibits strong alteration to chlorite, hematite, and epidote, and contacts with pre-Upper Triassic rocks are brecciated. Locally the diorite contains up to 5 per cent pyrite, and traces of chalcopyrite both as disseminations and on fractures. It intrudes the pre-Upper Triassic rocks and is locally agmatitic. Angular blocks of greenstone-metagrabbro 0.3 metre to 2 metres in diameter, have been incorporated into the diorite. Dykelets of felsite cut both the foliated diorite and the intruded greenstones; later fracturing offsets these dykelets.

UNKNOWN AGE (MIDDLE JURASSIC ?) (UNIT 6)

Four occurrences of narrow dykes of hornblende diorite composition were noted — three in the area of the Totem silica zone and one in drill core from the Fleece Bowl zone. The dykes cut all older rocks. A sample for possible age dating was collected from a dyke cutting foliated hornblende diorite on the east side of the Totem silica area. In Fleece Bowl, a 'felsic dyke', which was mineralized in several sections, was intersected by drilling.

MIOCENE (UNIT 8)

A 1-metre-thick dyke of black basalt, probably a feeder to Level Mountain Group flows, crops out in Bear Main zone.

BEAR MAIN ZONE (Fig. 25-3; Plate 25-1)

The silicified 'pod' on Bear Main zone has been traced by drilling along a length of 1 kilometre, across a width of 10 metres and to a depth of at least 200 metres. The 'pod' is composed of silicified dolomite and is bounded on the west side by altered tuffs. Rare

Plate 25-1. View northerly over Muddy Lake toward Bear Main Zone

bedding at 085/23 south was preserved as were remnants of isoclinal folds. The dolomite locally displays a quartz stockwork with resistant veinlets of quartz. The southern portion of the 'pod' is strongly brecciated; the breccia zones commonly have relatively sharp contacts and occur between the silicified dolomite and altered tuff. Two varieties of breccia exist:

(1) **Heterolithic breccia**: contains fragments of fuchsite-bearing tuff, white-grey limestone, black carbonaceous siltstone, white to grey quartz, and black limestone in a dolomitic matrix.

(2) **Monolithic breccia**: consists of silicified white limestone fragments in a grey, silicified limestone matrix.

Both varieties of breccia contain vuggy quartz and pyrite up to 10 per cent by volume.

The hangingwall fault (Bear fault) cuts the tuffaceous rocks and is marked by a zone of black gouge. A thick section of ash, lapilli and crystal tuffs, and what appear to be local mafic flows, occur above the hangingwall. The only marker observed is a chalcopyrite 'zone' within the lapilli tuff. Slickensided fractures have attitudes of 045/48 northwest. A 1-metre dyke of black basalt (Tertiary ?) intrudes silicified dolomite and altered tuff on Bear Main zone.

Near the north end of the main outcrop (elevation 1 520 metres, Fig. 25-3) soil and talus drape over the silicified and/or dolomitized limestone.

FLEECE BOWL ZONE

The West Wall and Black faults bound the Fleece Bow zone on the west and east respectively (*see* Fig. 25-2). The Black fault occurs in a graphitic, siliceous siltstone and dips to the east; the fault zone ranges from 6 to 20 metres in width. Late-stage calcite veinlets cut the rock which is locally vuggy. The hangingwall zone consists of fuchsite-bearing tuff with trace arsenopyrite in quartz veinlets. The West Wall fault cuts silicified limestone and silicified dolomite and dips steeply to the east. A slice up to 12 metres wide with strong, north-striking foliation consists of fuchsite-bearing tuff with quartz-carbonate veining, and breccia containing angular fragments of fuchsite-bearing tuff, and silicified limestone up to 15 centimetres in diameter is exposed in a north-south trench (Fig. 25-2). The rocks contain 1 to 2 per cent pyrite as disseminations and fracture fillings. The hangingwall fault in this 'slice' is marked by black gouge which contains anomalous gold values. The hangingwall sequence consists of well-banded silicified limestone and dolomite.

Diamond drilling encountered a 'felsic' dyke which consists of fine-grained white quartz eyes in a pervasively sericitized groundmass and contains up to 10 per cent pyrite as fine disseminations and fracture fillings. The dyke is anomalous in gold (Chevron personnel, personal communication).

TOTEM SILICA ZONE

A large (1 100-metre by 200-metre) zone of intense silicification with or without dolomitization occurs on the northern portion of the property (Fig. 25-2). The host rocks are well-bedded, locally intensely folded limestones with some dolomites; they occupy the core of a north-trending anticline. The limestone beds have local, strata-bound breccia zones.

Two phases of folding are prominent: phase 1 consists of tight, isoclinal, commonly recumbent folds that are consistently S-shaped, when viewed southerly down the plunge; phase 2 consists of broader, open anticlinal folds that trend northerly, as do regional, broad anticlinal folds at the northwest end of Tatsamenie Lake. Local minor folds occur on the limbs of phase 2 folds.

Strong, late-stage northeasterly trending crossfracturing is prominent. 'Boudinaging' of quartz in banded silicified limestone is locally well developed, as are breccias with large, quartz-lined vugs around silicified limestone fragments. In vuggy quartz-calcite breccias in 'sandy' limestones, rhombs of calcite grow on quartz crystals. Pyrite occurs in trace amounts within the silicified limestone and locally occurs as 'wispy' rims around white silicified limestone fragments in breccias.

The southwest side of the zone is characterized by silicified dolomite with quartz stockworks that are weakly mineralized with tetrahedrite occurring as disseminations and on fractures.

On the west side of the Totem Silica zone, which is on the west limb of the anticline, bedding is steep near the fault contact between silicified limestone and interbedded fuchsite-bearing tuff and carbonaceous siltstone. This fault zone strikes north and dips east; it is brecciated with hematite-rich slickensides plunging 45 degrees to the south, indicating that the west side moved down.

The hangingwall section both east and west of the Totem Silica zone consists of foliated hornblende tuff, chloritic tuff, and fine-grained greenstone with hematitic fractures. A foliated hornblende diorite intrudes the rocks on the east. Hornblende-feldspar porphyry dykes of intermediate composition that trend southwest and dip steeply, cut silicified diorite. These dykes have been altered to epidote, chlorite, and clay minerals.

STRUCTURE

Three main episodes of tectonic activity have occurred in the region: (1) Mid-Triassic Tahltanian Orogeny, (2) Upper Jurassic; and (3) Eary Tertiary. Monger (1977) stated that "the Stikine assemblage was emplaced by poorly understood, complex motions that involve transcurrent movement, subduction on both sides of a narrowing basin floored by 'trapped' oceanic crust and, in the final stages of closure, eastward obduction of the basin floor". A prominent northerly to northwesterly trending fault zone, locally referred to as the Ophir Break zone, extends through the property and has been traced on the surface and by drilling from Muddy Lake northward to Tatsamenie Lake — a distance of more than 10 kilometres (*see* Fig. 25-1). The zone is about 3 500 metres wide and defined by areas of intense fracturing, abundant slickensiding, areas of carbonaceous and siliceous black siltstone and gouge, and linear Fe-carbonate, quartz ± fuchsite-bearing tuff (listwanites) and quartz-dolomite alteration zones. The zone is bounded on the west by the West Wall fault and on the east by the Ultramafic fault so named because it contains elongated serpentinite pods. Several minor fault structures occur within the Ophir Break zone. Locally slices of fuchsite-bearing tuff belonging to the pre-Upper Triassic greenstone package occur within Permian limestone, such as in the bluffs immediately northwest of Bear Main zone.

Two directions of younger crossfaulting have been observed. One strikes northwesterly and shows left-lateral movement of up to 100 metres between limestone and greenstone west-northwest of Bear Main zone (*see* Fig. 25-2); the other strikes northeasterly and shows right-lateral offset within silicified dolomite in Bear Main zone.

As described for Totem Silica zone, two phases of folding exist: Mid-Triassic age, isoclinal, commonly recumbent, S-type folds; and Late Jurassic broad, open folds, similar to those at Tatsamenie Lake. The cores of anticlines occasionally contain crackle breccias (for example, Ram/Tut property). Phase 1 and phase 2 folding are prominent in Totem Silica zone, and phase 1 is a minor feature in Bear Main zone. The quaternary debris flow with slump blocks or detached slices was discussed previously.

ALTERATION

Two dominant alteration types occur:

(1) Quartz-dolomite, which occurs primarily in the limestone unit.

(2) Quartz-iron carbonate-pyrite fuchsite (listwanites), which occur in the tuff unit.

Both types are most intensely developed adjacent to or in fault zones and both appear to increase in intensity toward the hangingwall.

The quartz-dolomite alteration consists of massive fine-grained quartz, quartz breccia, and lesser dolomite. Outward from a zone of intense silicification, with or without brecciation, silica decreases gradually from massive quartz to vein quartz to stringer quartz in a dolomite matrix. Further out, alteration grades into dolomitic limestone and finally to unaltered limestone. This sequence of alteration is well developed in the footwall of The Bear Main zone and less so in the Fleece Bowl and Totem Silica zones. Heterolithic and monolithic breccias are locally well developed in the quartz-dolomite alteration zone (Fig. 25-3). Abundant replacement dolomite and carbonate veining may result from release of magnesium and some calcium from the greenstone unit or from a deep-seated ultramafic source.

The listwanitic quartz-iron carbonate-pyrite fuchsite alteration assemblage is restricted mainly to tuffaceus rocks of the greenstone unit. The zones range in width from 1 metre to 20 metres and are strongly foliated. Carbonate minerals noted include ferroan dolomite, ankerite, calcite, and aragonite. X-ray determination of the clay-sized fraction shows mainly illite and sericite and traces of sodium-rich alunite. The rocks also have kaolinite veinlets and gypsum coating fractures. Other accessory minerals identified in the listwanitic zones include talc, chlorite, hematite, and pyrite, which occur as veinlets, breccia fillings, rimming clasts, and as fine laminations. Jarosite is conspicuous on silicified dolomite bluffs at the southern end of Bear Main zone. A spectrographic analysis of listwanite collected from Fleece Bowl gave the following results: Si >10%, Al >10%, Mg 4.5%, Ca 7.0%, Fe 8.0%, Pb -, Cu 0.3%, Zn 0.05%, Mn 0.08%, Ag -, V 0.06%, Ti 0.5%, Ni 0.06%, Co 0.02%, Na <0.3%, K >2.0%, W -, Sb 0.25%, Cr 0.2%, and trace As, Ga, Mo, Zr, Sr, Ba, B, Rb, Nb, and P.

The process of listwanitization corresponds to a CO_2-Ca metasomatism of ultramafic rocks, with addition of potassium in fuchsite-rich listwanites. Gold values are randomly distributed within listwanite lenses at Muddy Lake, as is the case in similarly mineralized areas around the world. A strong positive correlation exists between gold, arsenic, and sulphur. Fuchsite formation involves transfer of Si and Fe^{3+}? from the zone altered to listwanite to the 'ore' zone; Mn, Ca, K, and C are introduced and other elements including Cr, are redistributed.

MINERALIZATION

Mineralization is of the 'no-seeum' gold type with minor silver values. Metallic mineralogy consists of 0.1 to 5 per cent pyrite, trace amounts of arsenopyrite and scorodite, native gold with values up to 27.8 grams per tonne gold and silver up to 67 grams per tonne (Schroeter, 1984), pyrrhotite, chalcopyrite in amygdules in lapilli and altered fuchsite-bearing tuff, Sb-bearing tetrahedrite, and hessite. The latter two minerals are listed in a private report by Chevron.

Tetrahedrite occurs in fractures in silicified dolomite on the west portion of the Totem Silica zone. Native gold is micron to submicron size (Chevron personnel, personal communication) and very erratic in distribution, a characteristic of listwanitic deposits. Locally within the Bear Main zone, gypsum is associated with mineralization. Pyrite occurs in at least two distinct stages: as late-stage veinlets; and as earlier breccia matrix filling, fragments within breccias, 'wispy' rims on silicified limestone fragments in breccia, and local laminations in fine bleached tuff. The younger, fine-grained pyrite veinlets rarely offset older breccia or lamination pyrite.

Two main 'zones' of mineralization have been identified: Bear Main and Fleece Bowl (Fig. 25-2). The Bear Main zone crops out in a fault bounded silicified and listwanitized block which has been traced by drilling along a strike length of nearly 1 kilometre, across an average width of 10 metres, and to a depth of at least 200 metres. The host rocks in the Bear Main zone include silicified dolomitized limestone and breccia and carbonatized tuffs (listwanites). The gold:silver ratios are high, greater than 2 to 1, and silver is rarely more abundant than gold in individual assays. Mineralization in the Fleece Bowl zone does not crop out; it has been intersected only in drill holes. Several short mineralized sections associated with quartz veining exist, as well as mineralization associated with a 'felsic' dyke which locally contains up to 10 per cent pyrite as disseminations and fracture fillings. The dyke contains white quartz eyes and has been extensively sericitized.

There is a positive correlation between Hg-As-Sb-Au and Ag in mineralized zones. The only sulphides identified to date on the Totem Silica zone are pyrite in the silicified limestone and tetrahedrite in the silicified dolomites. Assays of samples taken during a visit to the property in 1984 are shown in Schroeter (1985). Assays from samples collected during the 1985 study will be available at a later date.

To date, no reserve figure has been released for the Muddy Lake gold deposit.

AGE DATING

Only limited age dating has been done in the area. The Late Triassic to Early Jurassic age of the foliated diorite is inferred from K/Ar whole rock dates obtained from two granitic boulders in the Takwahoni Formation. Chevron has obtained a whole rock K/Ar date of approximately 177 Ma from sericite from the Muddy Lake prospect (H. Wober, personal communication).

Hewgill (1985) obtained a K/Ar whole rock date of 171 ± 6 Ma from albitite on the Ram/Tut property, located approximately 10 kilometres northwest of Muddy Lake. The albitite apparently represents the latest stage of hydrothermal activity of a Jurassic calc-alkaline quartz diorite to tonalite intrusion. Hewgill has determined strontium isotopic initial ratios for albitite of 0.7029 to 0.7038, ratios that would be typical of a mature island arc formed at a convergent margin. Several other samples were collected by the writer during 1985 for age dating including a hornblende diorite dyke adjacent to mineralization at the Nie (2 Oz. Notch) showing (Fig. 25-1); an intermediate hornblende-feldspar porphyry dyke cutting foliated hornblende diorite on the east side of Totem Silica zone (Fig. 25-2); and samples of several schistose sericitic and/or chloritic fault zones within Bear Main zone (Fig. 25-3).

OTHER PROPERTIES

A number of other brief property visits in the region were conducted. Following are brief remarks about some of these properties:

NIE (Lat. 58°21' Long 132°18'; 104K/8W)

The Nie claims contain the Nie or "2 Oz. Notch" showing (Fig. 25-1) which consists of a quartz vein more than 1 metre wide with abundant disseminated and massive pyrite and minor pyrrhotite veins adjacent to a hornblende diorite dyke of suspected Middle Jurassic age. Both the vein and dyke occur along the trace of the West Wall fault, which extends between Tatsamenie and Muddy Lakes. North of the showing, also along the trace of the West Wall fault, the most northerly known slice of limestone is in contact with fuchsite-bearing tuff. Post-Middle Jurassic quartz monzonite stocks and hornblende diorite dykes also occur. To the east of the showing, fault-bounded, altered ultramafics crop out, as do flat-lying Miocene plateau basalts. To the south there is a small asbestos showing noted on Souther's (1971) map (Fig.. 25-1).

MISTY (Lat. 58°19' Long. 132°17.5'; 104K/1W)

The Misty claims are underlain by pre-Upper Triassic volcanic rocks which have been intruded by Middle Jurassic dioritic to granodioritic stocks. Minor skarn mineralization, consisting of magnetite, chalcopyrite, pyrrhotite, iron carbonate, and hematite, has been noted.

RAM/TUT (Lat. 58°17' Long. 132°25'; 104K/8W)

The Ram/Tut property is underlain by a section of pre-Upper Triassic rocks overlying Permian limestones and dolomites that have been intruded by albitite. The limestone unit consists of massive to well-bedded grey limestone with local beds and 'boudins' of chert and/or pyrite. Locally limestone beds exhibit stratabound brecciation, and are silicified and vuggy. Mineralization noted in the silicified limestone units includes fracture-controlled and disseminated tetrahedrite and an isolated massive sulphide 'pod' 1 metre in diameter containing galena, sphalerite, pyrite, and arsenopyrite. Isoclinal phase 1 and open phase 2 folds occur in the limestone unit. Crackle breccia occurs near the core of a phase 2 anticlinal fold. Lying conformably above the limestone unit and locally in fault contact with it is phyllite of the pre-Upper Triassic sequence. The albitite intrudes the section and is locally mineralized with pyrite, boulangerite (Hewgill, 1985), and tourmaline. Another showing occurs where silicified and/or dolomitized limestone is in contact with both Miocene basalt and Cretaceous (?) dykes in a fault zone that trends 080 degrees. Here pyrite and scorodite (?) occur in a silicified zone. To the south, several small veins of stibnite exist on the property.

Mineralization on this property, and also regionally, might involve solutions ascending up a fault through the limestone units and into the overlying phyllitic package. The mineralizing solutions may have travelled outward along stratabound breccia in the silicified and/or dolomitized limetone beds beneath the 'impermeable' contact with a minor amount of 'leakage' into the phyllites. The age of mineralization may be related to the albitization event at about 171 Ma.

SLAM (Lat. 58°14' Long. 132°07'; 104K/1E, 8E)

The Slam property consists of silicified zones in limestone and carbonaceous siltstone cut by clay-altered feldspar porphyry dykes. Resistant silica-rich knobs are anomalous in gold.

ORO AND TAN GROUPS (Lat. 58°10' Long. 132°18'; 104K/1)

An undivided sequence of 'greenstone', including coarse pyroclastics, underlies both claim groups. Minor intermeditae dykes cut the sequence as do minor pyritic altered zones. Trace amounts of chalcopyrite have been reported associated with the pyritic altered zones.

OUTLAW (Lat. 58°33' Long 132°44'; 104K/10E)

The Outlaw property is located approximately 7 kilometres northwest of Trapper Lake. Two types of mineralization were observed:

(1) Arsenopyrite, tourmaline, stibnite, and pyrite with gold and silver values that occur in quartz veinlets associated with highly sericitized feldspar porphyry.

(2) Strong psilomelane and minor pyrite in a quartz vein (Mancuso vein) that cuts pre-Upper Triassic rocks.

INLAW (Lat. 58°28′ Long. 132°44′; 104K/7E)

The Inlaw property is also located approximately 7 kilometres west of Trapper Lake. Quartz-calcite veinlets with galena, sphalerite, and pyrite occur in a 7-metre-wide, silicified, northwesterly trending zone in Stuhini Group pyroclastics. Silicification is both pervasive and patchy.

ORE DEPOSITION MODEL

The main ore depositional event which produced the Bear Main gold deposit is postulated to have resulted from large-scale, low-temperature circulation of gold-bearing hydrothermal solutions during the late stages of listwanite alteration of the greenstone unit. The tectonic contacts in the Bear fault zone between silicified limestone-dolomite and/or breccia and altered fuchsite-bearing tuff acted as channelways for CO_2-Ca-rich brines which were responsible for the carbonatization process. Acidic, gold-bearing solutions precipitated silica-pyrite arsenides and free gold in silicified rocks, breccias, and altered tuffs, including listwanites when gold transporting complexes became unstable when they entered the reducing and alkaline environment of the carbonatized rocks.

Mineralization is of the 'no-seeum' type and is very erratic. Nevertheless, it tends to be concentrated in silicified 'pods' or slices of silicified dolomitized limestone and/or altered, fuchsite-bearing tuff. A possible genetic association with a Middle Jurassic hornblende diorite intrusive event is suggested but more data are required to support this hypothesis.

Regionally, a similar fault control is envisaged with the added possibility of stratabound mineralization being associated with stratabound zones of silicification and brecciation in the limestone unit underlying the phyllite unit.

ACKNOWLEDGMENTS

The writer would like to thank Chevron Canada Resources Ltd. (especially Helmut Wober, Ken Shannon, and Godfrey Walton) for providing base maps, for providing access in the area, and for their kind hospitality and openness while on the property. Pat Desjardins acted as an able field assistant.

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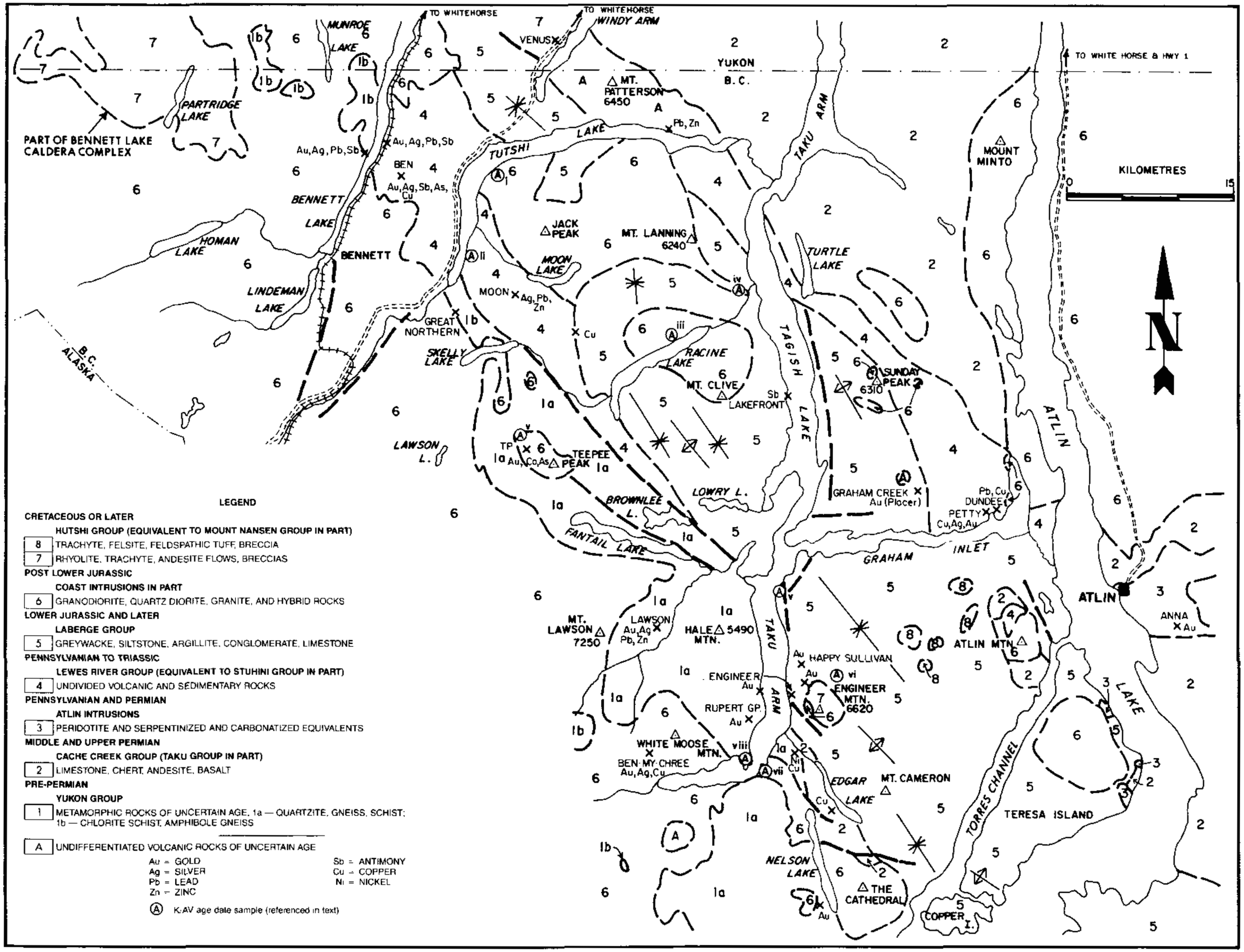

Figure 26-1. Compilation of geology, structure, and mineral deposits, Bennett area.

BENNETT PROJECT (104M)

By T. G. Schroeter

INTRODUCTION

During July 1985 the writer spent five field days on a continuing project entailing the examination of mineral prospects with special emphasis on precious-metal bearing prospects in the area between Atlin and Bennett (*see* Fig. 26-1). The writer has examined various showings within the area over the past several years and plans to continue the project in conjunction with an anticipated remapping program by Chris Dodds with the Geological Survey of Canada in 1986.

The well-known Engineer gold mine is situated within the study area; the significant Venus and Skukum gold-silver deposits are located just northwesterly across the British Columbia/Yukon border along geologic and structural trends.

This preliminary report presents a brief description of regional geology and structure in the area as well as a preliminary classification of deposits. A more comprehensive report is planned at a later date.

ACCESS

Access into the area is best gained by helicopter. The Whitehorse-Skagway road (Highway 7) crosses the northwestern portion and the Jakes Corner-Atlin road provides access to the southeastern portion (Fig. 26-1). Access is also by boat from either Atlin or Carcross. In earlier days the White Pass and Yukon Railroad between Whitehorse and Skagway also provided access; however, since 1982 it has been closed indefinitely.

REGIONAL GEOLOGY

The central part of the study area is underlain by the Whitehorse trough which extends southeasterly from south-central Yukon into northwestern British Columbia. Mesozoic strata within the trough are separated from oceanic Upper Paleozoic Atlin terrane to the northeast by the presumed northwesterly striking, northeasterly dipping Nahlin fault and from Upper Paleozoic and older amphibolite to greenschist facies metamorphic rocks and plutons of the Coast Plutonic Complex to the southwest by the presumed northwesterly extension of the sub-vertical Llewellyn fault system.

The Whitehorse trough is a synclinorium with basal Upper Triassic strata of the Stuhini Group, which is equivalent to the Lewes River Group, exposed only along the margins. Lower and Middle Jurassic clastic strata of the Laberge Group dominate the centre of the trough.

Pre-Permian rocks of the Yukon Group consist of a variety of metamorphic rocks of uncertain age, including quartz-plagioclase-orthoclase gneiss, schist, chlorite schist, and amphibole gneiss. They have been correlated with metamorphic and sedimentary rocks of the Omineca Crystalline Belt to the east (Templeman-Kluit, 1976).

Middle to Upper Paleozoic rocks of the Cache Creek Group consist mainly of massive marine limestones in the northeast part of the study area, but include chert, argillite, volcanic greywacke, and serpentinized ultramafic rocks to the east and southeast of Atlin.

The Upper Triassic Stuhini Group consists mainly of an assemblage of mafix flows and associated volcaniclastic rocks interpreted as having formed in a fore arc basin associated with a Perm an to Jurassic island arc terrane adjacent to the east margin of Stikinia during its convergence with North America (Morrison, 1981). Within the study area Bultman (1979) sub-divided this group into the Racine Lake and Tutshi Lake units.

Earliest to late Middle Jurassic rocks of the Laberge Group consist of a thick, repetitive succession of deep-water facies, greywacke, sandstone, siltstone, shale, and conglomerate; these correlate with the Inklin Formation to the southeast.

Middle to possibly Late Cretaceous rocks of the Hutshi Group (Mount Nansen Group) and possibly the Sloko Group unconformably overlie the Mesozoic and older strata. They consist of layers of volcanic rocks, predominantly andesite and rhyolite flows, deposited on a sub-aerial surface of pronounced relief (Bultman, 1979).

The Coast Plutonic Complex of post-Early Jurassic age consists of several phases of granodiorite, quartz diorite, granite, and hybrid rocks in this area. Bultman (1979) noted five separate phases between Ben-My-Chree and Mount Lawson. Included here are Late Cretaceous biotite granites from Tutshi Lake, Racine Lake, and Engineer Mountain, which are discussed in a following section.

A younger, possibly Tertiary, quartz monzonite crops out on Teresa Island and on Atlin Mountain in the southeast corner of the study area.

REGIONAL STRUCTURE

The Llewellyn fault system separates the Whitehorse trough from the Coast Plutonic Complex. The trace of the steeply dipping Llewellyn fault passes through the Nelson Lake valley, under Tagish Lake near the mouth of Fantail Creek, and northwesterly to the south end of Tutshi Lake. Several mineral prospects occur along, or are associated with, subsidiary splays of this fault, including the Engineer mine.

The Nahlin fault system separates the Whitehorse trough from oceanic rocks of the Atlin terrane to the northeast. It has a steep northeasterly dip where it crosses Montana Mountain.

The Whitehorse trough has been shortened in a northeast-southwest direction, resulting in closed to open, symmetric, and asymmetric folds with wave lengths ranging up to 10 kilometres. Folding in the Laberge Group is particularly well developed.

The contact with the Coast Plutonic Complex is complex; largely it is faulted, elsewhere it is an unconformity.

ISOTOPIC AGE

Potassium-argon age dates were obtained by Bultman (1979) (*see* Fig. 26-1 for sample locations) and are listed in Table 26-1.

Mineralization in the vicinity of Engineer Mountain and Bee Peak may be genetically related to a hydrothermal event associated with intrusive activity. Similarily, the Hushi Group volcanics may be genetically related to intrusive rocks of the Coast Plutonic Complex, particularly those of Late Cretaceous age.

ECONOMIC GEOLOGY

Engineers working on the White Pass and Yukon Railroad and prospectors first entered the study area in 1878. The famous Klon-

British Columbia Ministry of Energy, Mines and Petroleum Resources, Geological Fieldwork, 1985, Paper 1986-1.

TABLE 26-1
POTASSIUM/ARGON AGE DATES

NO.	LOCATION	ROCK TYPE	APPARENT AGE (Ma)
1	Tutshi Lake	Biotite granite	89.5±2.6
2	Tutshi Lake	Biotite granite	77.9±1.6
3	Racine Lake	Biotite granite	82.0±2.1
4	Racine Lake	Biotite granite	56.2±1.1
5	East of Fantail River	Granodiorite boulder in Inklin conglomerate	180.8±4.7
6	Bee Peak	Hornblende tonalite	80.3±2.4
7	Wann River	Granodiorite	120.2±2.4
8	Wann River	Amphibolite gneiss	165.5±3.3

dike Gold Rush between 1897 and 1898 saw a tremendous influx of prospectors into the area, either on their way to the Klondike gold fields or working their way eastward to the Atlin gold camp. Since 1898, approximately 34 300 kilograms of placer gold has been won from the Atlin gold fields.

However, west of Atlin only small vein-type gold prospects have been worked, with the exception of the well-known Engineer gold mine which produced 597 176 grams of gold from 1913 until 1932.

To the northwest of the study area, the Venus and Skukum properties have outlined sufficient reserves to warrant mining operations under suitable economic conditions.

Many prospects occur within northwesterly trending shear zones, but they do not exhibit widespread alteration. Silicification in the form of quartz veins and/or breccia is commonly an important component of the mineralizing events.

TYPES OF DEPOSITS

GOLD AND GOLD-TELLURIUM-BEARING QUARTZ VEINS WITH TRACE BASE METALS

Engineer (MI 104M-14, 15, 16)

The Engineer deposit was found in 1899 and produced 597 176 grams of gold between 1913 and 1932. Native gold, telluride(s) (probably calaverite), pyrite, and trace allemontite (SbS), arsenopyrite, and needles of berthierite ($FeS \cdot Sb_2S_3$), which were identified by X-ray analysis, occur in a gangue of quartz, calcite, and mariposite. Good comb-structures, as well as banding and vugs, characterize quartz veins. Host rocks include shales and greywackes of the Laberge Group.

TABLE 26-2
LAWSON PROPERTY SAMPLE ASSAY RESULTS

SAMPLE NO.	ROCK DESCRIPTION	Au ppm	Ag ppm	Cu %	Pb %	Zn %
30089	Quartz vein with altered wallrock plus 2% pyrite (lower adit)	24.7	<10	ND	ND	ND
30090	10 cm quartz vein with 10% pyrite plus silver black metallic? mineral (Blacksmith dump)	31	27	0.017	1.46	0.013
30091	7.62 cm quartz vein with 10% pyrite (Blacksmith dump)	0.3	<10	ND	ND	ND
30092	5 cm quartz vein with 15% banded pyrite (Blacksmith dump)	15.8	55	ND	ND	ND
30093	5 cm quartz vein with 15% banded pyrite (Blacksmith dump)	167	62	ND	ND	ND
30094	10 cm quartz vein with 10% banded pyrite plus 3% galena (Blacksmith dump)	34	16	0.13	2.75	6.50
30095	Quartz vein with 75% pyrite and 0.5% galena (Blacksmith dump)	71	33	0.27	0.55	0.078
30096	3.8 cm quartz vein with 10% pyrite (Incline dump)	40	18	ND	ND	ND
30097	Silicified schist with 5% disseminated pyrite (Incline dump)	2.7	<10	ND	ND	ND
30098	5 cm quartz vein breccia with 2% pyrite and 10% galena (Incline dump)	<0.3	113	0.16	7.76	14.1
30099	7.62 cm quartz vein with 3% galena, 3% sphalerite, and 1% pyrite (Incline dump)	33	25	0.16	3.25	3.65
30100	7.62 cm quartz vein with 20% banded pyrite and 3% galena (Incline dump)	71	40	0.054	2.90	3.65
30101	Quartz vein with 15% spalerite, 3% galena, and 1% pyrite (Incline dump)	11	12	0.17	3.05	15.6
30102	Quartz vein with 6% sphalerite, 2% galena, and 4% pyrite (Incline dump)	3.4	<10	0.08	1.25	6.70
30103	Quartz vein with 5% galena, 20% spalerite, and 2% pyrite (Incline dump)	17.8	22	0.30	6.85	22.8
30104	Quartz vein with 10% pyrite (Incline dump)	3.2	11	ND	ND	ND
30105	Quartz breccia with 10% galena, 25% sphalerite, and 10% pyrite (Incline dump)	2	25	0.076	8.85	25.1
30106	7.62 cm quartz vein with 5% pyrite, 8% galena, and 4% sphalerite (Incline dump)	96	63	0.66	7.90	4.10
30107	10 cm quartz vein with 5% pyrite (approximately 17 metres in Incline dump)	297	120	ND	ND	ND

TABLE 26-3
BEN-MY-CHREE SAMPLE ASSAY RESULTS

SAMPLE NO.	ROCK DESCRIPTION	Au ppm	Ag ppm	Cu %	Pb %	Zn %
30052	Quartz-calcite vein with 3% galena	3.4	1 147	0.054	2.10	0.013
30053	Quartz vein with 2% pyrite	<0.3	<10	0.012	0.025	0.0035
30054	Quartz vein with 2% pyrite + minor galena + malachite	11	736	0.27	7.65	0.0019
30055	Foliated diorite with disseminated chalcopyrite	0.3	184	0.60	0.27	0.61
30056	Quartz vein with 4% galena and pyrite	11	450	0.14	4.25	0.037
30057	Foliated diorite with disseminated chalcopyrite	1.7	1 621	1.41	1.57	0.25
30058	Quartz veinlet with 2% galena + 2% pyrite	14.4	3 774	0.33	2.10	0.06

Note: Samples collected from 1 860-metre elevation, except 30057 and 30058, which are taken from 1 830-metre elevation

Happy Sullivan (MI 104M-13

The Happy Sullivan prospect was also discovered in 1899. During the winter of 1984-85 De Baca Resources Inc. completed an 80-metre-long adit near elevation 1 128 metres which tested irregular quartz veining with high-grade gold values. The veins are within a shear zone which measures about 42 metres in width and greater than 3.2 kilometres in length; it strikes northerly. The mineralogy and geologic setting is similar to that at the Engineer mine, however, locally there is up to 20 per cent arsenopyrite and dendritic crystals of native gold have been found (Assessment Report 7923).

Skukum

The Main zone of the Mount Skukum deposit, in the Yukon, has reserves estimated at 148 980 tonnes grading 24.98 grams per tonne gold and 20.5 grams per tonne silver. Additional reserves exist in the Brandy zone. The quartz-calcite vein of the Main zone has been traced for 200 metres; its width averages 5 metres and it continues to a vertical depth of at least 80 metres. Gold occurs principally in electrum and sulphides are uncommon.

GOLD-SILVER QUARTZ VEINS WITH BASE METALS

Lawson (MI 104M-6, 7)

The Lawson gold prospect consists of a gold-bearing quartz vein that has been traced intermittently along a horizontal length of 920 metres and over a vertical distance of greater than 460 metres. The vein averages 1.1 metres in thickness and contains pyrite plus minor chalcopyrite, galena, sphalerite, and native gold. The vein cuts hornblende (± chlorite) schists and feldspar porphyry of the Yukon Group. During 1985, the writer examined and sampled the Incline, Blacksmith, and Lower (caved) adit levels. Assay results are listed in Table 26-2.

Ben-My-Chree (MI 104-11)

Pyrite plus minor chalcopyrite occur in quartz veins within Coast Plutonic Complex rocks. Results of grab samples taken in 1985 are listed in Table 26-3. Another example of this type of showing is on the Rupert claims (MI-104M-8).

GOLD-COBALT ± SKARN ± As Bi

TP

The TP prospect, located on the southwest flank of Teepee Peak was visited during 1983 while Trigg, Woolett Consultants were working on the property on behalf of their client, Texaco Canada Resources Ltd. The property is underlain by pre-Permian gneisses schists, and minor marble of the Yukon Group which are unconformably overlain by Upper Triassic volcanic rocks of the Stuhini Group. These rocks are cut by intrusions of several ages that range in composition from granodiorite to hornblendite. Locally marble has been replaced by garnetiferous magnetite, amphibole, calc-silicate, and calcite skarns. The Main showing has been traced 200 metres in a northwesterly direction; it has an average width of 15 metres. Mineralization consists of native gold, erythrite and cobaltite, and minor arsenopyrite in two fracture zones which coincide with skarn. The strong northwesterly Teepee fault may have been important for mineralization.

Assays of samples taken by the writer in 1983 from the Main showing are listed in Table 26-4.

In addition, an XRD report on the garnet showed sub-equal amounts of the end members andradite and grossularite.

ARSENOPYRITE-STIBNITE VEINS

Ben

The Ben prospect, located approximately 10 kilometres north-northeast of Bennett, was examined in 1983. Two northwesterly trending faul zones (Ben and Paddy), each approximately 6 metres

TABLE 26-4
TP SAMPLE ASSAY RESULTS

LAB NO.	ROCK TYPE	Au ppm	Ag ppm	Cu %	Pb %	Zn %	Co %	Ni %	As %	Bi %
28562M	Cobalt-arsenopyrite skarn	30.2	<10	0.012	0.04	ND	3.27	1.24	6.57	2.27
28563M	Massive magnetite	0.7	<10	0.003	0.01	0.013	0.079	0.005	7.76	0.06
28564M	Banded cobalt-arsenopyrite	32.2	90	0.011	0.01	0.01	16.3	0.017	21.5	1.09
28565M	Cobalt-arsenopyrite	24.3	<10	0.006	0.025	0.009	7.87	0.022	10.2	1.05
28567M	Massive cobalt-arsenopyrite	35	57	0.035	0.07	0.18	0.37	0.018	32	0.18

TABLE 26-5
BEN SAMPLE ASSAY RESULTS

LAB NO.	ROCK TYPE	Au ppm	Ag ppm	Cu %	Pb %	Zn %	As %	Sb %	Bi %
28581M	Chalcopyrite-sphalerite in contorted gneiss	0.3	80	0.21	0.14	4.1	ND	65 ppm	<0.02
28582M	Chalcopyrite-sphalerite-stibnite in gneiss	<0.3	710	0.041	0.97	1.2	2.7	0.43	<0.02
28583M	Arsenopyrite-pyrite-stibnite in gneiss	3.4	769	0.02	ND	ND	10.6	3.50	<0.02
28584M	Pyrite-galena-sphalerite	18.2	684	0.02	8.15	0.83	24.8	0.6	0.08
28585M	Massive stibnite + sphalerite + chalcopyrite in bleached silicified rock	<0.3	929	0.017	8.00	29.2	ND	16.8	<0.02
28586M	Gneiss	1.7	158	0.019	1.16	1.48	4.89	0.62	<0.02

wide, host gold-silver mineralization. Four different styles of mineralization exist:

(1) Quartz veins (less than 1 metre in width) containing pyrite, arsenopyrite, galena, sphalerite, stibnite, chalcopyrite, and rare siderite hosted by either schists and gneisses of the Yukon Group or volcanic rocks of the Stuhini Group.

(2) A cobalt mineral, pyrite, and massive arsenopyrite in shears.

(3) A stratabound disseminated sulphide zone (approximately 1 metre wide) containing galena, sphalerite, stibnite, arsenopyrite, pyrite, and pyrrhotite in gneisses adjacent to a shear zone.

(4) A pyrrhotite-bearing amphibole skarn.

Assays of samples taken by the writer are listed in Table 26-5.

ANTIMONY VEINS

Lakefront (MI 104M-5)

Bedded quartz-stibnite veins with traces of galena averaging 1 metre in thickness occur in Laberge Group shales. Approximately 40 tonnes of ore is scattered on the shore of Atlin Lake below a caved adit.

DISSEMINATED AND VEIN ARSENOPYRITE PLUS MINOR GALENA AND SPHALERITE

Moon Lake

The Moon Lake silver prospect consists of disseminated arsenopyrite, pyrite, galena, and sphalerite in a sheared granodiorite and is similar to the Big Thing prospect on Montana Mountain in the Yukon. Assays of samples taken in 1983 from the Moon Lake prospect are shown in Table 26-6.

The setting of these prospects suggests that magmatic waters may have been involved in their formations.

ARSENOPYRITE-PYRITE-GALENA-SPHALERITE ± PYRARGYRITE ± TETRAHEDRITE QUARTZ VEINS

Venus

The Venus gold-silver prospect is located on the southeast flank of Montana Mountain just north of the British Columbia/Yukon border. Arsenopyrite, pyrite, galena, sphalerite, with rare realgar, orpiment, yukonite, kankite, quenstedtite, pyrargyrite, and tetrahedrite occur in quartz ± ankerite ± chlorite ± illite ± calcite veins in Hutshi Group (Mount Nansen Group) andesitic volcanic rocks. Mineralization is known over a vertical length of 397 metres with an average width of 1 metre. The style of mineralization probably represents a transition zone between mesothermal and epithermal types.

Reserves are estimated at 61 676 tonnes grading 10.97 grams per tonne gold, 305.14 grams per tonne silver, 2.5 per cent lead, 1.5 per cent zinc, plus 13 605 tonnes grading 14.4 grams per tonne gold, 360 grams per tonne silver, 2.7 per cent lead, 1.3 per cent zinc from 2 850 level, plus 12 154 tonnes grading 5.83 grams per tonne gold and 147.4 grams per tonne silver stockpiled from development of the upper levels (Lori Walton, personal communication, 1985).

OTHER DEPOSIT TYPES

Several other deposit types have been found. Pyrite-pyrrhotite-chalcopyrite-galena-bearing skarn and disseminated sphalerite in flow-banded rhyolite occur at the Selly showing (Needlands and Strain, 1982). There are also cupriferous gold-silver veins at the Petty (MI-104N-4), Dundee (MI-104N-3), and Great Northern (MI-104M-27) showings.

ORE DEPOSIT MODELLING

Preliminary investigations indicate that precious-metal-bearing mineralization ranges from mesothermal to epithermal in style and

TABLE 26-6
MOON LAKE SAMPLE ASSAY RESULTS

LAB NO.	ROCK TYPE	Au ppm	Ag ppm	Cu %	Pb %	Zn %	As %
28554M	Quartz vein with tetrahedrite	0.3	490	0.096	1.39	0.26	1.37
28555M	Altered granodiorite with arsenopyrite and pyrite	0.3	25	0.042	0.40	1.69	3.21
28556M	Altered granodiorite	<0.3	27	0.013	0.17	0.13	0.16
28557M	Altered granodiorite with disseminated arsenopyrite, galena, and sphalerite	<0.3	55	0.008	0.71	0.44	2.39
28558M	As above	<0.3	29	0.018	0.45	0.30	0.16

that it is structurally controlled by northwesterly trending fractures. There may also be a genetic association with Upper Cretaceous to Tertiary plutonic and/or volcanic activity.

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British Columbia Geological Survey
Geological Fieldwork 1985

TATSHENSHINI MAP-AREA* (114P)

By T. G. Schroeter and D. G. MacIntyre

INTRODUCTION

The authors extended their studies of mineral deposits and environments in the Tatshenshini map-area (114P) during a 5-day period in late August 1985. Brief visits were made to Windy-Craggy, Red Mountain (Fair), Mount Henry Clay, and Gold Cord. Access to all properties was by charter helicopter from either Noranda's base camp or Stryker/Freeport Resources' base camp, located on the Haines Road at kilometre 151 (Mile Post 94) and kilometre 72 (Mile Post 45) respectively.

MOUNT HENRY CLAY (Lat. 59°23′ Long. 136°29.5; 114P/7, 8)

Mount Henry Clay is situated along the British Columbia/Alaska border (Fig. 27-1), 65 kilometres northwest of Haines, Alaska and approximately 10 kilometres west-southwest of the border crossing at Pleasant Camp. Access is by helicopter from the Haines Road.

Recent exploration interest in the area, both on the Canadian and American sides of the border, stemmed first from the discovery of the large and potentially economically significant Windy-Craggy deposit located 75 kilometres to the northwest, and second from discovery of large, bedded, polymetallic massive sulphide boulders at the toe of the small Mount Henry Clay hanging glacier, which transects the unsurveyed border. On the Canadian side, Stryker/Freeport Resources staked numerous claims to cover potential source areas for these boulders as well as several newly discovered showings. On the American side, Bear Creek Mining Company has also been searching for the source of the high-grade boulders. During 1985 Bear Creek Mining Company diamond drilled five holes through the hanging glacier; the results of the program are not known.

GEOLOGICAL SETTING

The reader is referred to MacIntyre and Schroeter (1985) for a description of the geological setting and mineral occurrences in the area.

LOW JARVIS PROSPECT (MOUNT HENRY CLAY)

In 1985 Stryker/Freeport Resources completed five diamond-drill holes totalling approximately 850 metres on the Low Jarvis prospect. The program attempted to locate, sample, and determine the source and extent of numerous high-grade zinc-copper-silver-barite float boulders found at the toe of the Mount Henry Clay hanging glacier on the Canadian side of the border.

The only rock exposure in the immediate area is on Jan Still Ridge (local name); it consists of a shallow (30 to 50), northwesterly dipping sequence of black shales overlain by volcanic agglomerate and massive chloritic andesite. Thin bands of quartzite and/or black shale are interbedded in the andesites. At the south end near the top of the ridge trace chalcopyrite was noted near the helipad. Immediately below the helipad (approximately 10 metres), on a vertical cliff, Stryker/Freeport Resources located an exposure of bedded barite and sulphides (mainly sphalerite and pyrite) which they call the Jumar showing.

North of the helipad and the Jumar Showing, Stryker/Freeport found massive sulphide boulders consisting of well-bedded sphalerite, pyrite, chalcopyrite, tetrahedrite, and barite (Fig. 27-1).

GOLD CORD (MOUNT McDONELL) (Lat. 59°27′ Long. 136°30′; 114P/7, 8)

INTRODUCTION

The Gold Cord gold prospect (Plate 27-1) is located 8 kilometres west of Pleasant Camp, the United States/Canada border crossing at kilometre 65 on the Haines Road. A caterpillar trail leads to the property from the Haines Road near Pleasant Camp; however, helicopter access was used from Stryker/Freeport Resources camp located near kilometre 72 on the Haines Road, approximately 12 kilometres from Gold Cord.

HISTORY

Mineralization on Mount McDonell was first discovered in the late 1890s by Indians associated with the legendary Jack Dalton, an Alaskan trader. In 1899 the Gold Cord showing was sampled by placer miners working in the nearby Porcupine placer mining camp in the United States, and described by United States Geological Survey geologist, Alfred Brooks, in the same year. It was later examined by Charles Wright (1904) and Henry Eakin (1919). In 1925 John D. Senbraten and his partner, William Bunting, staked the property and traced the Gold Cord vein for approximately 2 900 metres by hand trenching and sank three shafts over the next five years. This work was partially financed by the Alaska-Juneau Gold Mining Co. who eventually participated in the excavation and deepening of 7 shafts and 32 pits on the property before 1929.

The property remained virtually dormant until 1968, except for some minor activity by the Alaska-Juneau Co. and Livingstone Wernecke in the late 1930's. In 1968, L. Combs and Assoc. of Whitehorse attempted to develop the property. An 11-kilometre road was built to the property and engineering studies were completed in 1969. Unfortunately further financing attempts failed.

In 1979 Karl and Jenny Gruber of Whitehorse restaked the property as the KARL 1-20 claims and optioned it to Exotic Gold Inc. However, work was not carried out and the property reverted to the Grubers.

In 1984 the property was optioned to Noranda Exploration Co. Ltd. who subsequently entered into a joint venture agreement with Canadian United Minerals Inc. In October 1984, Noranda completed three diamond drill holes totalling 163.5 metres on the Gold Cord vein. Unfortunately core recovery was very poor and weather conditions forced the program to be stopped prematurely due to a lack of drilling water; consequently, the vein was not adequately tested by this program. No work was carried out in 1985.

PROPERTY GEOLOGY AND MINERALIZATION

The host rock for the Gold Cord vein is a homogeneous, equigranular, fine to medium-grained diorite, which is one of several elongate, northwesterly trending Oligocene (?) intrusions that are part of the Tkope River intrusions. The diorite is unaltered except

* This project is a contribution to the Canada/British Columbia Mineral Development Agreement.

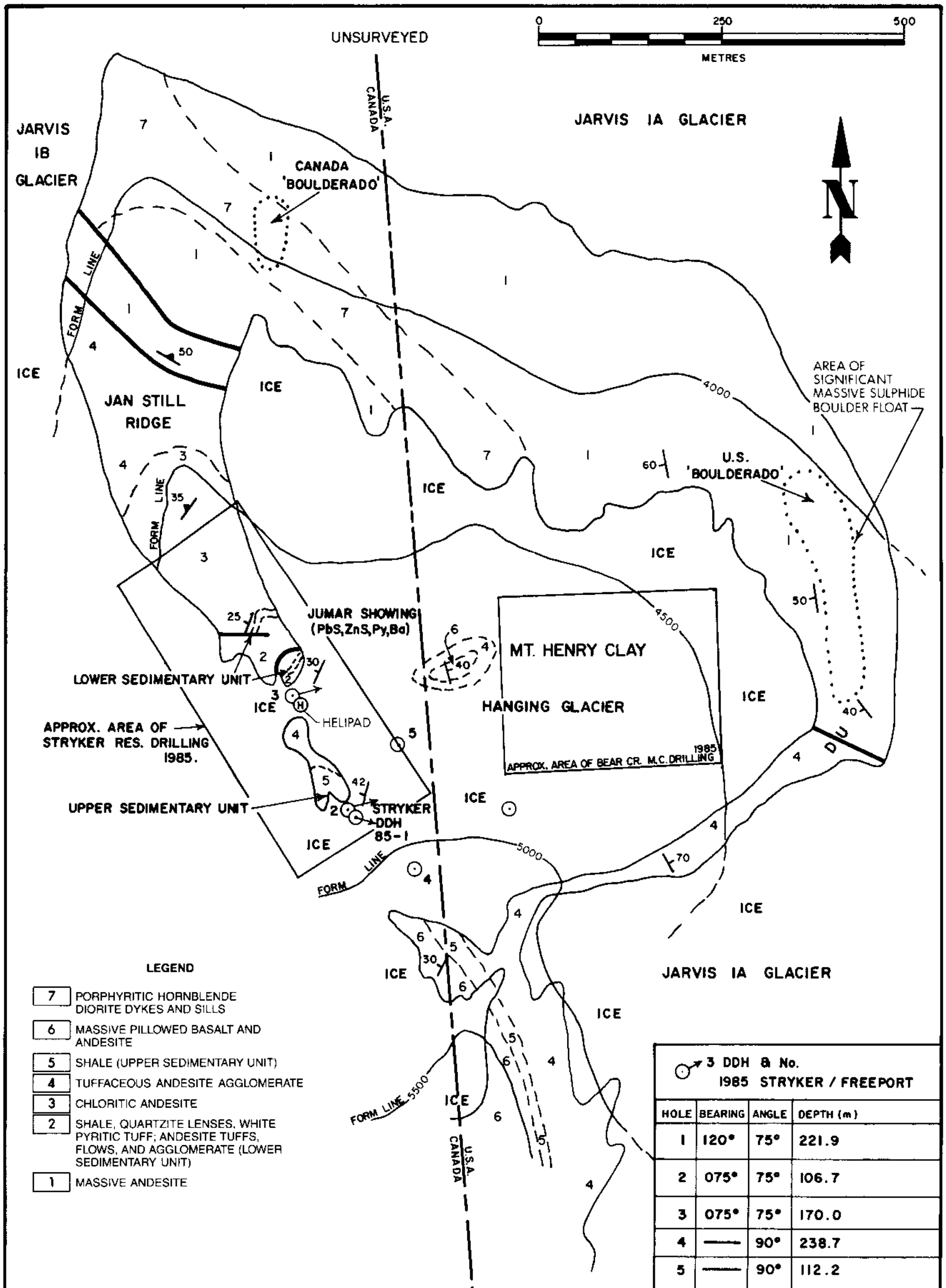

Figure 27-1. Geology of Low Jarvis Area, Mount Henry Clay (after company plans).

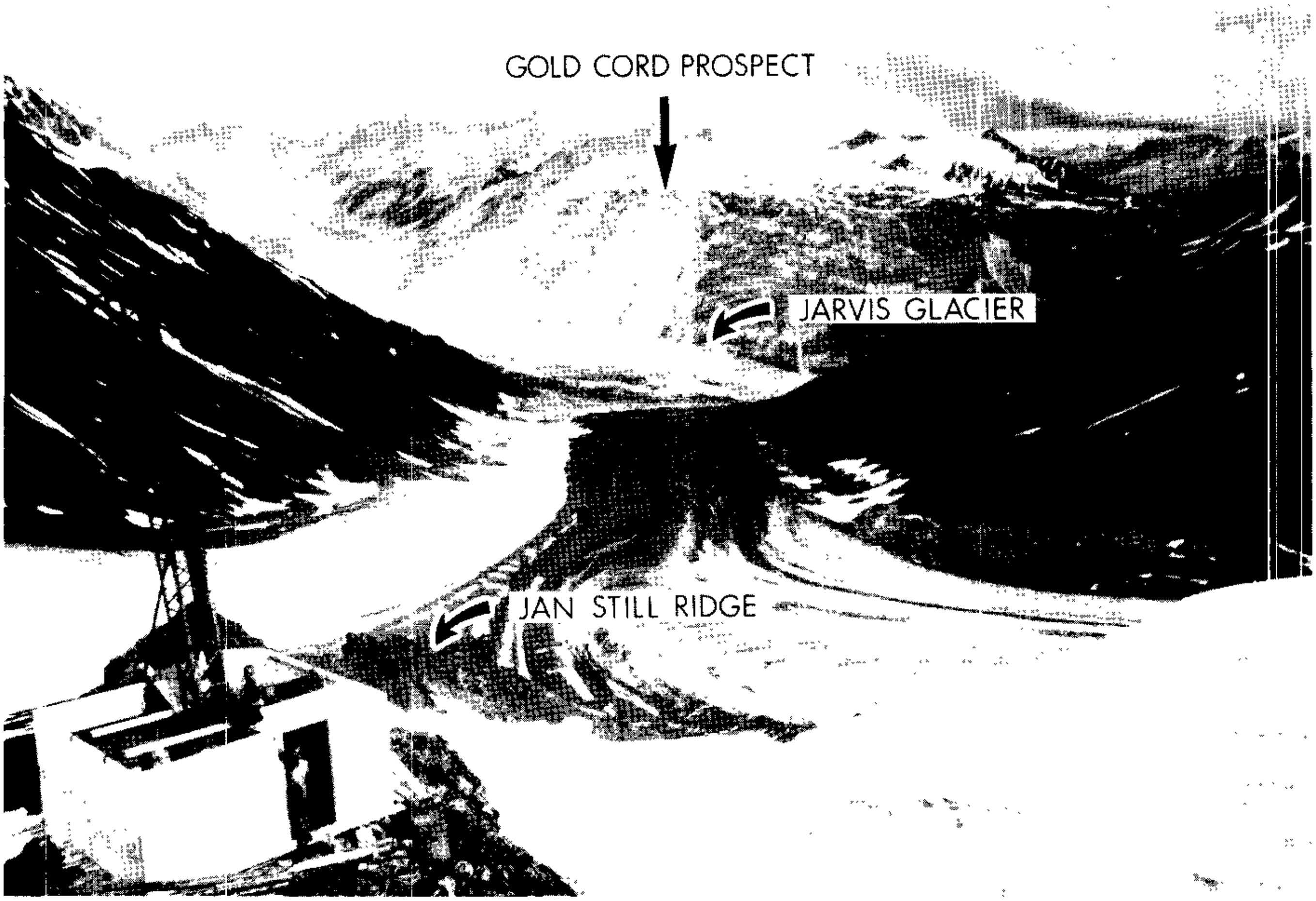

Plate 27-1. Looking northerly from Mount Henry Caly past Stryker Resources drill setup to the Gold Cord prospect.

TABLE 27-1. GOLD CORD VEIN

SAMPLE NUMBER	SAMPLE DESCRIPTION	GOLD ppm	SILVER ppm	COPPER per cent
GC-85-1	Grab of quartz vein with minor malachite and sphalerite (dump)	19.0	22.0	0.51
GC-85-2	Grab of 0.6-metre quartz vein	<0.3	< 10.0	0.40
GC-85-3	Grab of 0.6-metre quartz vein	16.4	21.0	1.02
GC-85-3a	Chip sample across 0.6-metre quartz vein with visible gold	72.0	190.0	2.13
GC-85-4	Grab of quartz from small dump	2.7	< 10.0	0.016
GC-85-5	Composite grab of quartz from 3 small dumps	7.5	13.0	0.013
GC-85-6	Grab of quartz (dump)	0.3	< 10.0	0.38
GC-85-7	Composite grab from large dump of quartz	83.0	42.0	0.41
GC-85-8	Grab of quartz (dump)	0.3	< 10.0	0.17

for local epidote-coated fractures in areas of shearing. In the area of the Gold Cord vein, the diorite is locally foliated. Foliation is defined by hornblende and is parallel to Gold Cord vein.

Numerous lineaments and faults trend easterly; some are eroded and form prominent depressions, others are infilled with quartz and form resistant ridges.

The Gold Cord vein consists of generally white quartz, sparsely mineralized with free gold, pyrite, local chalcopyrite, and trace sphalerite. The vein fills a shear zone within the diorite and follows the south or footwall side of the structure. It strikes approximately 115 degrees and dips from 30 degrees to 80 degrees toward the north; it has been traced over a surface length of 470 metres. The vein, situated at elevation 1 475 metres, has been tested in the past by two main shafts. Apparently within these shafts the vein splits into two or three distinct 30 to 120-centimetre-wide veins that are separated by 5 to 45 centimetres of weakly pyritized diorite. On surface the vein ranges from 0.1 metre to 0.75 metre wide; it is commonly oxidized and coated with limonite; rarely, malachite is present. Thin selvages of gouge material usually accompany the vein. The shafts and old stonehouse are caved.

The writers collected grab samples along a 500-metre interval of the Gold Cord vein (Fig. 27-2) and the results are presented in Table 27-1. Native gold was identified at sample site GC-85-3 in the hangingwall portion of the 0.6-metre quartz vein.

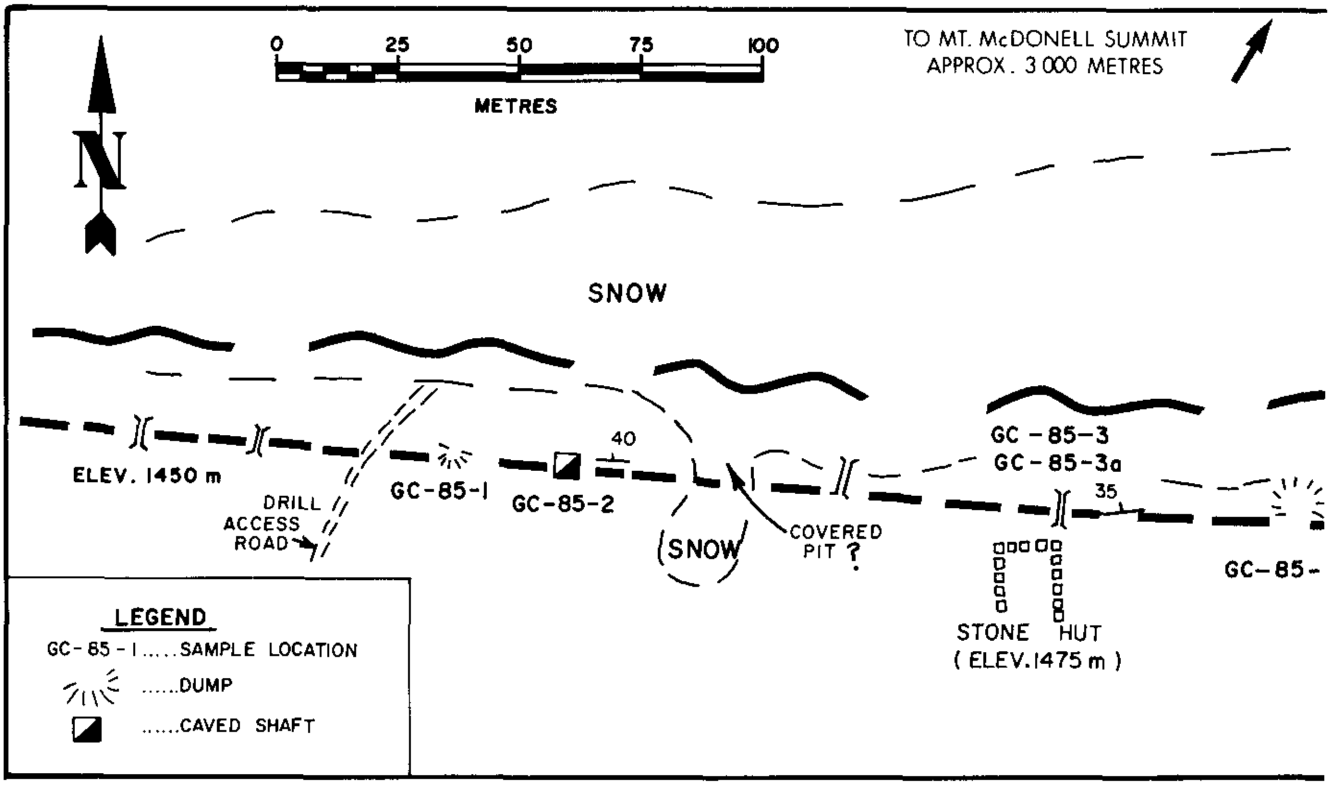

Figure 27-2. Sketch map of Gold Cord (Vein) prospect.

RED MOUNTAIN (FAIR)
(Lat. 59°42′ Long. 137°10′; 114P/11)

INTRODUCTION

The Red Mountain property is located approximately 30 kilometres west of the Haines Road (from kilometre 113 or Mile Post 70). The Fair claims straddle Red Mountain, which is 7.5 kilometres east-northeast of the confluence of the O'Connor and Tatshenshini Rivers. On 1:250 000 topographic maps, the Red Mountain prospect is located approximately 4 000 metres south of the top of Red Mountain. Access is by helicopter from the Haines Road. An old caterpillar trail leads from the road to an abandoned airstrip located 7 kilometres east of Red Mountain.

Red Mountain is the most prominent feature in the immediate area with its reddish brown colour, north-south elongated, rounded top, and steep east and west sides.

PREVIOUS WORK

The only previous work in the area was done on the east side of Red Mountain. Since the 1960s claims have been staked to cover a sub-horizontal shear zone containing quartz, sphalerite, galena, and pyrrhotite on the east-facing cliff (Joe showing).

The area was mapped by Campbell and Dodds as part of the Geological Survey of Canada's 'Operation Saint Elias', in 1978.

PROPERTY GEOLOGY

The Red Mountain property is underlain by limestones and fine-grained clastic rocks of probable Paleozoic age which are overlain unconformably or structurally by younger volcanic and associated intrusive rocks. A hornblende feldspar porphyry dyke swarm intrudes all these rocks.

In the claim area the suspected Paleozoic rocks consist of well-bedded, grey fine-grained, and white crystalline limestone interbedded with grey cherty argillites and minor quartzites. These are deformed into open to moderate folds with north-trending axial planes.

On the south part of the claims these rocks may be overlain by another sequence of limestones that contain quartz veins; the second sequence may be a facies equivalent of Norian age limy siltstones in the Windy-Craggy area, which is located approximately 32 kilometres to the west. Samples of both types of limestone on the Red Mountain property were collected for potential microfossils.

Unconformably overlying the Paleozoic rocks is a package of argillite (exhalite?), submarine volcanic rocks, and associated intrusives. Near the upper contact of the Paleozoic limestone package, fine-grained, siliceous dykes appear to be feeders to overlying cherty tuffaceous beds which contain disseminated and occasionally massive pyrrhotite and pyrite. Locally, the cherty units are brecciated and consist of white siliceous fragments embedded in a black cherty matrix. The volcanic rocks are bimodal, consisting of pillowed andesite to basalt (?), and massive to fragmental dacite. The pillowed volcanics may correlate with pillowed volcanic rocks in the Windy-Craggy area, which are of Norian age. Interbedded laminated argillites containing disseminated and streaky pyrite with or without pyrrhotite may be of exhalative origin.

The contact between the volcanic rocks, cherty tuffs, and limestones is obscured by talus but diamond drilling shows skarn-type alteration; the limestone has been either recrystallized to marble or silicified to fine-grained, banded to wispy, streaked, white-coloured 'porcellanite'. The associated irregular alteration zone contains quartz, andalusite, and minor amounts of plagioclase, sillimanite, muscovite, trace K-feldspar, and minor pyrrhotite. The pinkish hue in some rocks is probably due to abundant andalusite.

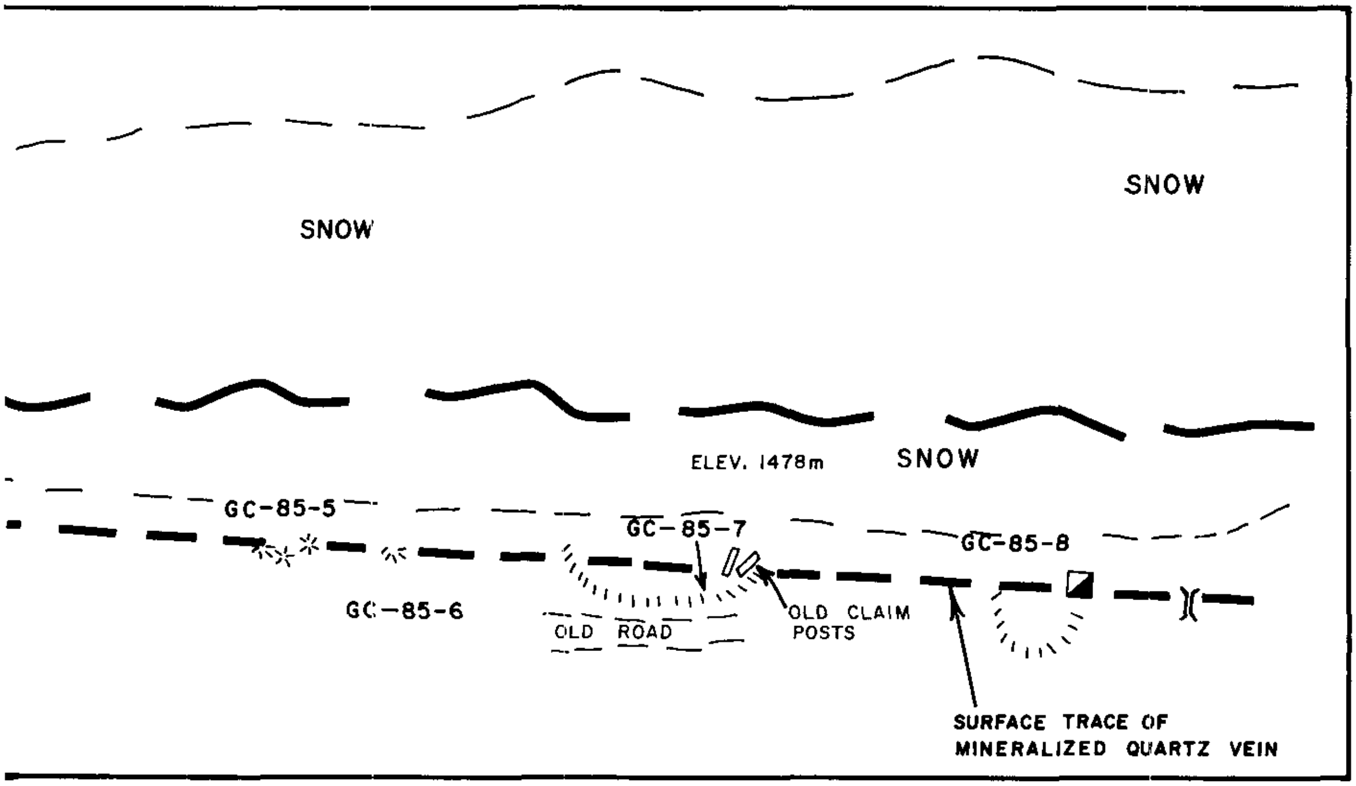

Figure 27-2. Sketch map of Gold Cord (Vein) prospect.

On top of Red Mountain, a 'diabase' crops out which has weak columnar jointing; it may be comagmatic with or intrusive into the pillow basalts. A similar situation occurs at Windy-Craggy, where several diabase dykes intrude the sequence.

Cutting all rock types, except the 'diabase', are a series of sub-parallel feldspar to hornblende-feldspar porphyry dykes which range in thickness from less than 1 metre to almost 100 metres.

MINERALIZATION

At least three different styles of mineralization have been observed on the property:

(1) Barren pyrrhotite-pyrite argillite and cherty tuff with or without breccia zones.
(2) Lead-zinc-silver-copper skarns.
(3) Arsenopyrite-base metal-quartz shear zones (such as the Joe showing).

Where sampled, the pyrrhotite-pyrite zones, which occur principally on the southern portion of the property, are barren. Pyrrhotite occurs in all rock types as disseminations, fracture fillings, or replacing amygdules.

Skarn mineralization occurs mainly in the northern portion of the property. It consists of small irregular 'pods' or patchy zones of galena, sphalerite, chalcopyrite, pyrite, and pyrrhotite in a gangue of epidote-diopside and rare garnets, which occur near or at the contact between limestone and light grey hornblende feldspar porphyry dykes. On the southern portion of the property, diamond drilling intersected narrow skarn zones in white 'porcellanite'; these contained disseminated and fracture-filling pyrrhotite, and traces of chalcopyrite and sphalerite in 0.5-metre-wide quartz veinlets.

Within the volcanic rocks, disseminated arsenopyrite and pyrite occur adjacent to narrow, sub-horizontal shear zones which carry base-metal sulphides. The Joe showing, for example, which occurs on the east-facing cliff of Red Mountain, consists of quartz, sphalerite, galena, and pyrrhotite in sheared volcanic rocks. Diamond drilling on the west side of the mountain intersected local, narrow (5-centimetre) quartz veins containing arsenopyrite (95 per cent), sphalerite (2 per cent), pyrrhotite (2 per cent), and calcite (1 per cent). Locally, pyrrhotite and trace amounts of chalcopyrite were observed in epidotized tuff.

WORK DONE

During 1985 Noranda Exploration Co. Ltd. completed three diamond-drill holes totalling approximately 550 metres on the southern part of the property. The writers briefly examined surface showings and drill core which were stored at elevation 1 036 metres.

WINDY-CRAGGY
(Lat. 59°44.5′ Long 137°44.5′; 114P/12)

A brief visit was made to the Windy-Craggy massive sulphide deposit (reserves estimated at 317 450 000 tonnes grading 1.5 per cent copper, 0.9 kilograms cobalt, plus gold and zinc) but bad weather prevented any geological work from being carried out.

During June and July of 1985 Newhawk Gold Mines Ltd., under a joint venture agreement with Geddes Resources Ltd., completed construction of an 850-metre airstrip capable of handling De Haviland Caribou aircraft. The airstrip was constructed approximately 2 kilometres north-northwest of Tats Lake for the purpose of flying in heavy equipment to allow future underground testing of the deposit.

ACKNOWLEDGMENTS

The writers gratefully acknowledge the hospitality and field discussions with Mike Savell, project geologist with Noranda Exploration Co. Ltd., Whitehorse office.

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THE GEOCHEMISTRY OF BASALTS HOSTING MASSIVE SULPHIDE DEPOSITS, ALEXANDER TERRANE NORTHWEST BRITISH COLUMBIA (114P)

By D. G. MacIntyre

INTRODUCTION

This paper presents and interprets the results of chemical analyses completed by the British Columbia Ministry of Energy, Mines and Petroleum Resources' Analytical Laboratory on samples previously collected from the Windy-Craggy and Mount Henry Clay areas of the Tatshenshini map sheet (MacIntyre, 1983, 1984; MacIntyre and Schroeter, 1985).

REGIONAL TECTONIC SETTING

The Windy-Craggy deposit and Mount Henry Clay occurrences are located within the Alexander terrane (Fig. 28-1; Berg, 1979; Campbell and Dodds, 1983). This terrane includes a thick succession of Precambrian to Permian basinal and platformal carbonate and clastic rocks with a subordinate volcanic component that is unconformably overlain by Late Triassic calcareous turbidites and a bimodal volcanic suite (Fig. 28-2). Paleomagnetic data indicates that this terrane has migrated northward from low paleolatitudes (Hillhouse and Gromme, 1980). The Paleozoic stratigraphy of the Alexander terrane is strikingly similar to that of the Cordilleran miogeocline; possibly the Alexander terrane is a slice of the continental margin that has been moved northward and stepped westward along major transcurrent faults to its present position. This hypothesis has been proposed by several authors (Jones, *et al.*, 1972; Muller, 1977; Monger and Irving, 1980).

The Alexander terrane is in fault contact with Wrangellia to the west and the Taku terrane to the east (Fig. 28-1). Recently, Davis and Plafker (1985) have presented evidence that the Taku and Wrangellia terranes were coextensive and have been offset by movement on the Denali fault system in Mesozoic and Cenozoic time. If this is true then the Alexander terrane must also have been coextensive with these terranes in Triassic time (Davis and Plafker, 1985).

Both the Wrangellia and Taku terranes are characterized by Middle to Late Paleozoic is and arc rocks, such as the Sicker Group of Vancouver Island and the Skolai Group of Alaska, that are unconformably overlain by a thick Triassic section. The base of this section locally includes a thin or absent clastic sedimentary unit containing Ladinian (late Middle Triassic) fossils that is overlain by the thick Karnian (early Late Triassic) submarine and/or subaerial basalt of the Karmutsen/Nikolai assemblage. The basalts are overlain by Norian-age limestone and calcareous sedimentary rocks such as the Quatsino, Parsons Bay, Kunga, Chitistone, and Whitestripe Formations. Like the Alexander terrane, Wrangellia has moved to its present position from low paleolatitudes (Packer and Stone, 1974; Jones, *et al.*, 1977; Hillhouse, 1977; Irving, *et al.*, 1980; Irving, *et al.*, 1985).

Stratigraphic columns for the Triassic rocks of the Alexander, Wrangellia, and Taku terranes are compared on Figure 28-2. The Triassic succession of the Alexander terrane differs significantly from adjacent terranes in the following ways:

(1) The basalts are of Norian rather than Karnian age.
(2) The basalts are underlain by and interbedded with a thick succession of distal to proximal turbidites and/or limestones.

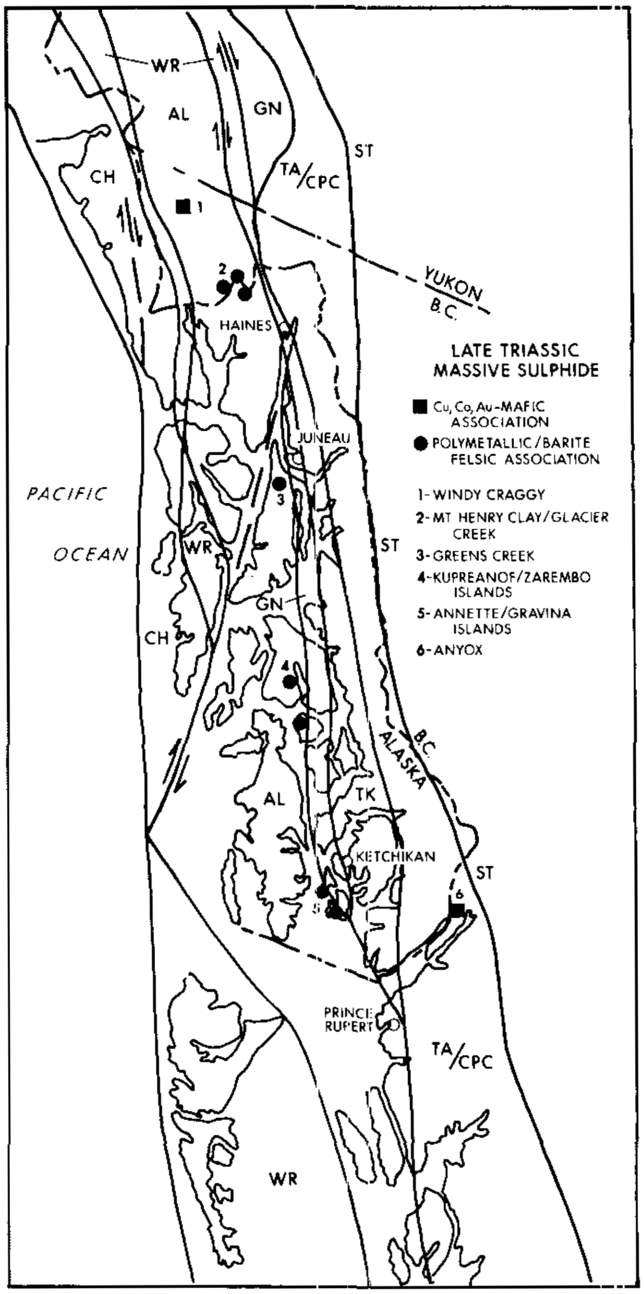

Figure 28-1. Tectonostratigraphic terranes of northwest British Columbia and southeast Alaska, and location of Late Triassic massive sulphide deposits. Terrane abbreviations used are: CH — Chugach; AL — Alexander; WR — Wrangellia; TK — Taku; GN — Gravina/Nutzotin; TA/CPC — Tracy Arm/Coast Plutonic Complex; ST — Stikinia.

British Columbia Ministry of Energy, Mines and Petroleum Resources, Geological Fieldwork, 1985, Paper 1986-1.

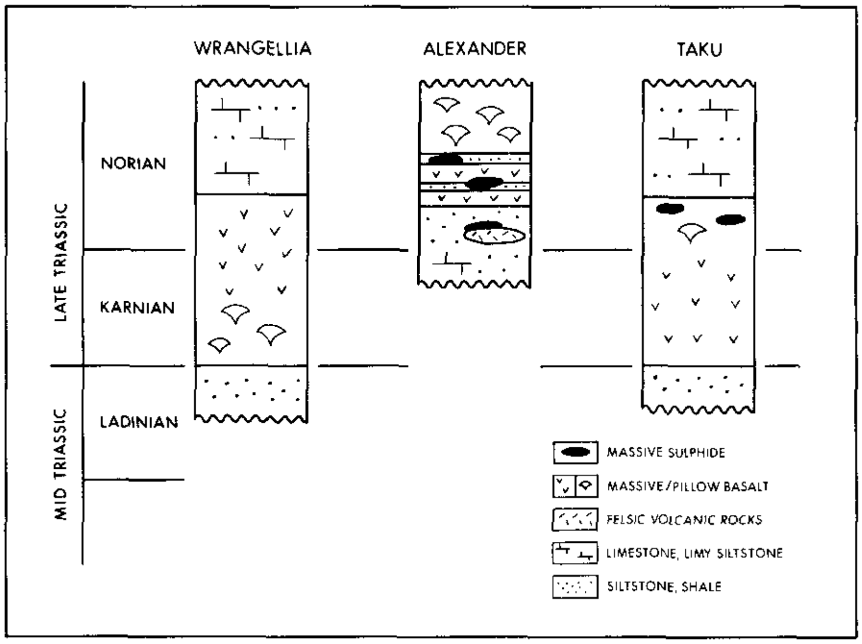

Figure 28-2. Triassic stratigraphic columns for the Wrangellia, Alexander, and Taku terranes.

(3) Sedimentary interbeds are common in the upper volcanic part of the section, which is mainly marine in origin. Karmutsen and Nikolai sections generally lack sedimentary interbeds and are both submarine and subaerial.
(4) Felsic fragmental and flow rocks occur locally in the Triassic section of the Alexander terrane. Felsic volcanic rocks do not occur in the Karmutsen and Nikolai sections.

Another important difference that will be documented in this report is in the composition of the volcanic rocks; those of the Alexander terrane have calc-alkaline characteristics typical of island arcs or back arc basins developed in continental crust; those of the Wrangellia and Taku terranes are mainly low-K tholeiites with oceanic or continental basalt characteristics (Davis and Plafker, 1985).

The timing of suturing of the Alexander and Wrangellia terranes into one superterrane is a matter of considerable debate. As mentioned earlier, Davis and Plafker (1985) have suggested that they were united by Triassic time, a conclusion favoured by this writer. Parts of the superterrane were dislocated by movement along crosscutting transcurrent faults in Mesozoic and Cenozoic time. In general, the current mosaic of terranes that comprise the Insular Tectonic Belt is probably the result of several episodes of oblique subduction and northward translation of slices of oceanic and continental lithosphere in a manner similar to that recently proposed by Bruns (1983) for the Yakutat block. In the Prince Rupert area the Alexander terrane appears to have been thrust eastward under the Coast Plutonic Complex (Woodsworth, *et al.*, 1985).

The Alexander, Wrangellia, and Taku terranes all include Jurassic and Cretaceous calc-alkaline volcanic and plutonic rocks and related back arc successor basin flysch deposits such as the Gravina-Nuzotin assemblage. This implies that these three terranes were together in Early Jurassic time and were probably situated above an eastward-dipping subduction zone. The flysch deposits have also been offset by as much as 300 kilometres of right lateral offset along the Denali fault system in Tertiary time (Eisbacher, 1976). Recently, Irving, *et al.* (1985) suggested that the Wrangellia, Alexander, Taku, Coast Plutonic Complex, and Stikine terranes were all amalgamated by Cretaceous time and travelled north as one superterrane in Late Cretaceous and Early Tertiary time.

Outboard of Wrangellia is the Chugach terrane, a melange-subduction complex which is also of Jurassic-Cretaceous age.

All the terranes of the northern Insular Belt are intruded by granitic rocks of Jurassic, Cretaceous, and Tertiary age again implying amalgamation as a superterrane by no later than Jurassic time.

LATE TRIASSIC STRATIGRAPHY OF THE ALEXANDER TERRANE

The geology, stratigraphy, and mineral deposits of the Windy-Craggy and Mount Henry Clay areas have been described in two previous reports (MacIntyre, 1984; MacIntyre and Scroeter, 1985). Preliminary stratigraphic columns for these two areas are shown on Figure 28-3 together with a typical Triassic section for southeast Alaska. The approximate stratigraphic positions of samples discussed in this report are also shown. The age of the volcanic rocks in the Windy-Craggy area has been established as Early Norian on the basis of conodonts collected from sedimentary interbeds (M. Orchard, pers. comm., 1983). The age of rocks hosting massive sulphide and barite deposits in the Mount Henry Clay-Glacier Creek area is not as well established. One sample collected by Ken Dawson, Geological Survey of Canada, from a sedimentary interbed approximately 50 to 100 metres stratigraphically above the Glacier Creek Main deposit has yielded conodont fragments. These fragments are most likely Triassic in age (M. Orchard, pers. comm., 1985). Elsewhere in the Mount Henry Clay area the age of host rocks is inferred from stratigraphic similarity to other faunally dated Late Triassic sequences in southeast Alaska (Berg, 1981).

The stratigraphic successions observed in the Windy-Craggy and Mount Henry Clay areas are very similar to those observed in other parts of the Alexander terrane, for example, the Glacier Creek area

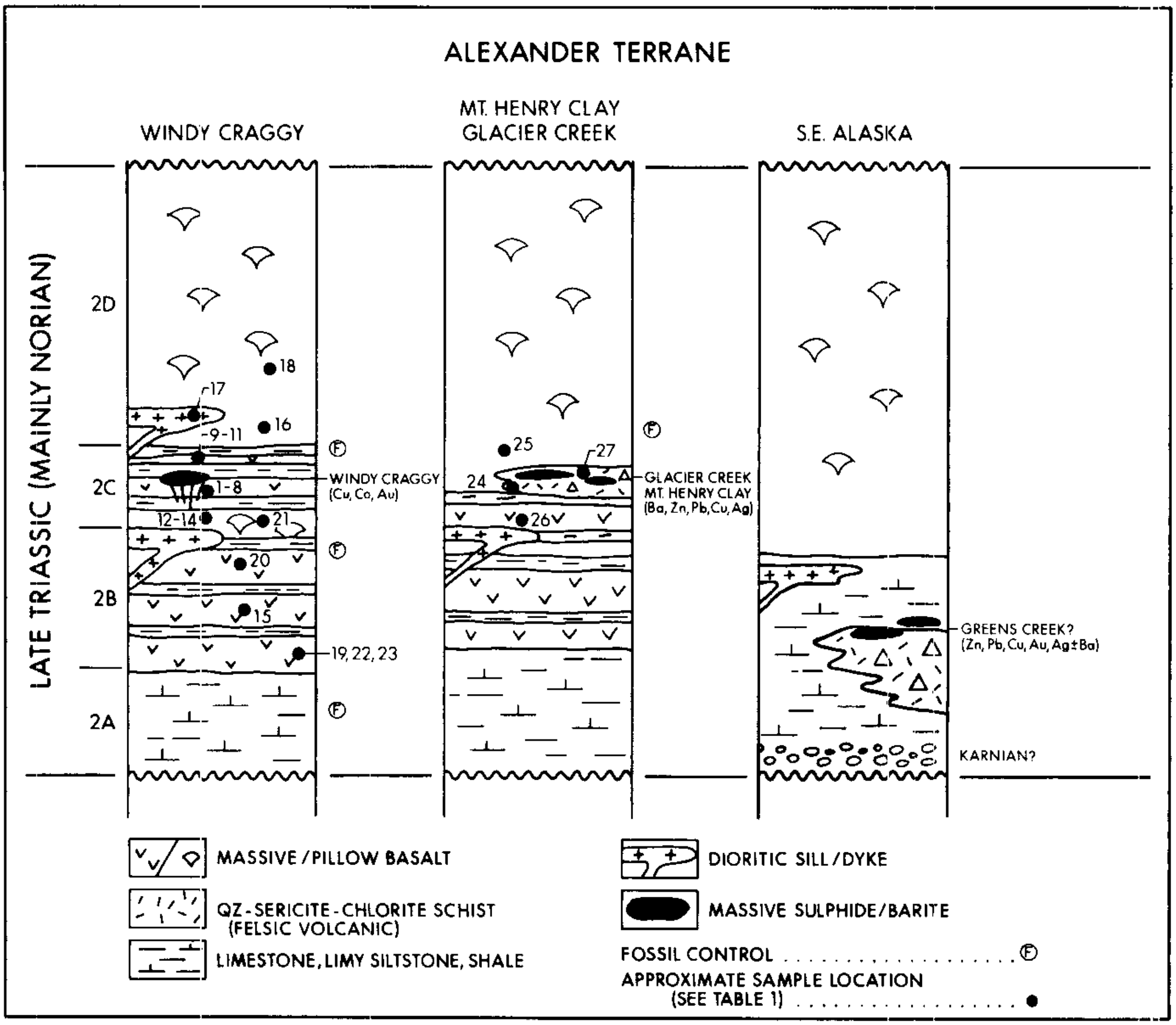

Figure 28-3. Triassic stratigraphic columns for the Windy-Craggy, Mount Henry Clay/Glacier Creek, and southeast Alaska areas of the Alexander terrane.

(Still, 1984) and Gravina Island of southeast Alaska (Berg, 19733; Fig. 28-3). In general, calcareous turbidites and, in southeastern Alaska, erosional conglomerates, occupy the lower part of the sequence. These rocks constitute the Nehenta Formation on Gravina Island (Berg, 1973). The lower sedimentary package grades up section into a thick pillow basalt unit which has been defined as the Chapin Peak Formation on Gravina Island (Berg, 1973). Fossil control is lacking in many parts of southeast Alaska where inferred Triassic rocks occur but, where present, fauna are mainly Norian in age (Berg, 1981); a few Karnian ages have also been reported in southeast Alaska. Karnian age fossils have not yet been found in the Windy-Craggy area.

Unlike other parts of the Alexander terrane, no quartz-sericite schist or phyllite interbeds occur in the Late Triassic mafic volcanic sequence in the Windy-Craggy area. These rocks, which are believed to be sheared rhyolitic fragmental rocks or rhyolite flows, occur in the lower sedimentary or middle mixed sedimentary-basalt parts of the Triassic successions of southeastern Alaska and in the Mount Henry Clay area. Polymetallic massive sulphide and barite deposits (Fig. 28-1), such as Glacier Creek, Low Herbert, Mount Henry Clay, occurrences on Zarembo, Kupreanof, Annette, and Gravina islands and possibly Greens Creek are associated with these felsic rocks (Berg and Grybeck, 1980; McDougall, *et al.*, 1983; Still, 1984; MacIntyre and Schroeter, 1985). The presence of felsic volcanic rocks in these predominantly mafic volcanic sections indicates volcanism in the Alexander terrane was bimodal.

BASALT GEOCHEMISTRY

The chemistry of volcanic rocks that host massive sulphide deposits has been the subject of many previous studies. This data provides important clues (with certain limitations) to the tectonic environment in which the host volcanic rocks were erupted, for example, at a convergent or divergent plate margin or within a plate.

Samples from the Windy-Craggy and Mount Henry Clay areas have been analysed for major and trace elements by the Ministry Laboratory. Results are tabulated in Table 28-1. Whole rock analyses of drill core have also been provided by Falconbridge Nickel Mines Limited for comparative purposes. In addition, Dr. Joe Fox, I.R.E.M./M.E.R.I., Montreal, provided immobile and rare earth

TABLE 28-1

CHEMICAL ANALYSES AND CIPW NORMS

	WINDY-CRAGGY DEPOSIT - FOOTWALL								HANGINGWALL			WINDY-CRAGGY AREA												MOUNT HENRY CLAY AREA			
No.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27
Sample	9-646	9-746	9-1630	12-700	82-3	82-9	82-10	82-11	5-190	82-5A	82-7	83-2	83-3A	83-4	83-16	83-34	83-70	83-80A	84-3	84-7	84-8	84-9	84-10	ST84-1	LH84-2	BC84-3	GL84-4
SiO_2	51.39	48.64	49.17	39.55	41.73	51.84	51.20	40.22	49.49	50.92	46.29	52.77	49.99	48.53	49.73	51.08	47.53	49.49	50.04	52.84	50.87	50.46	52.77	45.84	66.40	57.16	70.70
TiO_2	0.84	0.94	1.13	1.51	0.89	1.14	1.25	1.25	0.90	0.90	1.17	0.75	0.43	0.41	1.34	0.91	1.13	0.97	0.67	0.52	0.84	1.33	0.85	1.24	1.43	1.53	0.63
Al_2O_3 ...	16.00	16.21	14.63	17.59	17.60	15.04	16.55	17.74	17.16	16.65	13.34	15.89	18.18	19.42	16.41	16.79	13.68	13.42	18.01	18.41	13.44	18.46	15.14	13.52	12.27	12.14	15.81
Fe_2O_3 ...	0.98	1.72	2.15	2.32	1.73	8.73	3.70	1.60	2.40	1.29	2.54	1.08	1.64	1.86	1.43	0.93	0.82	0.94	1.32	1.81	0.87	1.88	0.91	4.68	7.41	8.13	1.82
FeO	8.72	15.20	16.60	18.60	12.20	9.73	10.40	16.10	6.35	5.46	5.35	7.27	6.30	5.84	6.42	6.42	7.51	5.29	6.48	5.48	8.15	4.61	0.55	9.66	0.43	6.55	0.36
MnO	0.07	0.06	0.11	0.11	0.06	0.08	0.06	0.18	0.06	0.05	0.11	0.09	0.15	0.13	0.12	0.09	0.14	0.13	0.12	0.15	0.15	0.12	0.15	0.19	0.01	0.16	0.01
MgO	10.61	6.49	7.07	4.91	14.20	1.77	5.33	3.16	4.87	10.08	10.48	6.45	5.68	6.30	5.50	8.04	11.57	4.49	5.97	4.28	9.60	5.81	8.33	7.00	0.48	4.83	0.56
CaO	0.95	1.13	0.58	2.31	0.38	0.03	0.38	5.44	3.70	3.20	7.31	5.82	11.53	11.16	8.44	3.72	7.36	12.51	8.86	8.49	9.71	7.08	4.94	6.06	0.03	0.50	0.06
Na_2O ...	3.96	3.87	2.22	4.24	2.27	3.50	4.67	4.61	4.09	1.63	1.26	5.98	3.53	3.32	4.68	5.09	3.15	5.36	4.19	4.50	2.89	5.70	4.93	4.36	0.21	2.18	1.97
K_2O	0.03	0.03	0.01	0.06	0.01	0.12	0.02	0.35	2.59	2.14	0.86	0.12	0.16	0.32	0.78	1.85	1.08	0.30	0.59	1.17	0.74	0.20	0.10	0.03	3.46	1.33	4.02
P_2O_5	0.41	0.45	0.43	0.88	0.37	0.10	0.44	0.79	0.44	0.49	0.56	0.45	0.06	0.14	0.67	0.55	0.54	0.38	0.13	0.51	0.27	0.97	0.12	0.43	0.10	0.29	0.15
CO_2	0.10	0.48	0.10	0.88	0.10	0.15	0.17	3.68	2.23	1.59	5.18	0.10	0.14	0.04	0.53	0.04	0.06	1.46	0.93	0.21	0.14	0.10	0.24	3.04	0.10	0.10	0.10
H_2O+ ..	4.47	4.80	4.60	5.02	8.68	4.79	4.96	5.34	3.46	4.62	5.68	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
H_2O- ..	0.29	0.27	0.21	0.20	0.41	1.92	1.12	0.22	0.34	0.24	0.21	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
LOI	—	—	—	—	—	—	—	—	—	—	—	2.40	2.20	2.60	5.00	3.50	4.10	6.20	2.54	1.50	1.83	2.96	3.32	5.58	6.02	4.28	2.81
TOTAL	98.82	100.29	99.01	98.18	100.63	98.94	100.25	100.68	98.08	99.26	100.34	99.17	99.85	100.03	100.52	98.97	98.61	99.48	98.92	99.66	99.36	99.58	100.11	98.59	98.26	99.08	98.90
CIPW NORM VOLATILE FREE																											
Q	5.57	4.02	14.20	0.00	0.00	26.44	10.25	0.00	0.00	10.05	4.71	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	55.59	32.24	44.81
C	9.27	9.33	11.63	9.19	15.16	9.94	9.42	1.95	2.13	7.55	0.00	0.00	0.00	0.00	0.00	1.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	8.87	7.28	8.56
Or	0.19	0.19	0.06	0.39	0.06	0.77	0.13	2.26	16.63	13.63	5.69	0.73	0.97	1.94	4.83	11.45	6.75	1.90	3.62	7.04	4.48	1.22	0.61	0.19	22.18	8.29	24.72
Ab ...	35.65	34.55	19.96	38.95	21.00	32.15	42.03	28.97	37.58	14.86	11.94	52.33	30.58	28.11	39.22	44.66	28.19	28.40	36.04	38.78	25.07	48.04	43.08	39.65	1.95	19.45	17.34
An ...	2.16	2.81	0.07	6.20	0.00	0.00	0.00	23.87	16.82	13.66	31.60	16.73	34.10	38.14	22.49	15.57	21.17	12.53	29.68	27.09	22.07	25.06	19.53	18.54	0.00	0.62	0.00
Ne	0.00	0.00	0.00	0.00	0.00	0.00	0.00	7.41	0.00	0.00	0.00	0.00	0.00	0.39	1.20	0.24	0.00	10.95	0.40	0.00	0.00	1.01	0.00	0.00	0.00	0.00	0.00
Di ...	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	3.91	8.26	19.68	14.42	13.66	0.00	11.05	41.95	12.28	10.18	20.71	3.80	4.07	8.80	0.00	0.00	0.00
Hy ...	42.96	43.50	47.44	7.60	53.79	14.48	29.10	0.00	14.51	35.20	34.09	0.05	1.57	0.00	0.00	0.00	3.84	0.00	0.00	6.72	14.04	0.00	17.79	6.83	1.30	15.94	1.45
Ol ...	0.00	0.00	0.00	28.71	4.60	0.00	0.00	28.43	5.61	0.00	0.00	17.75	9.72	13.13	12.16	22.53	24.17	−0.29	14.38	5.33	10.08	13.14	11.62	15.10	0.00	0.00	0.00
Wo ...	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.41	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Mt	1.51	2.63	3.32	3.65	2.74	13.74	5.71	2.54	3.78	2.02	4.13	1.62	2.43	2.77	2.17	1.41	1.26	1.46	1.99	2.67	1.29	2.82	1.36	7.30	0.00	12.43	0.00
Il	1.70	1.88	2.28	3.11	1.85	2.35	2.53	2.60	1.86	1.84	2.49	1.47	0.84	0.80	2.66	1.81	2.27	1.97	1.32	1.01	1.64	2.61	1.67	2.53	1.02	3.07	0.80
Hm	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	8.04	0.00	1.89
Ru	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.02	0.00	0.23
Ap	1.02	1.11	1.07	2.23	0.94	0.25	1.09	2.01	1.11	1.23	1.46	1.09	0.14	0.33	1.63	1.34	1.33	0.95	0.31	1.21	0.65	2.34	0.29	1.08	0.25	0.71	0.36
AN= .	5.73	7.53	0.36	13.73	0.00	0.00	0.00	45.17	30.91	47.89	72.58	24.23	52.73	57.57	36.44	25.85	42.89	30.61	45.16	41.13	46.82	34.28	31.19	31.86	0.00	3.08	0.00
Ba	12	10	8	28	4	34	11	83	358	860	114	20	20	10	400	760	680	20	220	470	310	120	170	90	3 050	780	2 900
Rb	15	19	6	16	5	9	7	9	33	39	24	15	4	20	20	50	—	13	10	27	9	6	45	10	47	11	75
Sr	51	60	43	77	26	43	34	86	171	128	171	—	—	230	450	630	—	—	371	913	447	674	312	160	39	34	70
Y	13	15	7	12	4	15	15	2	12	13	10	17	6	20	20	10	—	11	6	8	18	22	14	27	24	31	5
Zr	120	130	155	150	68	162	164	164	45	116	118	105	10	20	120	180	—	159	83	93	86	194	60	93	90	211	15
Nb	—	—	—	—	—	—	—	—	—	—	—	—	—	10	50	50	—	—	10	14	8	38	12	11	10	7	3
Cr	241	210	153	155	249	24	25	399	10	170	439	156	130	210	110	150	—	177	100	94	360	83	113	24	13	13	45
Cu	118	43	63	126	81	830	117	74	133	60	49	53	130	125	45	20	59	11	40	72	24	32	100	62	36	16	22
Pb	4	5	5	6	7	5	4	7	5	5	5	4	3	2	2	2	3	3	5	5	5	5	5	5	670	5	35
Zn	20	27	51	40	93	148	30	825	67	68	81	47	60	56	53	58	75	48	70	84	72	71	87	117	0	272	33
Co	28	12	26	23	22	9	9	16	27	19	28	36	44	39	41	29	10	29	47	30	50	26	40	53	50	33	30
Ni	102	45	48	44	76	9	21	115	21	70	250	75	71	76	77	150	320	102	75	42	183	75	64	64	21	21	10

— = not determined.

N.B. Totals do not include CO_2 if L.O.I. determined.

SAMPLE DESCRIPTIONS TO ACCOMPANY TABLE 28-1

1 — Drill core, DDH 9, 197 metres, Windy-Craggy. Medium grey to green chloritic basalt with disseminated pyrrhotite. Near base of massive sulphide.

2 — Drill core, DDH 9, 227 metres, Windy-Craggy. Similar to No. 1.

3 — Drill core, DDH 9, 497 metres, Windy-Craggy. Similar to No. 1.

4 — Drill core, DDH 12, 213 metres, Windy-Craggy. Medium to dark green intensely chloritized and sheared volcanic rock from stratigraphic footwall of massive sulphide deposit.

5 — Surface sample, Windy-Craggy. Sheared, chloritic volcanic rock from stratigraphic footwall of massive sulphide deposit.

6 — Surface sample, Windy-Craggy. Chloritized amygdaloidal flow from outcrop adjacent to DDH 12.

7 — Surface sample, Windy-Craggy. Fine-grained green chloritic pillow lava from outcrop adjacent to DDH 12.

8 — Surface sample, Windy-Craggy. Similar to No. 7.

9 — Drill core, DDH 5B, 58 metres, Windy-Craggy. Massive, fine-grained grey carbonate-altered basalt flow. Sample is interpreted to be from the lower part of the lower volcanic unit of the Tats Group (map unit 2B).

10 — Surface sample, Windy-Craggy. Light grey-weathering, carbonate-altered basalt flow from outcrop up slope from DDH 12. Sample is interpreted to be in stratigraphic hangingwall of the massive sulphide deposit.

11 — Surface sample, Windy-Craggy. Light green-weathering, spotted carbonate-altered, amygdaloidal basalt flow from outcrop located up slope from DDH 12. Sample is interpreted to be in the stratigraphic footwall of the massive sulphide deposit.

12 — Buff-weathering pillow lava, middle volcanic-sedimentary unit, Tats Group.

13 — Buff-weathering amygdaloidal, porphyritic basalt flow, middle volcanic-sedimentary unit, Tats Group.

14 — Buff-weathering pillow lava, middle volcanic-sedimentary unit, Tats Group.

15 — Massive, grey-weathering basalt flow, lower volcanic unit, Tats Group.

16 — Massive, dark grey-weathering pillow basalt, upper volcanic unit, Tats Group.

17 — Massive, grey-weathering microdioritic dyke cutting upper volcanic unit, Tats Group.

18 — Massive, dark grey-weathering pillow basalt with carbonate-filled amygdules, upper volcanic unit, Tats Group.

19 — Medium-grained, chlorite-altered diorite sill, lower volcanic unit, Tats Group.

20 — Fine-grained, dark grey hornblende andesite or basalt, lower volcanic unit, Tats Group.

21 — Fine-grained, dark grey chlorite-altered hornblende andesite or basalt, middle volcanic-sedimentary unit, Tats Group.

22 — Medium-grained, diorite sill, lower sedimentary unit, Tats Group.

23 — Fine-grained, dark grey basalt or andesite, lower volcanic unit, Tats Group.

24 — Amygdaloidal, chlorite-altered pillow basalt overlying Low Herbert mineralized zone, Mount Henry Clay area.

25 — Grey, foliated, quartz-sericite-altered vitric tuff with disseminated pyrite, Low Herbert mineralized zone, Mount Henry Clay area.

26 — Greenish grey, foliated chlorite-altered andesitic tuff or sheared flow, Boulderado occurrence, Mount Henry Clay.

27 — Cream-coloured, foliated quartz-sericite-altered lithic tuff, mineralized zone, Glacier Creek Main deposit, Mount Henry Clay area.

TABLE 28-2
TRACE AND RARE EARTH ANALYSES

Sample	83-16	83-34	N-MORB	
Rb	20	50	1	LIL
Ba	510	1 000	12	LIL
Th	2.9	5.5	0.2	LIL
K	5 810	14 520	830	LIL
Sr	450	630	3	LIL
La	35.5	59.7	10.0	LIL
Ce	70	100	136	LIL
Nb	50.0	50.0	2.5	HFS
Ta	1.70	1.80	0.17	HFS
Nd	31	36	8	HFS
Sm	6.43	6.37	—	HFS
P	2 616	3 139	570	HFS
Hf	3.3	4.1	2.5	HFS
Zr	120	180	88	HFS
Eu	1.80	1.68	1.20	HFS
Ti	10 242	7 008	8 400	HFS
Tb	0.80	0.70	0.71	HFS
Y	20	10	35	HFS
Yb	1.87	1.89	3.50	HFS
Lu	0.29	0.28	—	HFS
Ni	77	150	138	
Cr	110	150	290	

Note: All values in ppm.
N-MORB values from Saunders and Tarney (1984).
Analyses by X-ray Assay Laboratories, Don Mills, Ontario.
Data provided by Dr. J. Fox, I.R.E.M./M.E.R.I., Montreal, Quebec.

analyses for two selected samples (WD83-16, WD83-34) from the Windy-Craggy area (Table 28-2).

The field occupied by basalts from the Wrangellia and Taku terranes is also plotted on Figures 28-7 to 28-16 for comparison purposes. The data used includes 24 analyses of Nikolai greenstone and Chilkat metabasalts (Davis and Plafker, 1985), 12 analyses of Karmutsen basalts (A. Sutherland Brown, pers. comm.) and six analyses of Anyox basalts (Sharp, 1980). All of these basalts are low-K tholeiites or ferrotholeiites in composition.

ALTERATION OF BASALT

Petrographic examination and the analytical data in Table 28-1 indicates most of the samples collected from the Windy-Craggy and Mount Henry Clay areas have been altered to some extent. Analyses 1 to 8 are from drill core and surface samples (Fig. 28-4) that are interpreted to be in the stratigraphic footwall of the Windy-Craggy deposit. These basalts are all pervasively chloritized and contain abundant disseminations and stringers of pyrrhotite. The analytical data suggests strong depletion in calcium, potassium, barium, and strontium relative to normal calc-alkaline basalt compositions. Analyses 4, 5, and 8 are also depleted in silica; iron is moderately to strongly enriched. These altered rocks are typically quartz and corundum normative.

Analyses 10 and 11 are from the stratigraphic hangingwall of the Windy-Craggy deposit and are also altered as indicated by high CO_2 and H_2O values. These rocks contain sericite, clay, and carbonate. Calcium abundances are relatively low compared to normal basaltic rocks; on the other hand K_2O ranges from 0.86 to 2.59 per cent and may be enriched. Corundum and quartz are present in the norm. This data suggests that footwall alteration is mainly chloritic whereas hangingwall alteration is predominantly phyllic to argillic. The phyllic and argillic alteration may be related to fluid boiling near hydrothermal vents.

Analyses 12 to 23 are from various stratigraphic levels in the Triassic section of the Windy-Craggy area (Figs. 28-3 and 28-5). Of these, analyses 13, 14, 15, 19, and 20 have CO_2, H_2O, and CaO concentrations like those of fresh basalt and appear to be the least altered. However, in thin section clay and carbonate alteration is also common in these samples, particularly in No. 14, which is a sample of pale-weathering pillow lava in the middle volcanic-sedimentary unit (2C) of the Tats Group.

Analyses 24 to 27 are from the Mount Henry Clay area and include altered basalt, andesite, and quartz-sericite-schist or phyllite. Sample locations are shown on Figure 28-6. No. 24 is from a pillow basalt flow that overlies the Low Herbert showing (MacIntyre and Schroeter, 1985). High H_2O and CO_2 values reflect the presence of numerous carbonate-filled vesicles in the sample. No. 26 is a foliated, chlorite-rich andesite collected from outcrop near a showing of massive sulphide boulders (Boulderado) on the north face of Mount Henry Clay. Nos. 25 and 27 are samples of quartz-sericite schist or sheared rhyolitic fragmental rocks that host bedded barite-sulphide and disseminated and semi-massive sulphide at the Glacier Creek and Low Herbert showings respectively. These samples are peraluminous (corundum normative), reflecting the presence of abundant sericite.

Basalts from the Windy-Craggy area are characterized by relatively low TiO_2 and high Na_2O, K_2O, and P_2O_5 compositions relative to mid-ocean ridge basalts (MORB). They are also enriched in large ion lithophile (LIL) elements. However, alkali and LIL element enrichment can result from low-grade seawater alteration of basalt (spilitization) and under such circumstances original rock chemistry is difficult to determine. Therefore, caution must be used in interpreting discriminant plots that use mobile elements such as Na, Ca, K, and to some extent SiO_2 and the LIL elements. Consequently, several different discriminant plots using both major oxide and immobile elements have been used in this study; the results from each are discussed and compared in the following sections. In each plot, the samples that plot in the unaltered field on the CaO versus MgO diagram (Fig. 28-7; Nos. 13, 14, 15, 19, and 20 in Table 28-1) of Spence (1985) are indicated by a special symbol so that altered and relatively unaltered samples can be compared.

ALKALINE VERSUS SUBALKALINE BASALTS

Several plots have been devised to identify alkaline and subalkaline series volcanic rocks. The most commonly used is the $Na_2O + K_2O$ versus SiO_2 plot (Kuno, 1966; MacDonald, 1964; Irvine and Baragar, 1971). On this diagram (Fig. 28-8) analysed samples cluster about the alkalic-subalkalic boundary; the least altered samples plot within or close to the subalkalic field. On Irvine and Baragar's (1971) normative olivine-nepheline-quartz ternary diagram (Fig. 28-9) most samples plot in the subalkaline field; the least altered samples plot on or near the alkalic-subalkalic boundary. Floyd and Winchester (1978) used a plot of LOG (Zr/TiO_2) versus SiO_2 to divide and classify alkaline and subalkaline rocks. This plot (Fig. 28-10) is especially useful for altered rocks because Si, Zr, and Ti are relatively immobile at low to moderate alteration levels. Mafic samples from Windy-Craggy and Mount Henry Clay plot in the subalkaline and alkali basalt fields; quartz sericite schists or phyllites from the Mount Henry Clay area plot in the rhyodacite field. A similar conclusion is derived using the Zr/P_2O_5 versus TiO_2 plot (Floyd and Winchester, 1975) although on this diagram (Fig. 28-11) a small group of samples plot in the alkaline field. Floyd and Winchester (1975) also use the ratio of Y/Nb to divide alkaline from subalkaline rocks but Y and Nb concentrations in the samples used in this study are too close to the XRF detection limit for these elements to be reliable.

Major and trace element chemistry of the analysed volcanic rocks from the Windy-Craggy and Mount Henry Clay areas suggest that they are mainly subalkaline in composition, although some samples are chemically similar to alkaline volcanic rocks.

THOLEIITIC VERSUS CALC-ALKALINE BASALTS

Subalkaline rocks include the tholeiitic and calc-alkaline series (Irvine and Baragar, 1971). Pronounced iron enrichment and Al_2O_3 concentrations between 12 and 16 per cent characterize the tholeiitic series; calc-alkaline rocks lack iron enrichment and generally have Al_2O_3 concentrations between 16 and 20 per cent (Irvine and Baragar, 1971). The most commonly used plot to distinguish the two series is the alkalies-total iron-magnesium (AFM) ternary diagram (Fig. 28-12). On this diagram, the least altered samples from the Windy-Craggy and Mount Henry Clay areas plot in the calc-alkaline field (Fig. 28-12); intensely altered samples are enriched in Fe and plot in the tholeiitic field. By comparison, unaltered basalts from the Wrangellia and Taku terranes plot mainly in the tholeiitic field.

TECTONIC SETTING

Major and trace element geochemistry of basalts from different tectonic environments has been examined by many researchers, and a diverse collection of discriminant diagrams has evolved. Most of these are based on relatively immobile trace elements such as Ti, Cr, Zr, Nb, Y, Ta, and Th (Pearce and Cann, 1973; Floyd and Winchester, 1975; Miyashiro and Fumiko, 1975; Garcia, 1978; Pearce and Norry, 1979). On the Ti versus Cr plot of Figure 28-13 the majority of Windy-Craggy samples plot within the island arc basalt (IAB) field, that is, they are mainly calc-alkaline or alkaline in composition; samples from the Wrangellia and Taku terranes plot *in the MORB or tholeiite field.*

Samples from the Windy-Craggy and Mount Henry Clay area have been analysed for zirconium. These samples show considerable scatter on the Ti versus Zr diagram of Figure 28-14 although in general there is a calc-alkaline basalt trend. Samples from the Wrangellia and Taku terranes plot along a well-defined linear trend that falls within the ocean floor basalt field. This plot further illustrates the more alkaline composition of the Windy-Craggy basalts compared to the predominantly tholeiitic Nikolai, Chilkat, Karmutsen, and Anyox basalts.

RARE EARTH ELEMENTS

Chondrite normalized rare earth concentrations for two samples of basalt (Table 28-2) from the Windy-Craggy area are plotted on Figure 28-15. The plot shows that the Windy-Craggy basalts are strongly enriched in the light rare earth elements (LREE) relative to those of the Wrangellia and Taku terranes (Davis and Plafker, 1985)

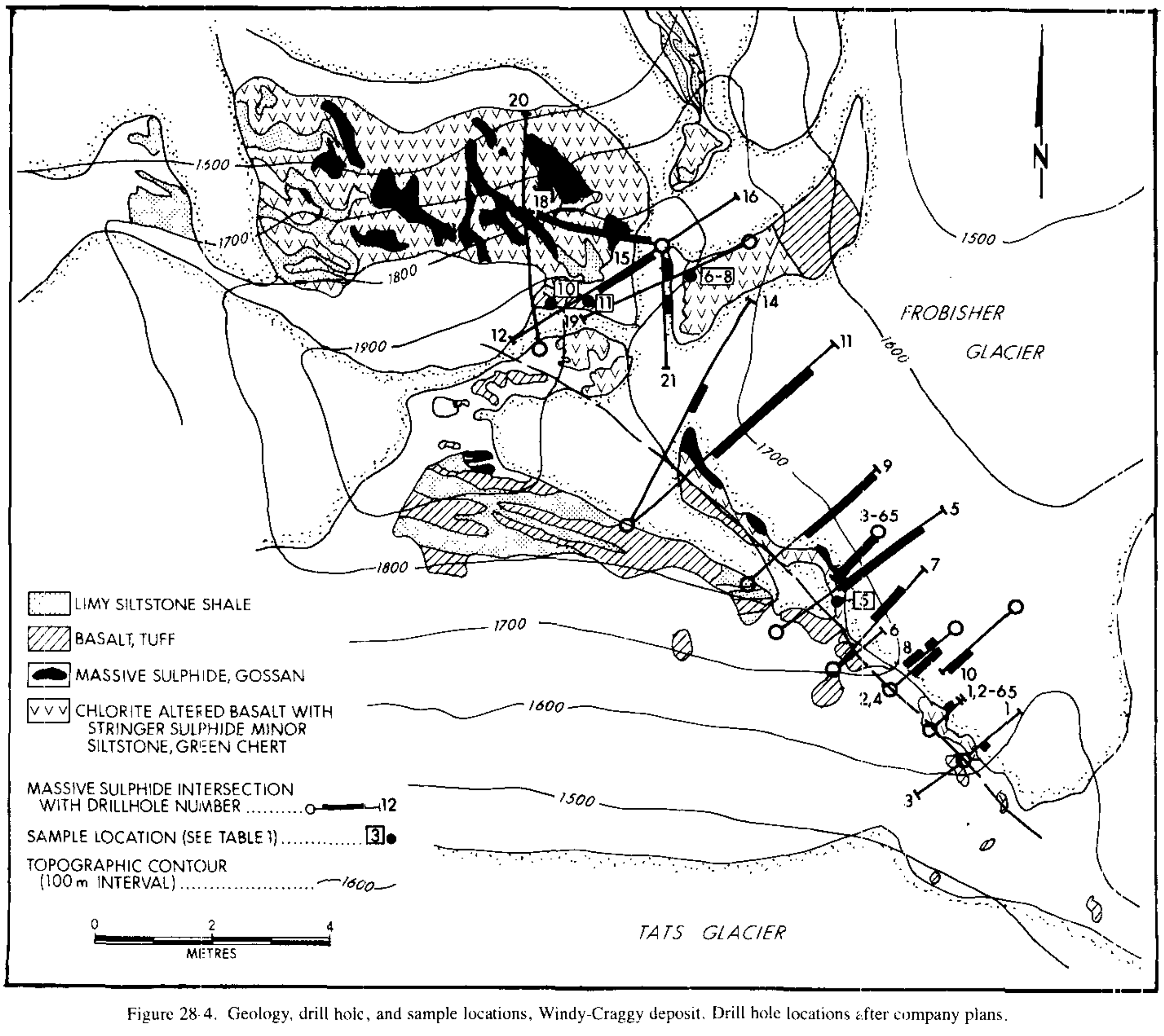

Figure 28-4. Geology, drill hole, and sample locations, Windy-Craggy deposit. Drill hole locations after company plans.

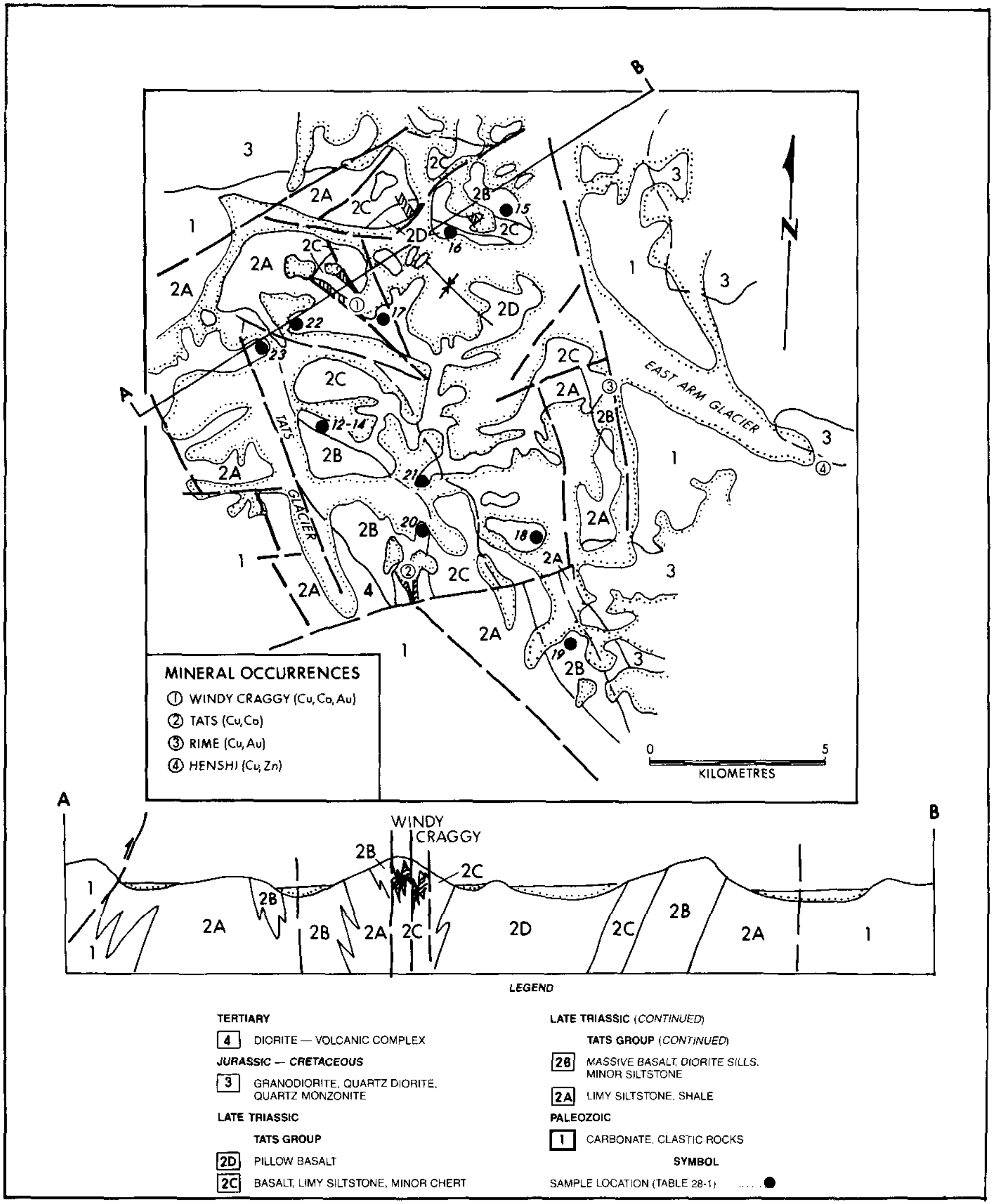

Figure 28-5. Geology and sample locations, Windy-Craggy area. Geology after MacIntyre (1984).

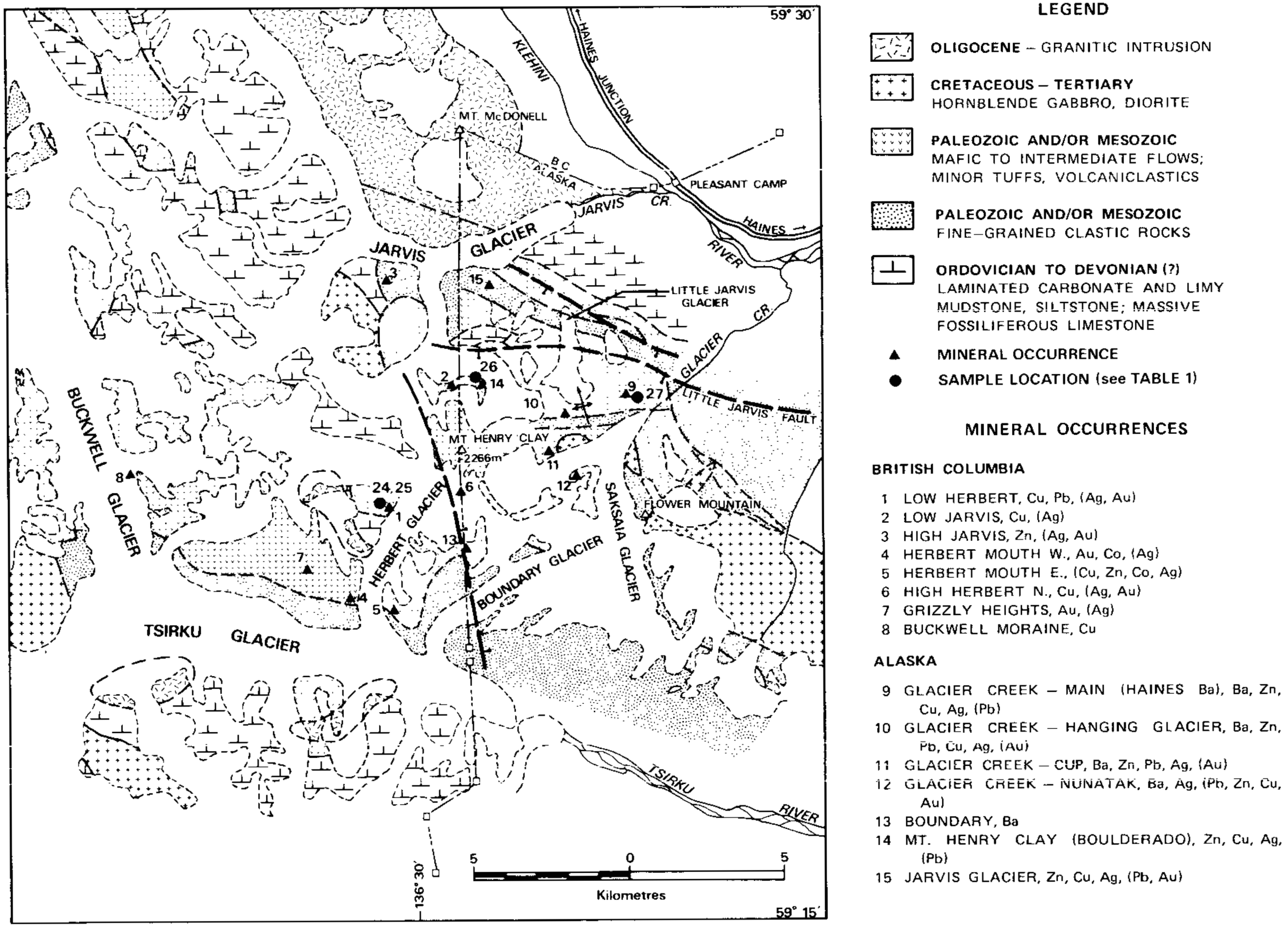

Figure 28-6 Geology and sample locations, Mount Henry Clay area. British Columbia geology after Campbell and Dodds (1983); Alaska geology after Still (1984).

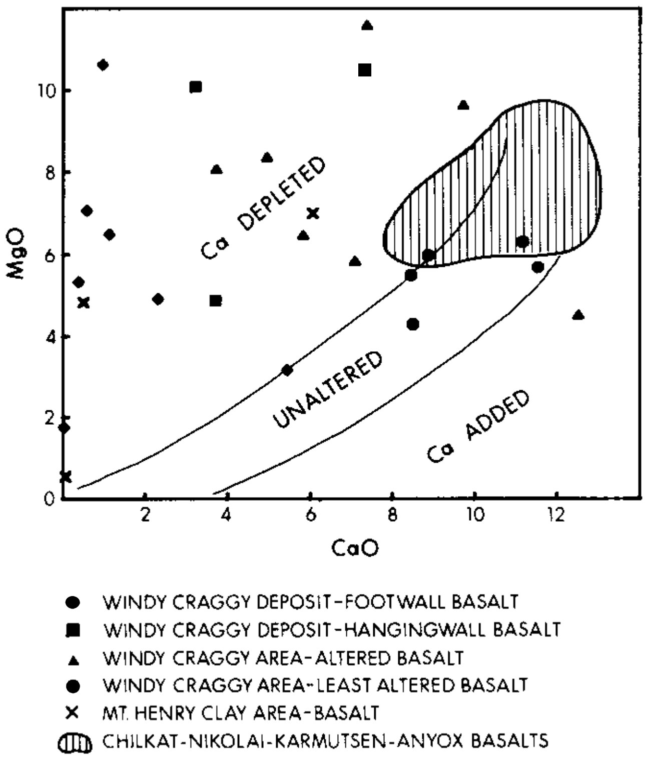

Figure 28-7. MgO versus CaO plot showing unaltered field of Spence (1985).

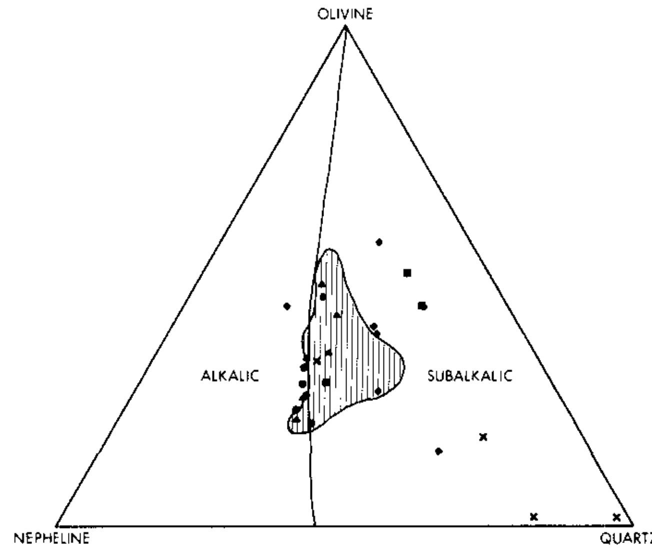

Figure 28-9. Normative olivine-quartz-nepheline ternary plot showing alkalic and subalkalic fields as defined by Irvine and Baragar (1971). *See* Figure 28-7 for explanation of symbols.

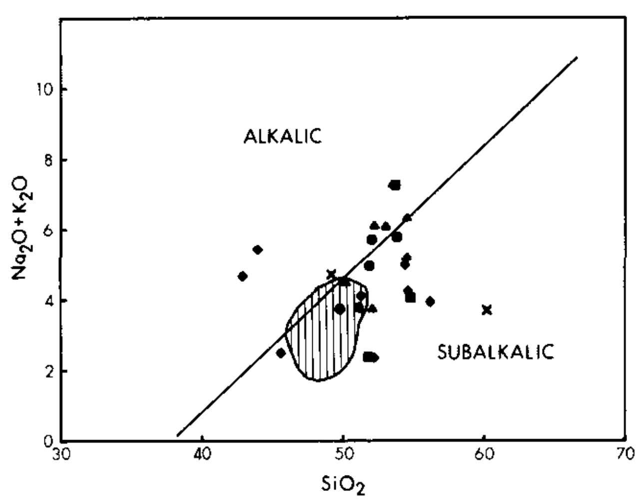

Figure 28-8. Alkalies versus SiO_2 plot showing alkalic and subalkalic fields. Dividing line after MacDonald (1964). *See* Figure 28-7 for explanation of symbols.

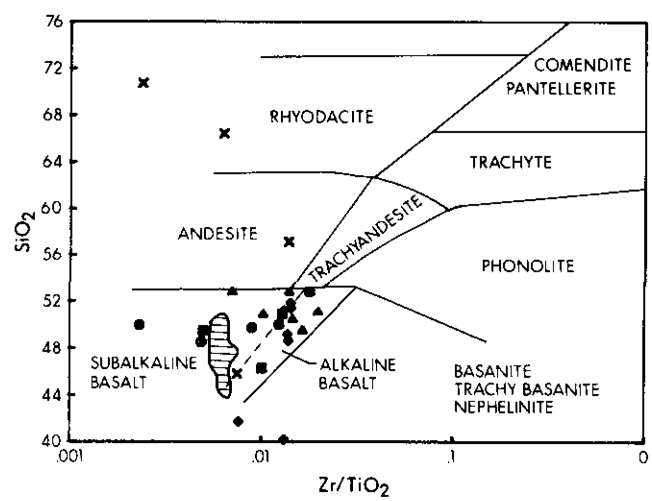

Figure 28-10. SiO_2 versus Zr/TiO_2 plot showing alkalic and subalkalic fields and rock type classification of Floyd and Winchester (1978). *See* Figure 28-7 for explanation of symbols.

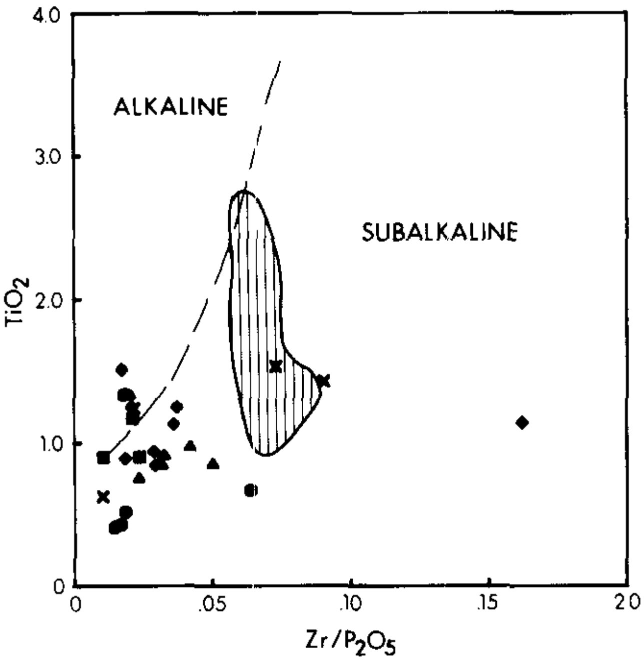

Figure 28-11. TiO_2 versus Zr/P_2O_5 plot showing alkalic and subalkalic fields of Floyd and Winchester (1975). *See* Figure 28-7 for explanation of symbols.

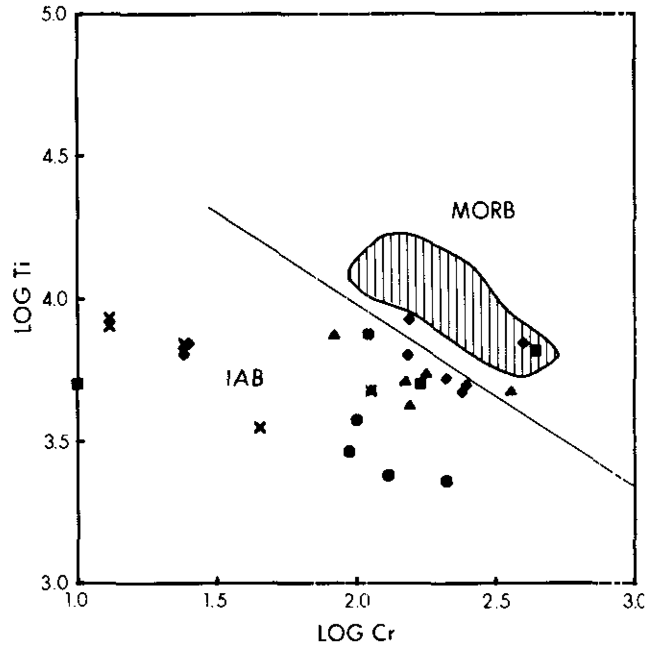

Figure 28-13. Log Ti versus Log Cr showing island arc basalt (IAB) and mid-ocean ridge basalt (MORB) fields of Pearce (1975). *See* Figure 28-7 for explanation of symbols.

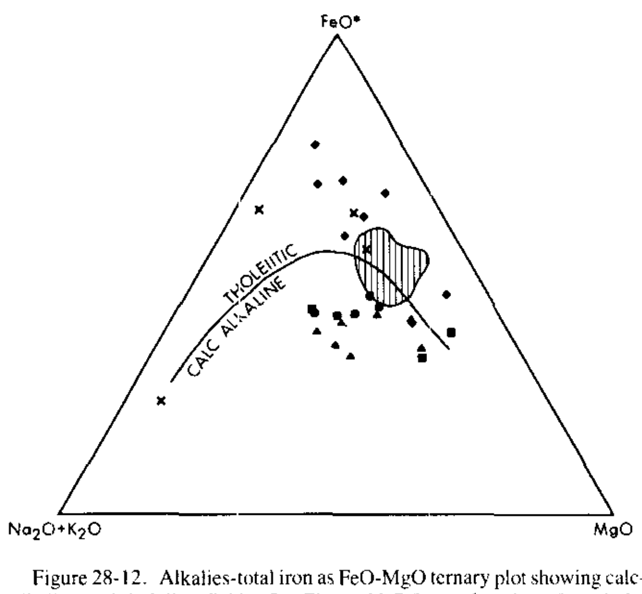

Figure 28-12. Alkalies-total iron as FeO-MgO ternary plot showing calc-alkaline and tholeiitic fields. *See* Figure 28-7 for explanation of symbols.

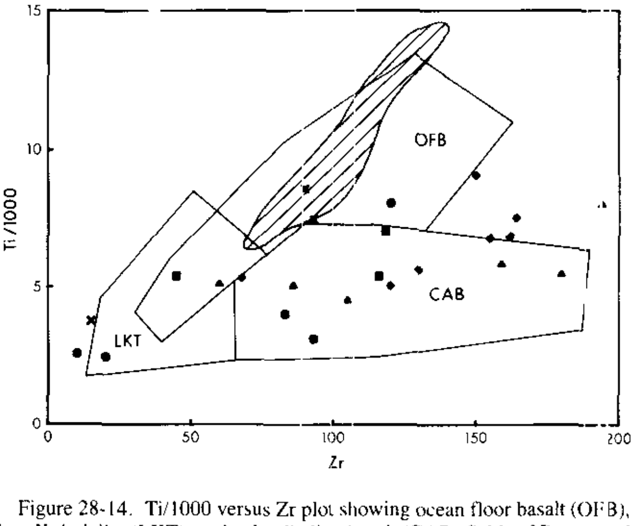

Figure 28-14. Ti/1000 versus Zr plot showing ocean floor basalt (OFB), low-K tholeiite (LKT), and calc-alkaline basalt (CAB) fields of Pearce and Cann (1973). *See* Figure 28-7 for explanation of symbols.

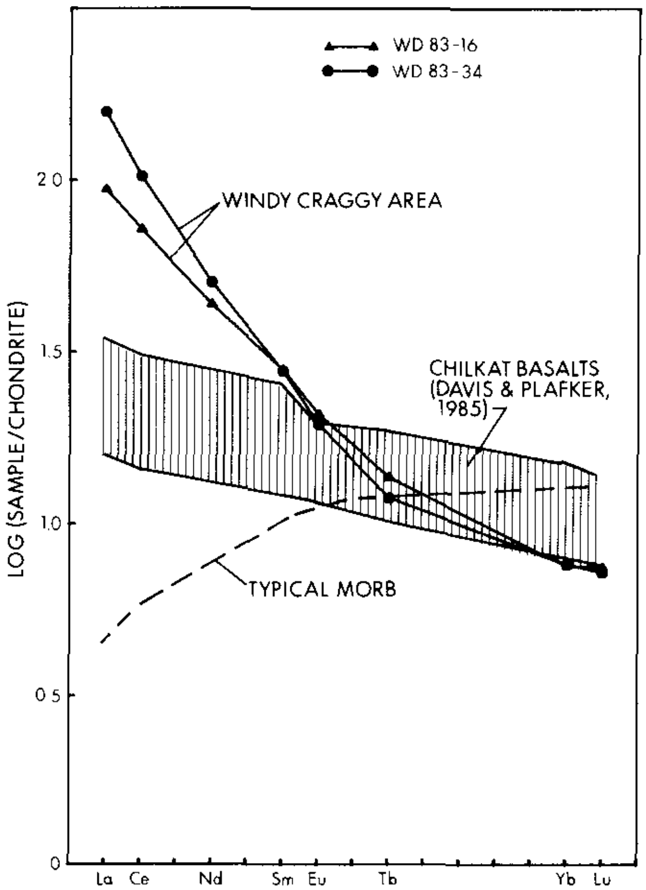

Figure 28-15. Chondrite normalized rare earth plot for two samples from the Windy-Craggy area. Also shown for comparison is the range of values for basalts from the Chilkat Peninsula, Taku terrane (Davis and Plafker, 1985), and a typical sample of MORB.

and to typical MORB. Light rare earth enrichment is characteristic of calc-alkaline and alkaline volcanic rocks (Haskin, *et al.*, 1966; Schilling, 1971; Jakes and White, 1972; Hanson, 1980), therefore the high alkali contents of basalts from the Windy-Craggy area may be a primary feature of these rocks. More rare earth analyses are required, however, to determine if these preliminary observations are applicable to all the basaltic volcanic rocks in the Windy-Craggy and Mount Henry Clay areas.

Tholeiitic basalts such as those from mid-ocean ridges (MORB) are typically depleted in the light rare earths. The Windy-Craggy and Chilkat-Nikolai basalts are enriched in LREE's; clearly they do not belong to this category of basalt.

Saunders and Tarney (1984) used a MORB normalized plot of large ion lithophile (LIL) and high field strength (HFS) elements to examine the chemistry of basalts erupted in back arc basins. Using their plot (Fig. 28-16), samples WD83-16 and WD83-84 show a strong enrichment in LIL elements relative to MORB. The HFS elements and Cr are depleted relative to MORB.

The LIL elements are relatively mobile and can be enriched by low-grade seawater-basalt hydrothermal alteration (Saunders and Tarney, 1984). However, Th is virtually immobile under these conditions and should reflect the primary composition of the basalt. The Th concentrations of the two samples plotted exceeds that of average MORB, suggesting the LIL element enrichment is probably a primary feature and is not due strictly to alteration.

The pattern of LIL element enrichment shown on Figure 28-16 is similar to that observed for calc-alkaline basalts erupted in back arc basins formed in continental crust, such as the Guaymas Basin. Such basins can also contain basalts with MORB-like characteristics. The calc-alkaline basalts are most common in narrow, submarine rift valleys associated with short-lived spreading centres. Such spreading centres are related to transform faulting produced by oblique plate convergence. High LIL element concentrations in basalts of back arc basins may be the result of mantle contamination by LIL element-rich hydrous fluids derived by dehydration of subducted oceanic lithosphere. Alternatively, partial melting of continental crust with concentration of the incompatible LIL elements by magmatic differentiation in shallowly emplaced sills may also be an important process. The latter may be particularly important for Late Triassic volcanic rocks of the Alexander terrane because the magmas apparently rose through a thick section of continental crust that included LIL element-enriched sedimentary rocks, and possibly a Precambrian crystalline basement.

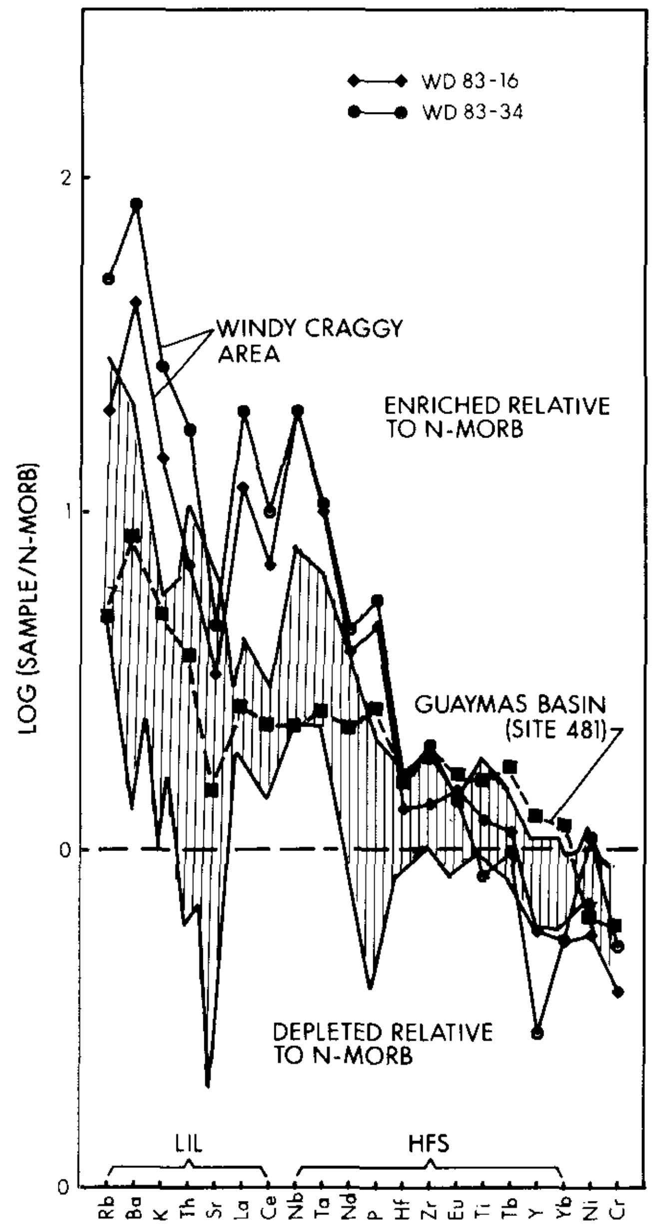

Figure 28-16. Plot showing variation of large ion lithophile (LIL) and high field strength (HFS) elements for samples from the Windy-Craggy area normalized against typical MORB concentrations (*see* Table 28-2). Also shown for comparison is the range of values for samples from the Chilkat Peninsula, Taku terrane (Davis and Plafker, 1985), and a sample of basalt from the Guaymas Basin of the Gulf of California. Plot after Saunders and Tarney (1984).

DISCUSSION

The Wrangellia and Taku basalts are Karnian low K-tholeiites that were extruded in both submarine and subaerial environments with little accompanying sedimentation. The thick and extensive nature of the basalt sequences implies extensive rifting and subsidence accompanied the outpouring of basaltic lava (Carlisle and Susuki, 1974). By contrast, the Alexander terrane was apparently an exposed area during Karnian time, as indicated by erosional conglomerates at the base of the Triassic section in southeast Alaska (Berg, 1973).

In Norian time limestone and calcareous sediments were deposited on the thick basalt sequences of the Wrangellia and Taku terranes, implying a warm, shallow water depositional environment. At the same time, the Alexander terrane was the site of a deep, reducing, sedimentary basin that was characterized by pelagic limestone and turbidite deposition. These turbidites contain abundant carbonate detritus, which may have been derived by erosion of platformal carbonates of adjacent terranes (assuming suturing of these terranes had occurred by this time). Evolution of the basin was accompanied by a progressive increase in volcanic activity, finally culminating in a tremendous outpouring of calc-alkaline to alkaline basalt pillow lavas. This implies the Alexander terrane was the site of subsidence and rifting in Norian time. This rifting may have been restricted to narrow, short-lived spreading centres along a major transform fault system, analogous to the current Gulf of California system.

The abundance of dioritic sills in the Late Triassic section of the Alexander terrane suggests eruption of basalt was accompanied by shallow level injection of basaltic magma into relatively unconsolidated basinal sediments. Slow cooling of these sills probably provided the heat needed to drive the huge hydrothermal system that produced the Windy-Craggy deposit. Positioning of such seafloor hydrothermal vents above subvolcanic sills has been observed in the Guaymas Basin.

Late Triassic felsic fragmental rocks of the Alexander terrane were probably produced by explosive release of LIL element, volatile-rich differentiates from large subvolcanic magma reservoirs. Submarine calderas may have formed in response to this periodic evacuation of the reservoirs; such calderas are common in the Kuroko district of Japan (Ohmoto and Takahashi, 1983). This process was apparently lacking in the Windy-Craggy area and adjacent terranes; there are no felsic fragmental rocks, and no associated polymetallic massive sulphide deposits in these Triassic sections.

If we assume that Wrangellia and the Alexander terrane were sutured by Triassic time, then there is an apparent eastward shift in the location of volcanic eruption centres from Karnian to Norian time. This shift is marked by an eastward compositional change from relatively primitive low-K tholeiites to more highly fractionated calc-alkaline to alkaline volcanic rocks. Similar transitions have been documented in several young island arcs of the southwest Pacific (Kuno, 1966; Garcia, 1978); the implication is that Triassic basalts of Wrangellia and the Alexander terrane represent a similar immature island arc and/or a marginal or back arc basin setting.

SUMMARY

The main conclusions of this paper based on the information available to date are:

(1) Massive sulphide deposits of the Alexander terrane occur in a Late Triassic submarine volcanic sequence that is calc-alkaline to alkaline in composition.

(2) Triassic volcanics of the Wrangellia and Alexander terranes are most likely part of an immature island arc/back arc basin system. Volcanism progressed eastward with time and became progressively more alkaline in composition. Volcanism may have been restricted to narrow rift valleys associated with spreading centres along a transform fault system analogous to that of the present day Gulf of California.

(3) Massive sulphide deposits of the Alexander terrane were formed by hydrothermal systems that developed above subvolcanic sills injected into rift valley sedimentary-volcanic successions. Differentiation of some of these sills resulted in explosive felsic volcanism and formation of polymetallic massive sulphide deposits.

ACKNOWLEDGMENTS

This paper is based on field and laboratory studies completed by the British Columbia Ministry of Energy, Mines and Petroleum Resources (MacIntyre, 1983, 1984; MacIntrye and Schroeter, 1985) in the Tatshenshini (Windy-Craggy) map-area. The author is most grateful to Falconbridge Nickel Mines Limited, Geddes Resources Limited, Stryker-Freeport Resources, and Bear Creek Mining Company for providing logistical support and encouragement for this study. The Geological Survey of Canada generously provided additional geologic data for the Windy-Craggy map-area, plus fossil identifications. Jan Still of the United States Bureau of Mines and Henry Berg of the United States Geological Survey also provided valuable information on southeast Alaska geology and mineral occurrences. Joe Fox (I.R.E.M./M.E.R.I., Montreal) kindly provided immobile and rare earth analyses of rocks collected from the area.

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STRATIGRAPHY AND STRUCTURE IN THE ANYOX AREA (103P/5)

By D. J. Alldrick

INTRODUCTION

This report summarizes preliminary results of a mapping project in sedimentary strata of the Anyox pendant between May 27 and June 6, 1985. The objectives of the program are to:

(1) Study the sedimentary section for marker horizons that may outline present structure and for facies relationships that may indicate paleotopography in the underlying volcanic rocks.
(2) Compare the sulphide-bearing ore horizon chert to strata-bound, sulphide-bearing 'quartz veins' reported within the sedimentary strata.
(3) Sample chert and carbonate sedimentary rocks for fossil studies.

OTHER RESEARCH

The most recent report on the Anyox area is also the most comprehensive. R. J. Sharp completed a Master's thesis at the University of Alberta, Edmonton, in 1980. The research focused on three of the deposits in the area but the thesis also presents a major review of the regional geology and an extensive bibliography.

D. G. MacIntyre (this volume) compared petrochemistry of several Triassic volcanic sequences in the Insular Tectonic Belt. F. V. Kirkham, at the Geological Survey of Canada, is compiling lead isotope data for volcanogenic massive sulphide deposits throughout Canada. Both these studies include data or samples provided from Sharp's work.

STRATIGRAPHY

Schematic stratigraphic columns are illustrated on Figure 29-2, which also shows the stratigraphic position of five major mineral deposits.

VOLCANIC SEQUENCE

Sharp (1980) describes lithologies within the volcanic sequence as predominantly pillowed tholeiitic basaltic flows with subordinate fragmental and tuffaceous layers. The fragmental strata may include tectonic, explosion, pillow, flow top and fault scarp breccias, and volcaniclastic conglomerates. Tuffaceous strata are preserved as chloritic schists. Pelitic rocks are locally interbedded; these form the host rock strata at the Double Ed deposit.

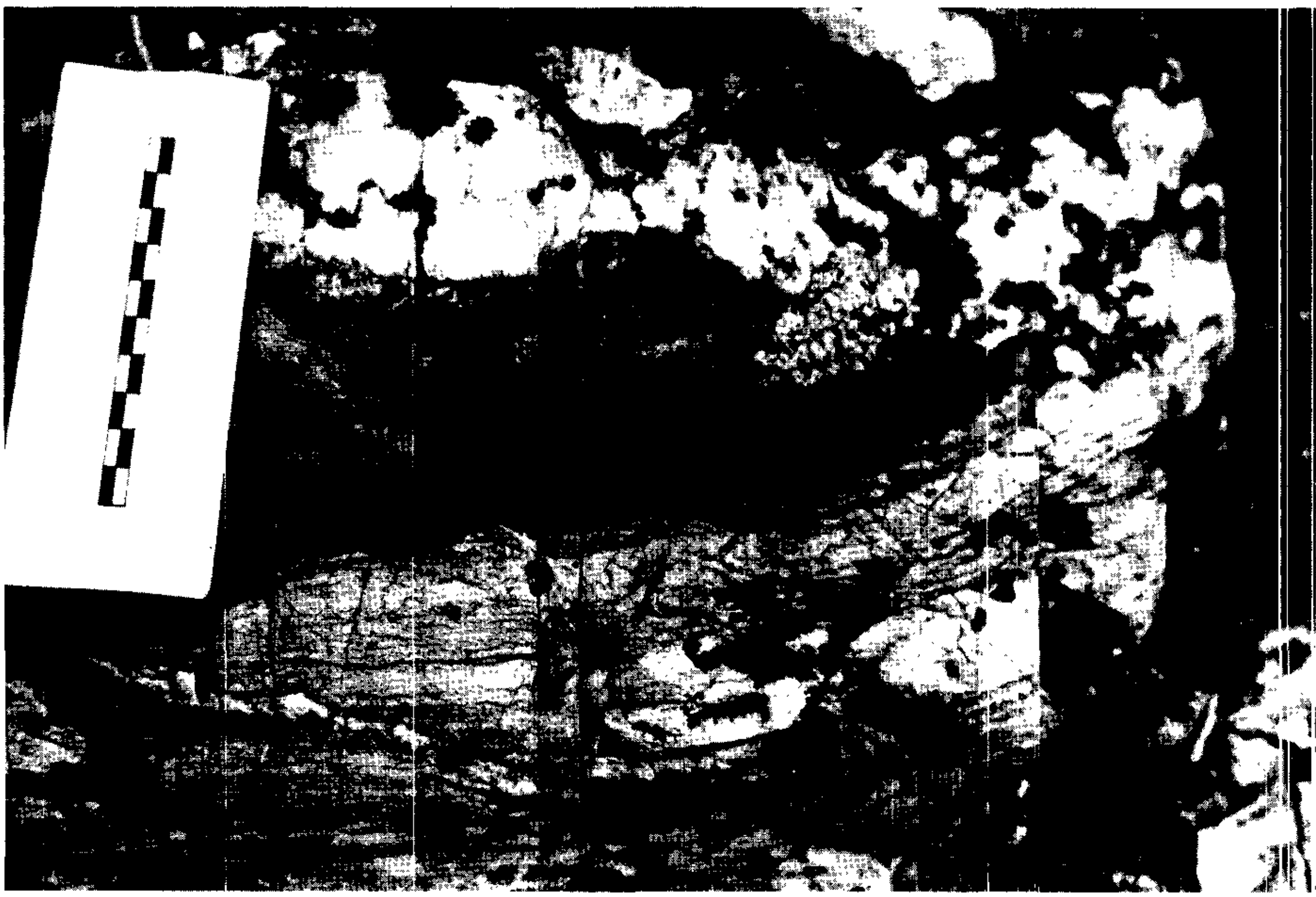

Plate 29-1. Bull quartz vein and foliated chert, 1.5 kilometres southwest of Hidden Creek mine. Scale bar 10 centimetres.

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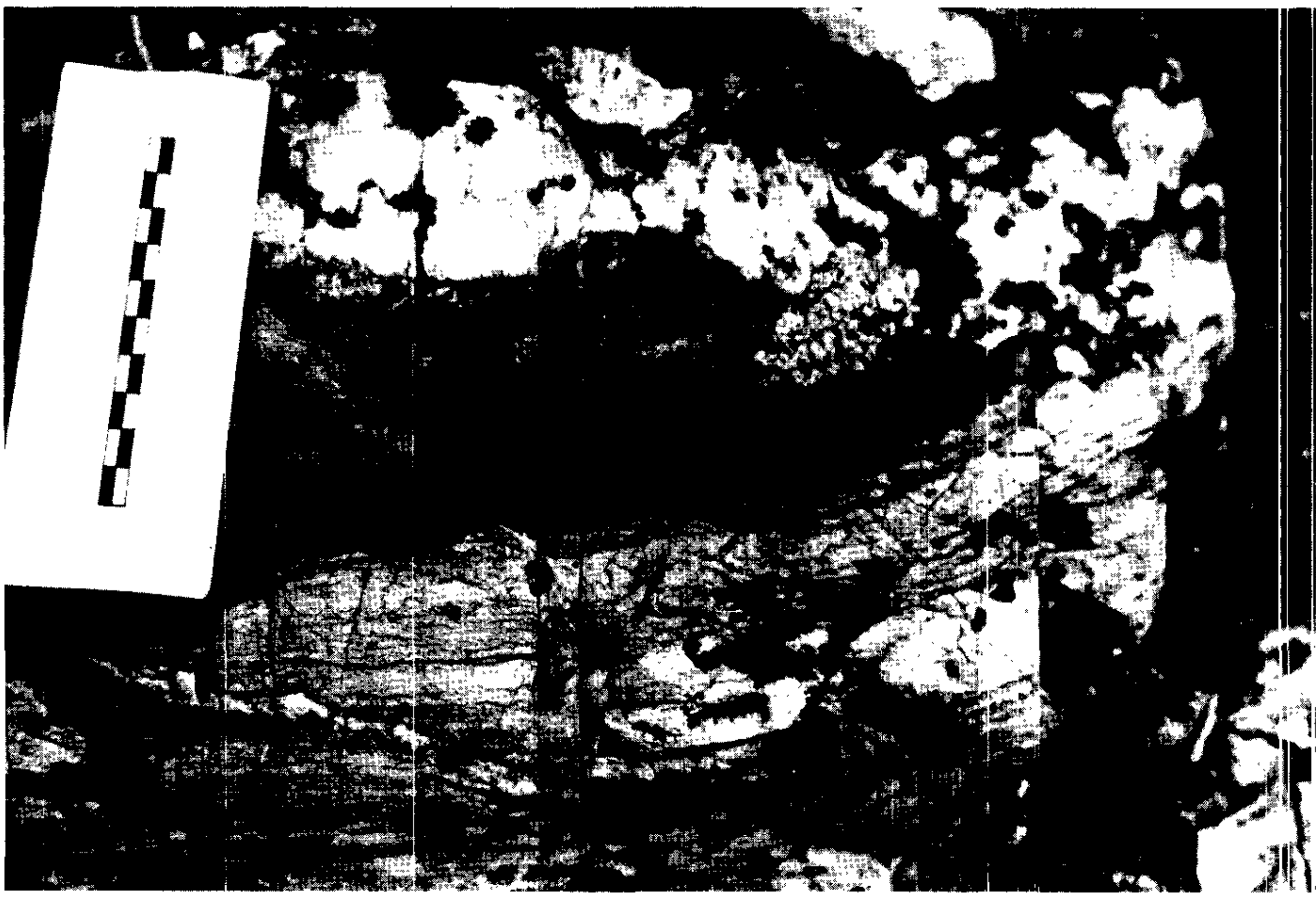

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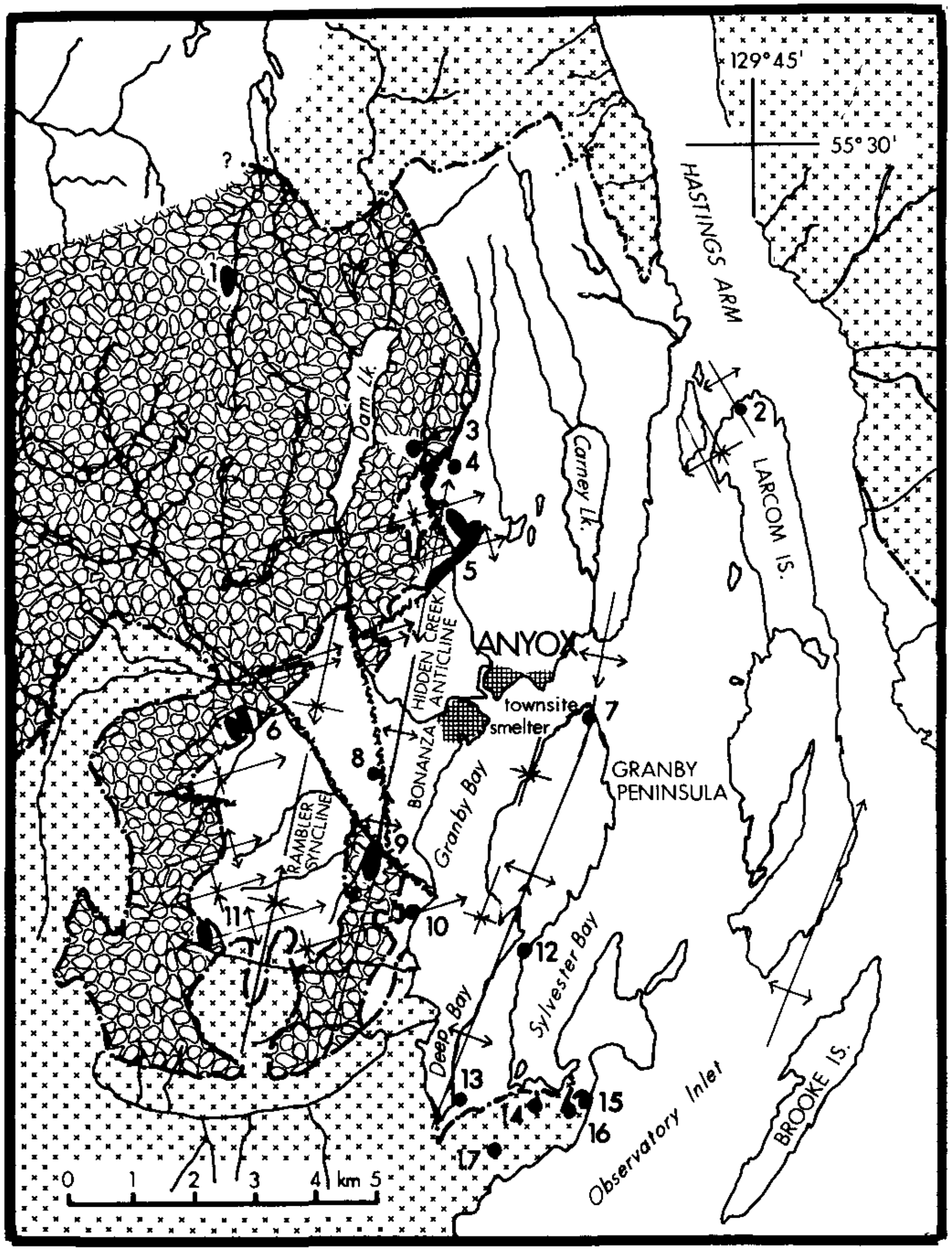
British Columbia Ministry of Energy, Mines and Petroleum Resources, Geological Fieldwork, 1985, Paper 1986-1.



LEGEND

COAST RANGE BATHOLITH

SEDIMENTARY SEQUENCE

PILLOW BASALTS SEQUENCE

SYMBOLS

MINERAL OCCURRENCES		COMMODITIES	MINFILE NUMBERS
1	EDEN	Cu, Zn	103P-026
2	LARCOM ISLAND QUARTZ	Si	103P-227
3	DEADWOOD QUARTZ	Si	103P-243
4	QUARTZ	Si	
5	HIDDEN CREEK MINE	Cu, Zn, Pb, Co	103P-021
6	DOUBLE ED	Cu, Zn	103P-025
7	GRANBY POINT QUARTZ	Si, Au	103P-022
8	RAMBLER QUARTZ	Si	103P-226
9	BONANZA MINE	Cu, Zn, Pb	103P-023
10	BLACK BEAR	Si	
11	REDWING	Cu, Zn, Pb	103P-024
12	GOLDLEAF	Au, Si	103P-028
13	GOLSKEISH	Si, Au	103P-027
14	MOLLY MAY — WEST ZONE	Mo	103P-228
15	MOLLY MACK	Mo	103P-228
16	MOLLY MAY — EAST ZONE	Mo	103P-228
17	MOLLY MAY — SOUTH ZONE	Mo	103P-228

Figure 29-1. Geology of the eastern Anyox pendant (with compilation from Sharp, 1980 and Grove, 1983).

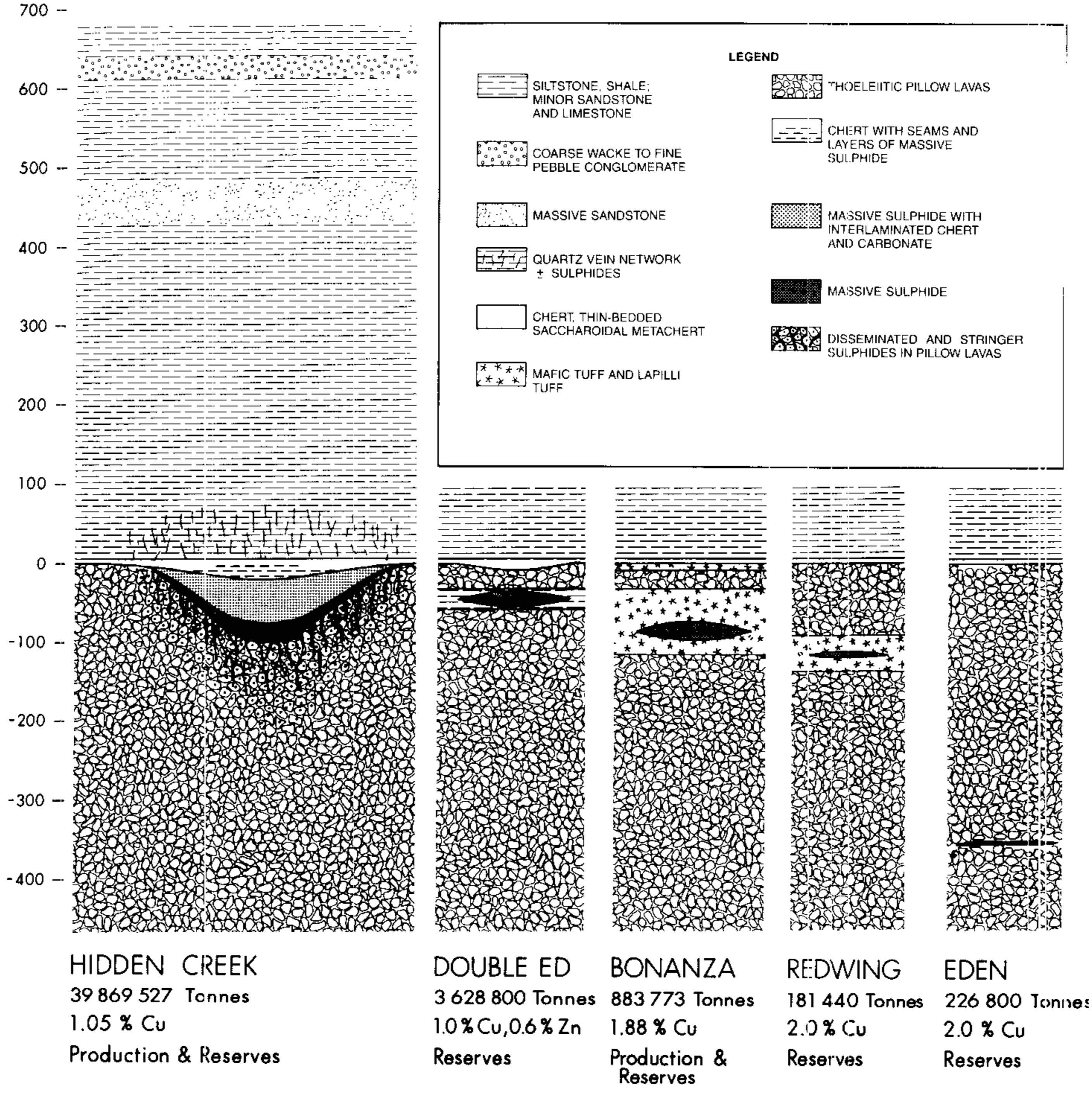


Figure 29-2. Schematic stratigraphic columns through five deposits (including compilation from Sharp, 1980).

ORE HORIZON CHERT

Chert is preserved as thin to thick-bedded, foliated, saccharoidal quartzite. The rock varies in colour from ivory to light grey depending on the amount of included tuffaceous material. Chert crops out along the volcanic-sedimentary contact throughout the Anyox pendant, although Sharp (1980) reports it is locally discontinuous. The chert may be interbedded with tuffaceous layers and the unit varies in thickness from a few tens of centimetres to over 1 metre. An abnormal thickness of chert is exposed in two areas; overlying the Double Ed deposit where the cherty strata thickens to 3 metres, and overlying and within the Hidden Creek deposit where the chert averages 30 metres in thickness and reaches 75 metres in one location where it is interlayered with massive sulphides and tuff (Sharp, 1980).

Chert is readily distinguished from massive, white bull quartz veins by its saccharoidal texture, prominent foliation, and pale grey to ivory colour (Plate 29-1). Further, chert is commonly interbedded with mafic tuffs and clastic sedimentary rocks.

SEDIMENTARY SEQUENCE

The hangingwall sedimentary strata comprise a flysch sequence of fine-grained, thin to medium-bedded shales and siltstones with minor carbonate and coarse clastic units. The formation is at least 700 metres thick. Its eastern limits were not examined in the study but no chert beds were identified within this sequence and no distinctive marker units were noted in the lower part of the formation.

Sharp (1980) documented thin, interbedded carbonaceous phyllite to graphitic schist layers in the basal 300 metres of the sedimentary sequence; he reports that discontinuous exposures of this rock type extend from the Hidden Creek mine to the Bonanza mine. Several thin, dark grey to black limestone beds are preserved within the immediate hangingwall of the ore deposits. Higher in the sedimentary sequence there are dark grey to black, thin-bedded to massive limestone beds, limestone lenses and nodules within grit beds, and calcite-cemented sandstones and grits. No macrofossils have been found in the Anyox pendant.

A thick section of massive sandstone beds exposed along the west shoreline of Granby Peninsula may correlate with a similar exposure reported by Bancroft (1918) east of Carney Lake. Coarse grits to fine pebble conglomerates crop out on the southwest end of Larcom Island and on the southeast end of Doben Island.

Sedimentary structures are well exposed in these strata. Graded beds are abundant; rounded, symmetric ripple marks were noted in two exposures; truncated crossbeds are well preserved in the pebble conglomerates at the southwest end of Larcom Island. Crossbed orientations indicate an eastward source for the clastic material.

The features of this flysch sequence suggest a deep water, reducing environment in which clastic sedimentation rates greatly exceeded those of chemical carbonate deposition. We found no diagnostic evidence to establish the tectonic setting.

STRUCTURE

There are numerous exposures of small-scale folds and axial plane cleavage in the sedimentary sequence and the ore horizon cherts, the volcanic sequence shows little evidence of deformation. Figure 29-1 illustrates the interpreted overall structure; the field data are plotted on a 1:25 000-scale topographic base map which is available for reference by contacting the author. Field evidence indicates two phases of deformation: a major F_1 event produced large-scale, north-northeast-trending open folds with steep west-dipping axial surfaces (Fig. 29-3); a later F_2 fold event produced smaller scale east-northeast-trending tight folds with near-vertical axial surfaces and local axial planar cleavage.

Phase 1 fold structures include the Rambler syncline and the Hidden Creek-Bonanza anticline (Figs. 29-1 and 29-3). The western anticlinal limb is flat to gently westward dipping; the eastern limb is vertical to steeply eastward dipping. This pattern also holds for other phase 1 anticlines. These early major folds have undulating fold axes, so the Rambler syncline, for example, is canoe shaped in longitudinal section. The Hidden Creek-Bonanza anticline is a saddle-shaped structure between the two orebodies, but forms a doubly plunging anticlinal dome at Hidden Creek mine.

Since limbs of early folds are either near-horizontal or near-vertical, they have been selectively eroded by recent glaciation. The flat-lying limbs, which are more resistant, underlie at least two major topographic features — Granby Peninsula and the ridge east of Rogers Creek, and Larcom Island.

Phase 2 folds are most easily recognized along the volcanic-sedimentary contact, and along the west side of Larcom Island (Fig. 29-1). These folds are tight with near-vertical, east-northeast-trending axial planar cleavage, and gently east-northeast-plunging axes. Topography and selective erosion have combined to influence the outcrop pattern of the contact trace so that some of these folds appear to be isoclinal (Fig. 29-1).

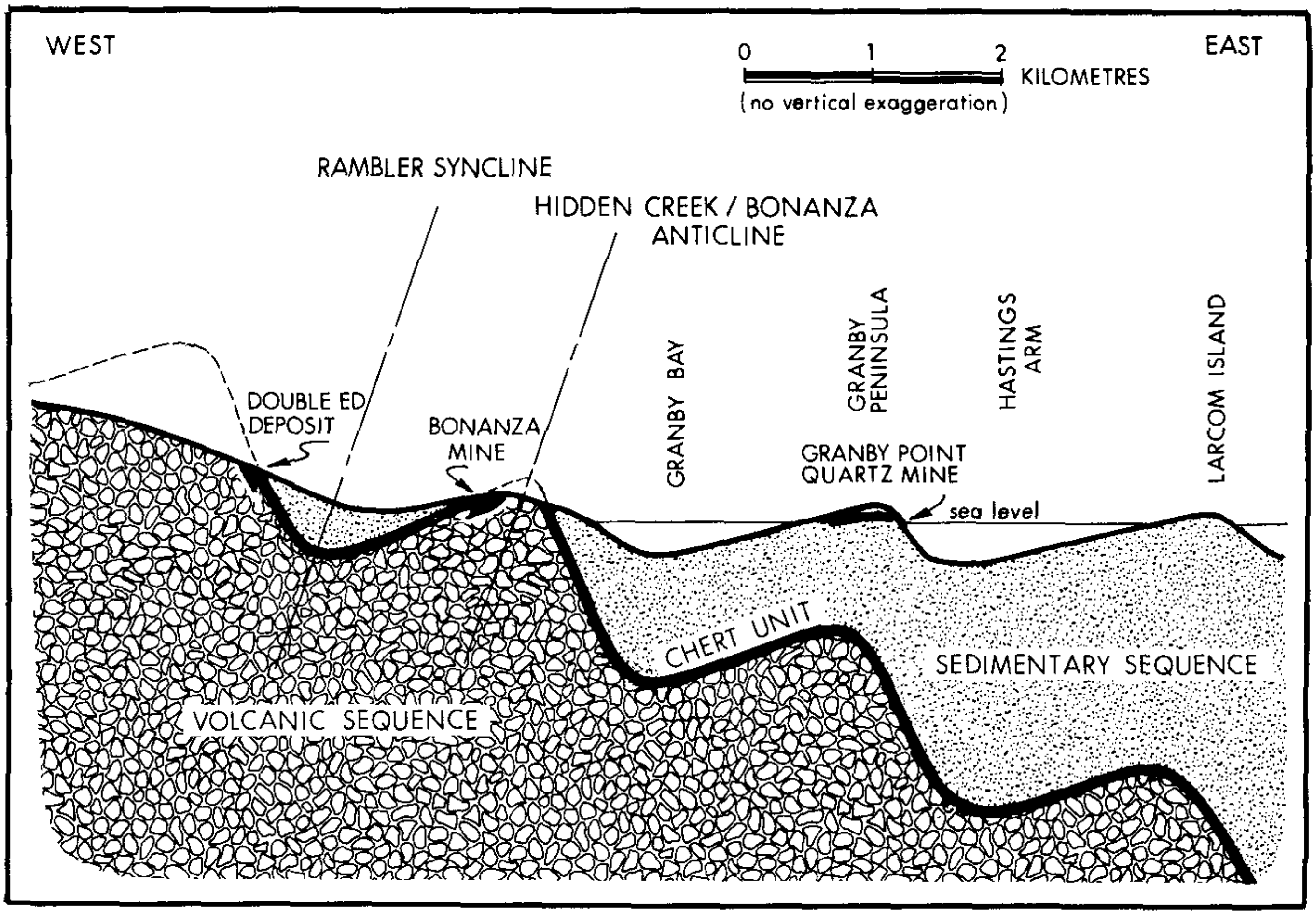


Figure 29-3. Schematic east-west cross-section in the southeastern Anyox pendant.

Interference patterns between intersecting F_1 and F_2 minor folds have produced complex, undulating fold noses and troughs at outcrop scale that resemble sheath folds of more intensely deformed terranes.

METAMORPHISM

The metamorphic grade of the Anyox pendant is, at most, lower greenschist facies. Much of the chloritic alteration in the pillow volcanics is attributed to ore-forming, hydrothermal processes. The sedimentary sequence is essentially unmetamorphosed since it has not undergone sufficient recrystallization to produce 'argillite' (Potter, *et al.*, 1980, p. 91). Primary hornblende occurs in porphyritic mafic dykes, sills, and flows that are scattered within the volcanic sequence; these were noted as evidence of amphibolite facies metamorphism by early workers.

QUARTZ VEINS

Sharp (1980, p. 31) recognized two distinct styles of quartz veining; both types were examined in this study and are as follows:

Type 1: Massive white bull quartz veins up to 5 metres wide are emplaced along bedding planes or along fractures within the sedimentary sequence. These veins may host patchy or disseminated base metal sulphides and recoverable gold (for example, Golskeish, Rambler, and Granby Point).

Type 2: Quartz vein networks or swarms are localized in basal sedimentary strata near fold axes. Silica in the vein networks was likely remobilized during deformation and recrystallization of the chert unit. Where fold axes coincide with sulphide deposits, the quartz vein networks host disseminated pyrite, pyrrhotite, and base metal sulphides, thus these vein swarms may be proximal hangingwall indicators of ore.

Type 1 veins occur in three settings: (i) along bedding planes throughout the sedimentary strata (Granby Point quartz quarry), (ii) in fractures parallel to the axial planar cleavage of F_2 folds within the hangingwall sedimentary rocks adjacent to the chert unit, (iii) along the contacts of dykes (Goldleaf, northern Golskeish quarry).

The massive, extensive vein at Granby Point is the best example of the 'stratabound' quartz veins. This vein lies along a bedding plane on the flat limb of an F_1 fold; minor folds are conspicuously absent. In this area, disharmonic stress was accommodated by bedding plane slip and dilation rather than by formation of parasitic folds.

The best example of Type 2 vein networks is in the hangingwall of the Hidden Creek deposit (Sharp, 1980). Another extensive outcrop area of these vein swarms lies along the crest and on the eastern shoulder of the bedrock ridge which trends south from the Anyox smelter stack (Fig. 29-1); quartz vein networks are exposed discontinuously for 1.5 kilometres. No sulphides were noted in the veins, but adjacent country rock carries minor disseminated pyrite. Significantly, these vein networks coincide with the projected trend of the Hidden Creek-Bonanza anticline and may indicate that the volcanic sequence is less than 200 metres below surface in this area.

AGE RELATIONSHIPS

No absolute age has been determined for rocks of the Anyox pendant. Grove (1973, 1983, in press) correlates Anyox strata with rocks of the Lower Jurassic Hazelton Group. However, the Anyox volcanic and sedimentary strata do not resemble Hazelton Group rocks exposed 20 kilometres to the east at the Kitsault River (Dawson and Alldrick, this volume). Sharp (1980, p. 13) suggested that Anyox stratigraphy correlates with Upper Triassic Karmutsen Formation units described on the Queen Charlotte Islands by Sutherland Brown (1968). The Anyox rocks are low-K tholeiitic basalts and are lithologically and chemically similar to Triassic volcanic-sedimentary formations of the Taku and Wrangellia Terranes; they differ signficantly in composition from Triassic volcanic-sedimentary formations of the Alexander and Stikine Terranes which are calc-alkaline to alkaline in composition (D. MacIntyre, pers. comm., 1985).

Sharp provided Anyox ore samples to Dr. R. V. Kirkham at the Geological Survey of Canada for lead isotope studies of the volcanogenic massive sulphide deposits. Analytical results are presented in Table 29-1.

TABLE 29-1
LEAD ISOTOPE RATIOS OF ANYOX SULPHIDES*

Sample and Location	$^{206}Pb/^{204}Pb$	$^{207}Pb/^{204}Pb$	$^{208}Pb/^{204}Pb$
Galena No. 6 Zone Hidden Creek Mine	18.691	15.562	38.267
Sphalerite No. 6 Zone Hidden Creek Mine	18.570	15.521	38.064
Pyrite Bonanza Mine	18.795	15.592	38.389

* Provided by R. V. Kirkham, Geological Survey of Canada, Ottawa.

'Common lead' isotope data can yield crude absolute age determinations if suitable models are available for their interpretation. A large data base from similar rocks and sulphides must be assembled before meaningful interpretations can be attempted. Lead isotope data are, however, useful for indicating relative age relationships between deposits, and between deposits and their host rocks. They may also provide indications about the source of lead in an ore deposit.

Anne Andrew compared the Anyox data from Table 29-1 to lead isotope ratios from whole rock lead and galena lead from the Sicker Formation, the Karmutsen Formation, and three intrusions on Vancouver Island (Andrew, in prep.). The plotted Anyox data coincide with a cluster of whole rock initial ratios and galena lead ratios from the Kartmutsen Formation on Vancouver Island and Texada Island. The coincidence of ratios for Anyox and Karmutsen leads suggests that the sulphide minerals at Anyox have a similar age and origin to the Karmutsen Formation volcanic rocks and sulphide minerals (A. Andrew, pers. comm., 1985). This supports Sharp's correlation of Anyox and Karmutsen stratigraphy.

The Karmutsen Formation is Late Triassic with a 'stratigraphic' age of 228 ± 5 Ma, and a new U/Pb zircon age of 215 to 218 Ma (Armstrong, *et al.*, in press).

DISCUSSION

It is unlikely that additional exploration work will be conducted in the Anyox area during the present cycle of depressed copper prices, but the area offers high potential for ore discovery and attractive logistics for a mining operation.

Fifteen volcanogenic massive sulphide lenses in seven deposits have been discovered within the Anyox pendant. Eleven of these lenses were exposed in outcrop; the other four are near-surface lenses that are part of the Hidden Creek deposit. Additional, blind deposits must exist along the down-dip continuation of the volcanic-sedimentary contact. The contact has been thoroughly prospected for outcropping sulphides but has not yet been mapped in detail along its entire length for proximal indicators of ore that were documented by Sharp (1980).

Although most volcanogenic massive sulphide deposits respond to both ground and airborne electromagnetic surveys, sulphide responses in the Anyox pendant will probably be 'overshadowed' by much stronger responses from graphitic shear planes within the carbonaceous phyllites near the base of the sedimentary sequence. A recent helicopter-borne Input survey did not detect any additional sulphide deposits; anomalies over known deposits were substantially weaker than those related to carbonaceous strata and graphitic shear zones (S. Quinn, pers. comm., 1984). One strategy would be to systematically drill all primary, secondary, and tertiary EM conductors, or at least to make ground checks for proximal ore indicators.

Future exploration programs in the Anyox pendant will require:

(1) Detailed mapping of the volcanic-chert-sediment contact area that focuses on: locating proximal ore indicators; detailed lithogeochemical analysis of volcanic, chert, and sedimentary rocks; and documenting evidence for analysis of paleotopography in order to locate either seamount or rift structures.

The lithogeochemical sampling would provide a direct exploration tool for near-surface deposits, and also a data base for the ultimate exploration program within the Anyox pendant:

(2) Systematic fence or grid drilling of the down-dip extension of the volcanic-sedimentary contact, similar to programs conducted in the Noranda district.

ACKNOWLEDGMENTS

Thanks to R. J. Sharp for suggesting aspects of Anyox geology that deserve further work. I am grateful to A. Andrew and R. V. Kirkham for sharing their lead isotope data and hard-won expertise. Ian Webster provided capable and cheerful field assistance through eleven days of unseasonable sunshine.

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URANIUM-LEAD AGE DETERMINATIONS IN THE STEWART AREA (104B/1)

By D. J. Alldrick
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and
J. K. Mortensen
Geological Survey of Canada
and
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Five concordant U-Pb dates have been determined for zircons from igneous rocks in the Stewart area. The sample locations and dates are listed in Table 30-1 and the relative position of the host lithologies within the stratigraphy is shown schematically on Figure 30-1. Uranium and lead analyses and data reduction were done by J. K. Mortensen at the University of British Columbia. Detailed descriptions of the rock types, their distribution, and their field relationships are provided in Alldrick (1985).

Three samples of hornblende granodiorite and one sample of K-feldspar megacrystic plagioclase porphyry, or 'Premier Porphyry,' all yielded clear, deep pink, euhedral zircons. The narrow age range and the distinctive zircon colour are consistent with a

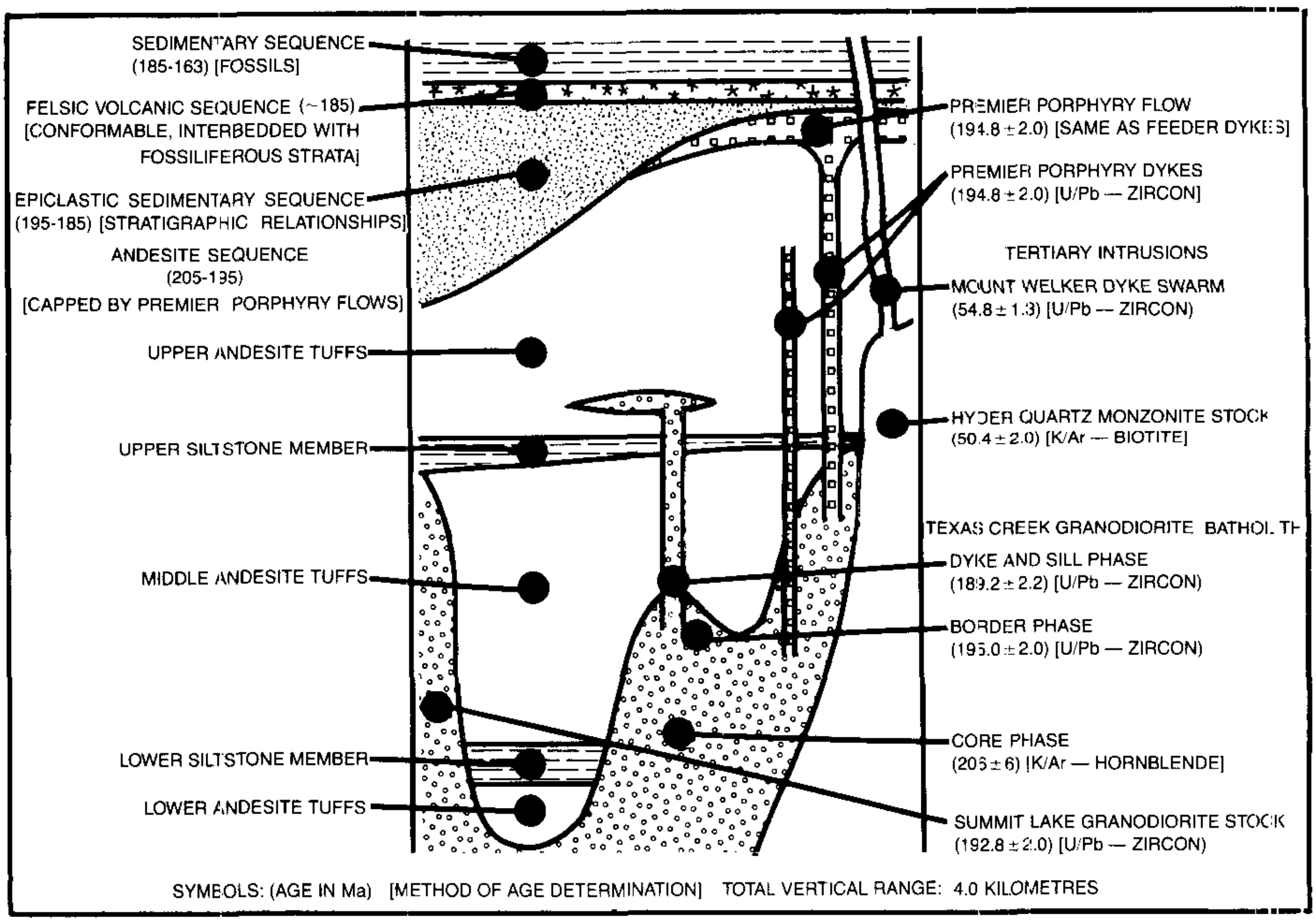

Figure 30-1. Schematic stratigraphic column for the Stewart mining camp (K/Ar dates from Smith, 1977; recalculated in Alldrick, 1985).

British Columbia Ministry of Energy, Mines and Petroleum Resources, Geological Fieldwork, 1985, Paper 1986-1.

common magmatic origin for these four samples. Since the two stocks of hornblende granodiorite have dates of 192.8 ± 2.0 and 195.0 ± 2.0 Ma and intrude the lower part of the andesite sequence, this indicates a minimum Early Jurassic age for the lower volcanic sequence.

The K-feldspar megacrystic plagioclase porphyry dyke was sampled from a trench that exposes an ore zone at the 2 Level portal of the Silbak Premier mine (MI 104B-054). This two-feldspar porphyry dyke, which forms the structural hangingwall to the sulphide mineralization, gave a date of 194.8 ± 2.0 Ma. Since the dykes cut the upper part of the andesitic sequence this is also a minimum age for the upper volcanic sequence.

The two-feldspar porphyry dykes have been interpreted as feeder dykes for green to purple two-feldspar porphyritic flows that cap the andesite sequence (Alldrick, 1985, p. 329). The age of these flows is also virtually the same as the age of the andesite sequence if Fisher and Schmincke's (1984) estimate that the average 'lifespan' of one million years for an andesitic stratovolcano is correct.

One sample of feldspar-porphyritic granodiorite dyke (PS-34-3) has been analysed as part of a major regional mapping program by R. G. Anderson of the Geological Survey of Canada. The dyke crosses the Silbak Premier mine road southwest of the old millsite, and is one of a broad swarm of Tertiary dykes termed the 'Mount Welker dyke swarm' (Alldrick, 1985, p. 333). The zircon date of 54.8 ± 1.3 Ma correlates well with K/Ar dates from major Eocene stocks of the Coast Range batholith (Smith, 1977; recalculated in Alldrick, 1985, p. 332).

ACKNOWLEDGMENTS

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TABLE 30-1
URANIUM/LEAD DETERMINATIONS FROM THE STEWART AREA

Sample No.	Location Longitude	(UTM Zone 9) Latitude	Descriptive Location	Rock Type	Rock Name	Age (Ma)
A84-1	432250E	6232320N	Plateau north of Scottie Gold mine 3600 portal	Coarse-grained hornblende granodiorite stock	Summit Lake granodiorite	192.8±2.0
A84-2	434400E	61216475N	Bed of Salmon River, 400 metres south of glacier toe. Dyke cuts A84-3	Coarse-grained hornblende granodiorite dyke, K-feldspar porphyritic	Dyke and sill phase, Texas Creek granodiorite	189.2±2.2
A84-3	434400E	61216475N	Bed of Salmon River, 400 metres south of glacier toe	Coarse-grained hornblende granodiorite stock, K-feldspar porphyritic	Border phase, Texas Creek granodiorite	195.0±2.0
A84-5	436760E	6208240N	2 Level trench, 20 metres north of 2 Level portal, Silbak Premier mine	K-feldspar megacrystic, plagioclase porphyritic diorite dyke	Premier Porphyry dykes and flows	194.8±2.0
PS-34-3	436300E	6212130N	At third switchback on Silbak Premier mine road	Biotite granodiorite dyke, Feldspar porphyritic	Granodiorite phase, Mount Welker dyke swarm	54.8±1.3

GEOLOGY AND MINERAL DEPOSITS OF THE KITSAULT VALLEY* (103P/11, 12)

By G. L. Dawson and D. J. Alldrick

INTRODUCTION

The Kitsault River valley was mapped from July 1 to September 1, 1985. Objectives of the program are to:

(1) Establish a stratigraphic column.

(2) Document the regional geological setting.

(3) Delineate areas of high mineral potential.

The area mapped, which covers 700 square kilometres, extends from Alice Arm north to the Cambria Icefield and for approximately 10 kilometres east and west of the Kitsault River. Work was carried out by two two-man fly camps moved every two to five days. Data was recorded on 1:25 000-scale enlargements of 1982 series 1:50 000-scale air photographs.

HISTORY

Prospecting in the Kitsault valley started in the early 1900's because of interest generated by discoveries at Anyox and in the Stewart region. By 1913 numerous claims had been staked, mainly on silver veins.

The Dolly Varden, Homestake, North Star, and Torbrit properties were mined between 1915 and 1959. Total production was 1 284 882 tonnes grading 485 grams silver per tonne, 0.38 per cent lead, and 0.02 per cent zinc.

The area saw renewed exploration focused on porphyry copper-molybdenum deposits from 1965 to 1970. The Ajax molybdenum prospect was staked during this period. Drilling at Ajax outlined indicated reserves of 526 967 000 tonnes grading 0.09 per cent Mo.

The regional geology has previously been described by McConnell (1913), Turnbull (1916), Hanson (1921, 1922a, 1922b, 1923, 1928), and Black (1951).

REGIONAL SETTING

The map-area lies at the western margin of the Intermontane Belt (Fig. 31-1). The volcanic and sedimentary rocks are correlative with the Lower to Middle Jurassic Hazelton Group. The Kitsault rocks were deposited in an active volcanic environment; characteristically units wedge and are intermixed. A sedimentary sequence of probable Middle Jurassic age overlies the volcanic-sedimentary assemblage. The entire Jurassic section has undergone greenschist facies metamorphism.

VOLCANIC AND SEDIMENTARY ROCKS

MAP UNIT 1

Unit 1 is a thick sedimentary formation consisting of interbedded, finely laminated black siltstone, argillite, and minor wacke. Rare sills or flows of augite porphyritic basalt and hornblende porphyritic andesite occur within the unit; four small quartz-feldspar porphyritic and biotite porphyritic quartz monzonite stocks intrude the unit. The base of unit 1 is not exposed in the map-area, but the unit is at least 1 200 metres thick.

The thick package of thin-bedded clastic rocks in unit 1 represents a period of flysch sedimentation in a deep water environment.

MAP UNIT 2

Unit 2 is a mixed sequence of volcanic and epiclastic rocks — augite, feldspar, and olivine porphyritic basalt flows, pyroclastics, and derived conglomerates. The unit is 150 to 700 metres thick. The contact with underlying unit 1 sedimentary rocks is sharp and marked by black limestone overlain by a discontinuous flow of olivine porphyritic basalt.

Dark green augite porphyritic basalt flows and pillowed flows are found above the olivine basalt. The augite phenocrysts range from 2 to 15 millimetres in diameter. An excellent exposure of pillowed flows crops out along the western side of the Varden Glacier. Above the augite porphyry flows are minor and discontinuous layers of olive green to black, locally augite or feldspar porphyritic basaltic tuff and breccia. Olive green to grey cobble conglomerates are uppermost in the unit. Clasts are rounded to subangular, matrix supported, and dominantly augite porphyritic basalt. The matrix consists of black volcanic silt to sand-sized grains.

These rocks represent a period of subaqueous basaltic volcanism followed by erosion and deposition of sediment derived from the basaltic flows and tuffs.

MAP UNIT 3

A sedimentary and volcanic sequence of siltstone, sandstone, wacke, grit, pebble to cobble conglomerate, and volcanic breccia comprise unit 3. The unit varies in thickness from 2 000 metres in the east to less than 400 metres in the west part of the map-area. The basal contact is gradational.

The lowermost lithology of unit 3 consists of finely laminated siltstone with lesser fine sandstone and wacke, and rare conglomerate. Overlying the siltstones are mottled, grey and maroon massive volcanic breccias that are the major component of the unit. The clasts are generally angular to subrounded, randomly orientated, and matrix supported. The breccias are heterolithic with clasts derived mainly from feldspar-hornblende andesite and to a lesser degree from augite porphyritic basalt. Minor finely laminated siltstone, sandstone, and limestone beds are intercalated within the breccias. Volcanic breccias are thickest along the eastern side of the map-area and wedge out in the centre.

The top of unit 3 is a sequence of grey to black interbedded finely laminated siltstones, sandstones, and grits including a distinctive polymictic conglomerate. Clasts of the conglomerate are well rounded and consist largely of white chert and black siltstone; there are also local volcanic pebbles and cobbles. The conglomerate is clast supported, with a matrix of silt to fine sand-sized grains

MAP UNIT 4

Unit 4 consists dominantly of andesitic pyroclastics, although within it are flows or subvolcanic sills of similar composition. Thin beds and lenses of epiclastic sedimentary rock, argillite, limestone chert, jasperoidal chert, and barite comprise 10 to 15 per cent of the unit and are randomly distributed throughout the andesite strata The unit is 500 to 2 000 metres thick; it has a sharp basal contact with unit 3 rocks.

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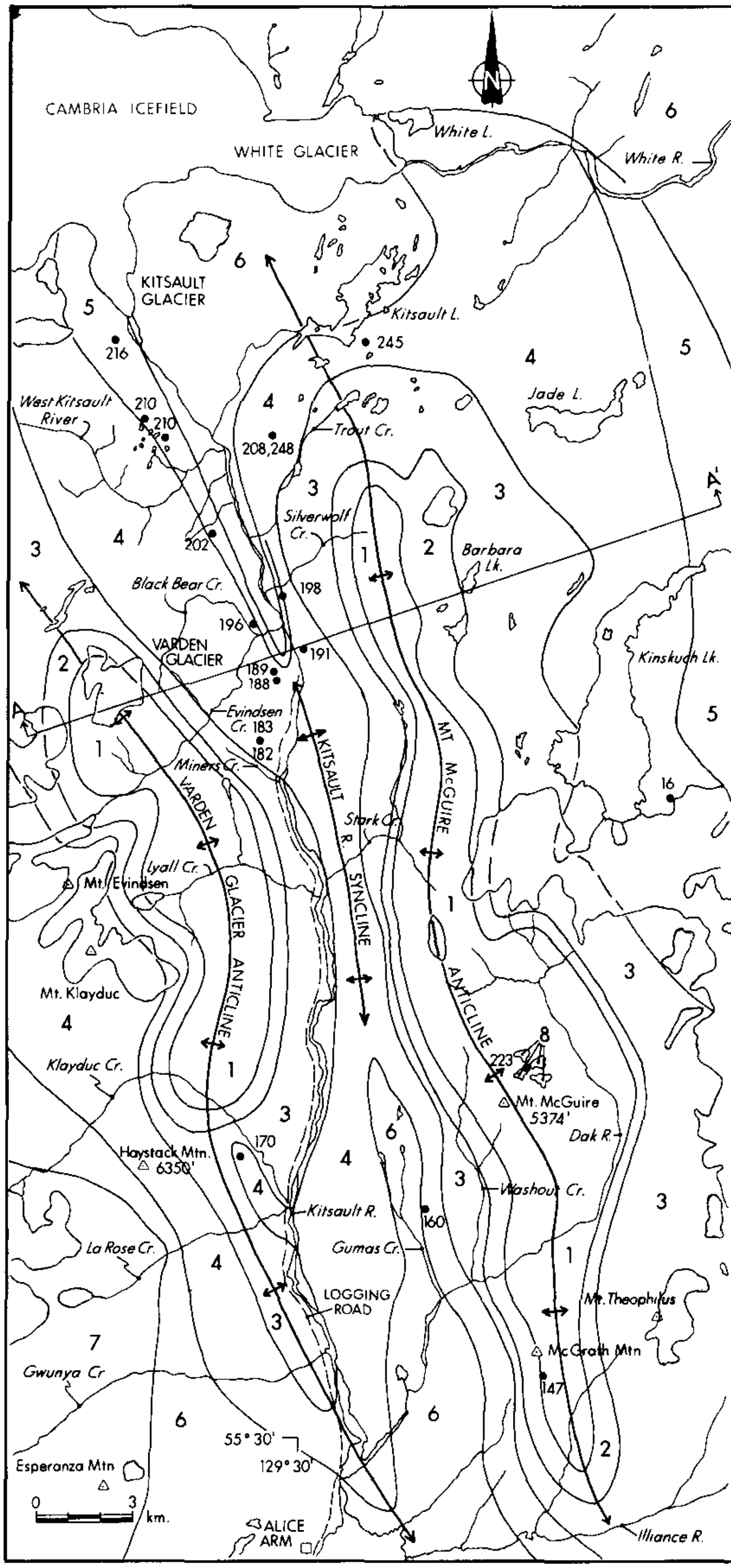
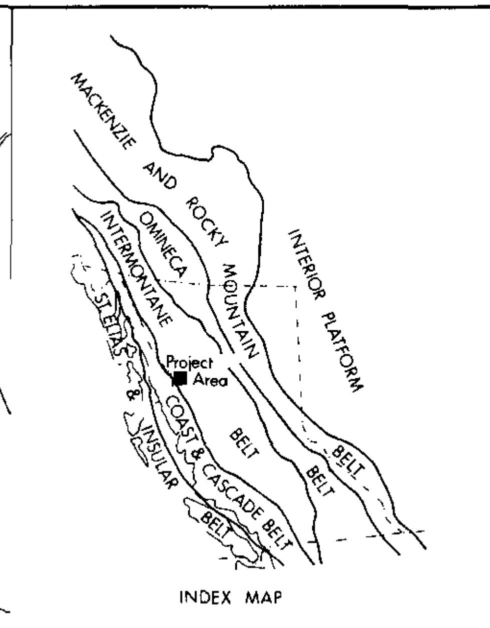
* This project is a contribution to the Canada/British Columbia Mineral Development Agreement.

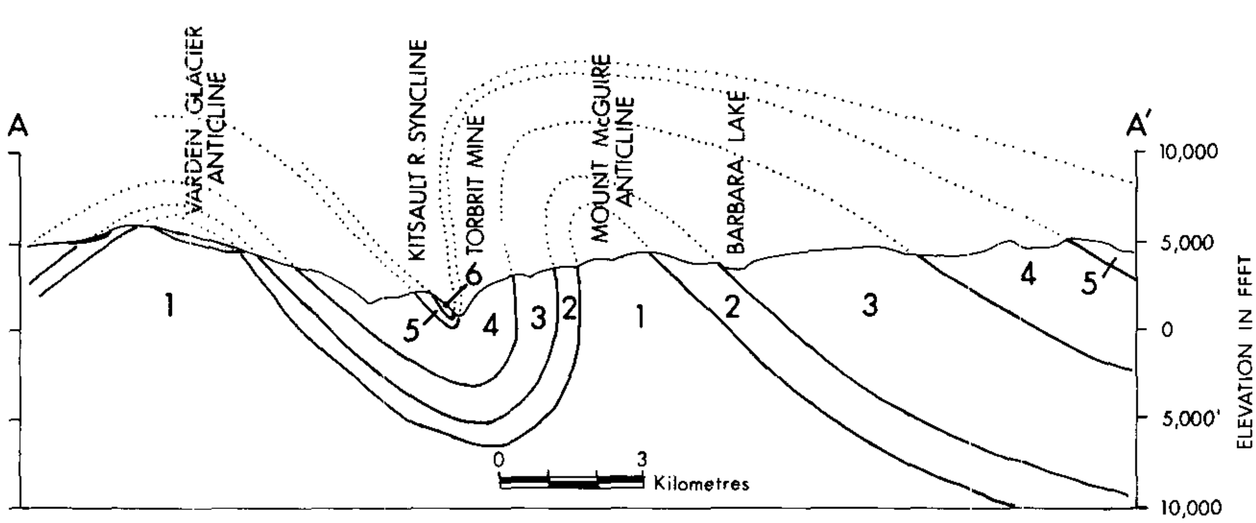




LEGEND

MINERAL PROPERTIES	COMMODITIES	MINFILE NUMBERS
KIT	Ag, Pb	103P-245
GALENA (ACE, TYEE)	Ag, Pb	103P-208, 248
WOLF	Ag, Pb, Zn	103P-198
TORBRIT	Ag, Pb, Zn	103P-191
NORTHSTAR	Ag, Pb, Zn	103P-189
DOLLY VARDEN	Ag, Pb, Zn	103P-188
LA ROSE	Ag, Pb	103P-170
HOMESTAKE	Au, Cu	103P-216
VANGUARD	Cu, Au	103P-210
COPPER CLIFF	Cu	103P-202
RED POINT	Cu	103P-196
E&D (BOBCAT, WILD CAT, MEDALLION)	Cu	103P-182, 183
RED BLUFF	Cu	103P-160
KINSKUCH (BIANCA, REINA, WOODLAND, GOLDSTRIKE)	Cu, Ag	103P-016
MAC (SUNRISE, SILVER BAND)	Zn	103P-147
AJAX	Mo	103P-223

Figure 31-1. Geology and major mineral occurrences in the Kitsault valley (for legend *see* Fig. 31-2).



LEGEND

INTRUSIVE ROCKS

TERTIARY

[9] MINOR DYKES: MICRODIORITE (a); GRANODIORITE (b); LAMPROPHYRE (c)

[8] AJAX INTRUSIONS: QUARTZ FELDSPAR PORPHYRITIC QUARTZ MONZONITE (a); BIOTITE QUARTZ MONZONITE (b); 55.1 Ma (K/Ar)

[7] COAST PLUTONIC COMPLEX: QUARTZ MONZONITE (a); GRANODIORITE (b); 43-51 Ma (K/Ar)

INTRUSIVE CONTACT

VOLCANIC AND SEDIMENTARY ROCKS

MIDDLE TO UPPER JURASSIC

[6] BASAL FOSSILIFEROUS WACKE (a); BLACK SILTSTONE AND WACKE (b); MINOR INTRAFORMATIONAL CONGLOMERATES AND LIMESTONE (c)

LOWER JURASSIC

[5] GREEN AND MAROON VOLCANIC BRECCIA (a); EPICLASTIC CONGLOMERATE AND SEDIMENTS (b), LOCAL DACITIC FLOWS AND PYROCLASTICS (c)

VOLCANIC AND SEDIMENTARY ROCKS (*CONTINUED*)

LOWER JURASSIC (*CONTINUED*)

[4] FELDSPAR-HORNBLENDE PORPHYRITIC ANDESITIC PYROCLASTICS (a) AND FLOWS/SILLS (b); MINOR INTERBEDS OF LIMESTONE, SILTSTONE, SANDSTONE, CHERT, AND BARITE (c)

[3] BASAL POLYMICTIC CONGLOMERATE, MINOR INTERBEDDED LIMESTONE, SILTSTONE, GRIT, SANDSTONE (a); SILTSTONE, ARGILLITE (b); VOLCANIC BRECCIA, MINOR INTERBEDDED SILTSTONE, SANDSTONE (c); INTERBEDDED SILTSTONE, SANDSTONE, AND PEBBLE CONGLOMERATE (MARKER HORIZON) (d)

[2] AUGITE (OLIVINE) PORPHYRITIC BASALT FLOWS, PILLOWED FLOWS (a); AUGITE-FELDSPAR PORPHYRITIC BASALT PYROCLASTICS AND VOLCANIC BRECCIAS (b); EPICLASTIC CONGLOMERATE, MINOR INTERBEDDED SILTSTONE, ARGILLITE, AND LIMESTONE (c)

[1] SILTSTONE, ARGILLITE, WACKE (a); RARE LIMESTONE (b);

BOTTOM OF UNIT NOT SEEN

SYMBOLS

VEIN MINERALIZATION .... |

STRATABOUND MINERALIZATION .... —

CRACKLE BRECCIA' MINERALIZATION .... ▲

PORPHYRY MINERALIZATION .... ∴

Figure 31-2. Geological cross-section, Kitsault valley (for location *see* Fig. 31-1).

The andesitic pyroclastics are generally green with local, minor maroon mottling; they comprise dust tuff, ash tuff, lapilli tuff, and minor tuff breccia. Lapilli are angular to subangular, randomly orientated, matrix supported, and heterolithic, although feldspar and/or hornblende crystal-rich andesites predominate. The matrix is fine grained.

Greyish green, massive, fine to medium-grained feldspar and/or hornblende porphyritic andesite units are probably flows or subvolcanic sills within the andesitic pile. Similar composition and limited exposure make lithological contacts difficult to distinguish, but the sills or flows may constitute up to 500 metres of the total thickness of map unit 4.

Although interbeds of brick red, epiclastic siltstone and sandstone, grey to black limestone, pale grey barite, red to pink jasperoidal chert, and white to grey chert are not volumetrically important, they are valuable because they enable structure within the volcanic sequence to be determined. Individual beds and lenses are generally less than 5 metres thick; however, on Tsimstol (Haystack) Mountain a 150-metre-thick lens of grey to black, interlaminated siltstone and limestone occurs within the andesite sequence. These sedimentary rocks represent brief periods of quiescence during andesitic pyroclastic activity in a predominantly subaqueous environment.

MAP UNIT 5

Unit 5 is a marine assemblage of alternating green and maroon volcanic breccias and conglomerates, with lesser dacite flows and pyroclastics, and minor black siltstones and limestones. The unit is exposed only along the northern and eastern perimeter of the map-area. Along the western edge of the Kitsault Glacier and northeast of Kinskuch Lake it has a maximum thickness of 1 500 metres. In the area of the Wolf mine the unit consists of dacitic dust tuff and is less than 100 metres thick. The lower contact of the unit is gradational.

The green and maroon volcanic breccias contain fragments which are angular to subrounded, matrix supported, and composed dominantly of feldspar crystal-rich unit 4 andesite. The matrix consists of sand-sized feldspar grains. The rock is generally massive but locally contains interbeds and lenses of finely laminated black siltstone, limestone, and sandstone. The alternating green and maroon colour of these breccias and conglomerates, and the interbedded limestone layers suggest the clastic rocks may be debris flows deposited in an alternating subaqueous to subaerial environment.

Pale green dacite flows and pyroclastics in the unit range up to 900 metres in thickness but are laterally discontinuous. The flows are fine to medium grained; often they contain megacrysts of zoned K-feldspar or prismatic plagioclase phenocrysts up to 3 centimetres long. Dacitic tuffs and lapilli tuffs on the west side of the Kitsault Glacier are rhythmically bedded, suggesting that they may be waterlain pyroclastics.

The dacite flows and pyroclastics probably derive from more than one felsic volcanic centre and the thick sections indicate that the exposures are near-vent accumulations. The felsic volcanic rocks lie at the top of unit 5 and mark the last volcanic event before an extended period of quiescence, during which unit 6 sedimentation took place.

MAP UNIT 6

Sedimentary rocks of unit 6 are well preserved in structural depressions. They are exposed around the margins of the map-area and in the axis of a north-south, doubly plunging syncline along the Kitsault River. The assemblage is marine and consists of black siltstone, shale, and wacke, with lesser amounts of sandstone, limestone, and intraformational conglomerate. The rocks are well bedded and display disharmonic fold features at outcrop and larger scales.

The lower contact of unit 6 is marked by a massive, 1 to 15-metre-thick, fossiliferous wacke. Macrofossils include belemnites and pelecypods. The contact with units 4 and 5 appears to be concordant, but the erosional interval represented by the accumulation of unit 5 conglomerates indicates the lower contact of unit 6 is a disconformity (Fig. 31-2 and 31-3).

INTRUSIONS

AJAX QUARTZ MONZONITE

The Ajax intrusions are four small stocks covering an area of 0.58 square kilometre on the east slope of Mount McGuire. The two northern stocks are medium grey, biotite-rich quartz monzonite; the two southern stocks are white to pink, quartz-feldspar porphyritic quartz monzonite. Potassium/argon analyses of biotite from the northern stocks give an age of 55.1 ± 3 Ma (Carter, 1982; p. 88; recalculated with constants from Steiger and Jager, 1977).

Sedimentary rocks of unit 1 have undergone contact metamorphism in a 250 to 1 000-metre-wide zone around the stocks. The thinly bedded siltstones grade from quartz-albite-epidote-garnet skarn near the stocks to brown and purple biotite hornfels further from the intrusive rocks.

COAST RANGE BATHOLITH

Quartz monzonite to granodiorite of the Coast Range batholith intrude all formations in the area and are exposed in the southwest corner of the map-area. Sedimentary and volcanic rocks along the contact show little or no contact metamorphism and little sign of deformation. The batholith can be distinguished on air photographs by its light colour and the presence of two prominent oblique fracture sets. The eastern Coast Range batholith has yielded K/Ar ages of 43 to 51 Ma (Carter, 1982).

DYKES

Numerous 0.5 to 3.0-metre-thick, microdiorite to lamprophyre dykes intrude rocks of the Kitsault valley. Dykes are the youngest intrusive rocks in the area and crosscut all the formations and mineralized rocks.

STRUCTURE

Northwest and northeast-trending faults transect the map-area. Displacements appear to be small on a regional scale. Many of these faults have been intruded by Tertiary microdiorite and lamprophyre dykes.

Faulting on a property scale complicates the search for mineral zones. Silver-rich quartz-jasper-barite mineralization at Dolly Varden and Torbrit is bounded by north-northeast-striking faults which are offset as much as 45 metres by northwest-striking faults. Brecciated and recrystallized gangue and sulphide minerals in the fault zones indicate that many have been reactivated (Campbell, 1959; Skerl, 1963).

Three parallel regional scale folds have been defined within the map-area (Figs. 31-1 and 31-2). These are:

(1) The Varden Glacier anticline, which is a doubly plunging anticline. Its axial trace lies 5 kilometres west of the Kitsault River.

(2) The Kitsault River syncline, which is also doubly plunging. Its axial trace lies along and just east of the Kitsault River.

(3) The Mount McGuire anticline, which is another doubly plunging anticline. Its axial trace lies 5 kilometres east of the Kitsault River.

Unit 6 sedimentary strata exhibit complex disharmonic folds at different scales due to ductility contrasts between shales, siltstones, wackes, and adjacent volcanic rocks.

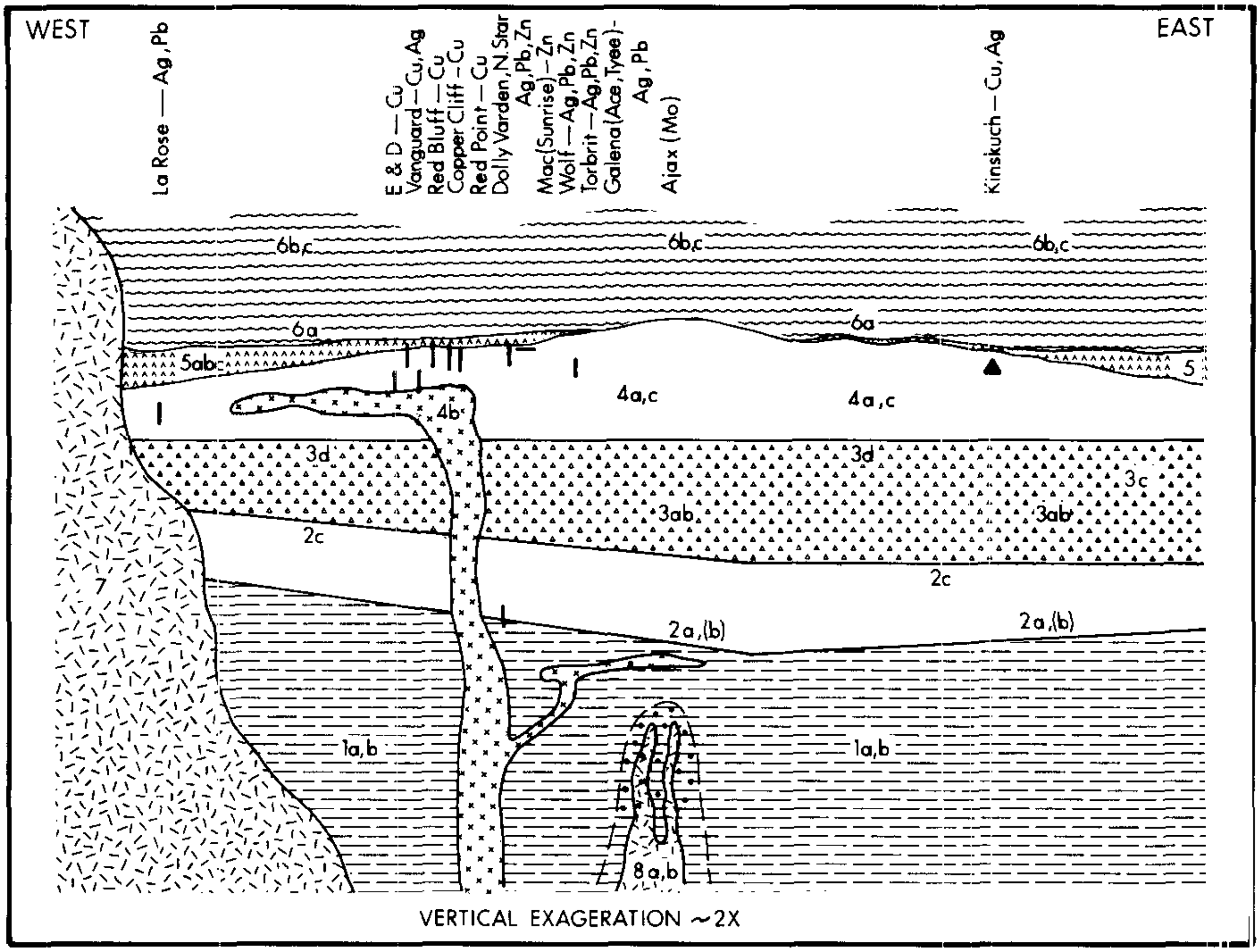


Figure 31-3. Schematic stratigraphic section showing major mineral occurrences, Kitsault valley (see Table 31-1).

MINERAL DEPOSITS

Most mineral occurrences in the area are hosted within volcanic rocks of units 4 and 5 (Figs. 31-2 and 31-3). Exceptions to this are the Ajax porphyry molybdenum mineralization and associated silver veins on Mount McGuire, and zinc-rich veins on McGrath (Wilauks) Mountain. The Ajax molybdenum deposit consists of coatings of molybdenite and quartz on random fractures within the Ajax intrusions and in the adjacent quartz-albite-epidote-garnet skarn alteration zone (Carter, 1982).

Two predominant styles of mineralization are developed within unit 4 andesite pyroclastics:

(1) silver-rich quartz-barite mineralization, and

(2) disseminated copper-gold mineralization.

SILVER-RICH QUARTZ-BARITE MINERALIZATION

Silver-rich quartz-barite-jasper ± sulphide zones occur along the axis and east limb of the Kitsault River syncline in the northern half of the map-area. Campbell (1959) interpreted the mineralization to be mesothermal to epithermal veins, deposited during folding in fractures and faults developed parallel to the axial surfaces of the folds. These mineralized zones have been the most economically interesting of the deposits in the valley; they include the Dolly Varden, North Star, Torbrit, and Wolf mines.

Varying amounts of galena, sphalerite, pyrite, chalcopyrite, tetrahedrite, pyrargyrite, and native silver occur as disseminations and pods within the zones. At the Torbrit mine, pyrargyrite is the principal silver mineral of the ore; it makes up approximately 80 per cent of the silver values. Gangue minerals in the deposits include quartz, barite, jasper, and minor carbonate. The veins show open vugs, banding, and colloform structures. Brecciated zones containing fragments of gangue, sulphides, and host rock are believed to be a result of later movement along the original ore-controlling structures. Host rocks show minor sericite, chlorite, and silica alteration close to the mineral zones.

This type of silver deposit occurs only in unit 4. It shows both stratabound and crosscutting relationships with individual rock layers within the unit. The silver zones also cut and postdate disseminated copper-gold mineralization of the 'Copper Belt' (Campbell, 1959, pp. 1467, 1476).

During 1985, Devlin mapped the North Star, Dolly Varden, and Torbrit mine areas as part of an M.Sc. thesis at the University of British Columbia (Devlin and Godwin, this volume). At the same time, P. Thiersh mapped the Wolf mine as part of his B.Sc. thesis at the university. Both studies are directed at documenting ore/host rock relationships and resolving the genesis of the deposits.

DISSEMINATED COPPER-GOLD MINERALIZATION

Several showings of copper-gold mineralization occur within andesitic pyroclastics and flows or sills of unit 4 and dacitic pyroclastics of unit 5. Typically, the zone is localized along the upper contact of a feldspar and/or hornblende porphyritic flow or subvolcanic sill. These deposits are collectively known as the 'Copper Belt.' The Copper Belt extends from a nunatak within the Cambria Icefield south-southeast along the west side of the Kitsault River to Evindsen Creek, where it crosses the Kitsault River and continues south-southeast to the Dak River. In outcrop it exhibits an extensive orange gossan due to weathering of minor but ubiquitous disseminated pyrite.

Mineralization consists of disseminations and stringers of pyrite and chalcopyrite with associated gold and traces of galena and sphalerite. Alteration is extensive along the contact and in the surrounding feldspar porphyry and pyroclastic rocks. Alteration consists of strong silicification, chloritization, and sericitization.

The Homestake, Vanguard, Red Point, and Red Bluff properties exhibit this style of mineralization, however none have been shown to have economic tonnages or grades.

CONCLUSIONS

Volcanic and sedimentary rocks of the Kitsault valley indicate a history of active volcanism with intermittent periods of quiescence in a predominantly submarine island arc environment.

The majority of mineral deposits can be classified under three deposit types:

(1) silver-rich quartz-barite deposits,

(2) disseminated copper-gold deposits, and

(3) porphyry molybdenum deposits.

The silver-rich and copper-gold deposits are distributed over a strike length of 40 kilometres and are hosted mainly in andesitic volcanic rocks of unit 4.

ACKNOWLEDGMENTS

The authors would like to thank J. D. Blackwell, B. Devlin, A. Taylor, P. Thiersh, and J. R. Woodcock for discussions about the geology and mineral deposits of the Kitsault valley. Jason Bosher and Ian Webster contributed to field mapping and provided excellent assistance in less than ideal weather conditions.

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GEOLOGY OF THE KLAPPAN COALFIELD IN NORTHWESTERN BRITISH COLUMBIA (104H/2, 3, 6, 7)

By J. Koo

INTRODUCTION

The Klappan Coalfield straddles the junction of the Tahtsedle Creek (104H/2), Sweeny Creek (104H/3), Klappan River (104H/6), and Buckinghorse Creek (104H/7) map sheets in northwestern British Columbia (Fig. 32-1). An open file map of the detailed geology of the Klappan Coalfield at scale 1:50 000 was released in January, 1986. The coalfield is approximately 150 kilometres northeast of Stewart and 500 kilometres northeast of Prince Rupert. The British Columbia Railway subgrade line, which runs across the northeastern part of the coalfield, is used as an access road. Gulf and Esso conducted active coal exploration for anthracite in the coalfield during 1985.

Coal in northwestern British Columbia occurs in four major sedimentary successions. These are the Early to Middle Jurassic Laberge, the Middle to Late Jurassic Bowser Lake, the Early to Late Cretaceous Skeena, and the Late Cretaceous to Tertiary Sustut-Sifton Groups. The Late Jurassic and Early Cretaceous successions contain coal seams which are potentially economic at present; coal measures in the Mount Klappan area occur within one of the successions, which has been referred to as the Mount Klappan succession (Koo, 1983, 1984, 1985).

During the summers of 1983 and 1984, the Mount Klappan succession was mapped in the central part of the Klappan Coalfield; fieldwork during the summer of 1985 completed the mapping of the succession in the remaining parts of the Klappan Coalfield. The present report summarizes results of the geological mapping.

SEDIMENTARY STRATIGRAPHY

The Klappan Coalfield is underlain by a 1 300 to 1 500-metre-thick succession of conformable marine and non-marine sedimentary strata — the Mount Klappan succession. It can be divided into five mappable stratigraphic units (Figs. 32-1 and 32-2).

Unit 1, which is the lowest 200-metre stratigraphic interval of the Mount Klappan succession, consists of claystone, siltstone, fine to coarse-grained sandstone, and conglomerate; marine bivalves and trace fossils occur in siltstones and sandstones. Unit 1 comprises coarsening upward cycles resulting from successive progradation of delta channels over fine-grained prodelta sediments. It is a typical marine deltaic sequence.

Unit 2, which is 350 to 420 metres thick, is the coal-bearing sequence of the Mount Klappan succession; it consists of two mappable sub-units, the lower and upper coal sequences.

The lower coal sequence in turn is made up of two distinct stratigraphic intervals. The lower interval, which is 200 to 270 metres thick, consists of coal seams, claystone, siltstone, and fine to coarse-grained sandstone. This interval is characterized by stacked, coarsening upward cycles containing marine bivalves and trace fossils. It is the type of succession deposited in a constructive deltaic system with subaerial delta plains and intermittent coal swamps. The upper interval, which is 100 to 150 metres thick, consists of coal seams, claystone, siltstone, fine to medium-grained sandstone, and conglomerate. This interval contains mainly fluvial cycles that are interlayered by several marine cycles. The environment of deposition changed between marine deltaic and non-marine fluvial conditions. The youngest of the marine cycles marks not only the top of the lower coal sequence but also the youngest marine tongue in the Mount Klappan succession.

The upper coal sequence of unit 2 comprises 100 metres of coal seams, claystone, siltstone, sandstone, and conglomerate. It consists of stacked, fining upward cycles deposited in a fluvial channel and backswamp environment.

Unit 3 comprises 220 metres of coaly claystone, mudstone, sandstone, and conglomerate in as many as 20 fining upward cycles. The sequence of rocks in unit 3 was deposited in a transitional environment from fluvial plains to distal alluvial fans.

Unit 4 ranges in thickness from 280 to 300 metres. It consists mainly of coarse to medium-grained sandstone and conglomerate; however, it also contains minor amounts of fine-grained sandstone and mudstone. There are as many as eight fining upward cycles. This unit represents an environment in which a system of braided river channels crossed a series of distal alluvial fans.

Unit 5 reaches 170 metres in thickness. It consists mainly of conglomerate and coarse to medium-grained sandstone but there are minor amounts of fine-grained sandstone and mudstone. This unit represents an environment in which streams with braided channels dissected proximal to intermediate alluvial fans.

The Mount Klappan succession is an accretional, coarsening upward megacycle; it resulted from a major marine regression in the Klappan basin. The rocks in the succession reflect a gradual transition from marine deltaic through fluvial to alluvial environments. Peat swamps were developed on the subaerial deltaic and fluvial plains during deposition of unit 2.

POST-SEDIMENTARY DEFORMATION

A major southeasterly plunging synclinorium embraces the whole Mount Klappan succession in the Klappan Coalfield (Figs. 32-1 and 32-2). The major synclinorium has gently folded limbs and a vertical axial surface. Its axial surface strikes north 45 degrees west and the axis plunges 10 to 20 degrees to the southeast. The northeast and southwest limbs of the synclinorium dip 20 degrees to the southwest and 15 degrees to the northeast, respectively. The synclinorium has many associated smaller scale folds and faults.

Minor folds within the synclinorium vary in amplitude from 200 to 400 metres, and in wavelength from 100 to 400 metres; their limbs vary in dip from 25 to 85 degrees. The folds are open and upright to tight and overturned. Axes of the minor folds plunge 10 to 20 degrees to the southeast, parallel to the axis of the synclinorium. The folds fan outward from the core of the synclinorium; many, if not all, of the fold limbs and axial surfaces dip southwest on the northeast limb of the synclinorium and northeast on the southwest limb.

The minor folds in the coarse-grained sandstones and conglomerates of units 4 and 5 are mostly open and nearly symmetrical; however, in relatively thick zones of fine to medium-grained sandstone and mudstone, they form box-shaped folds.

The minor folds in units 1, 2, and 3 are usually of tight, asymmetric, chevron style. Steeply dipping and generally overturned limbs of the minor folds are associated closely with thick layers of

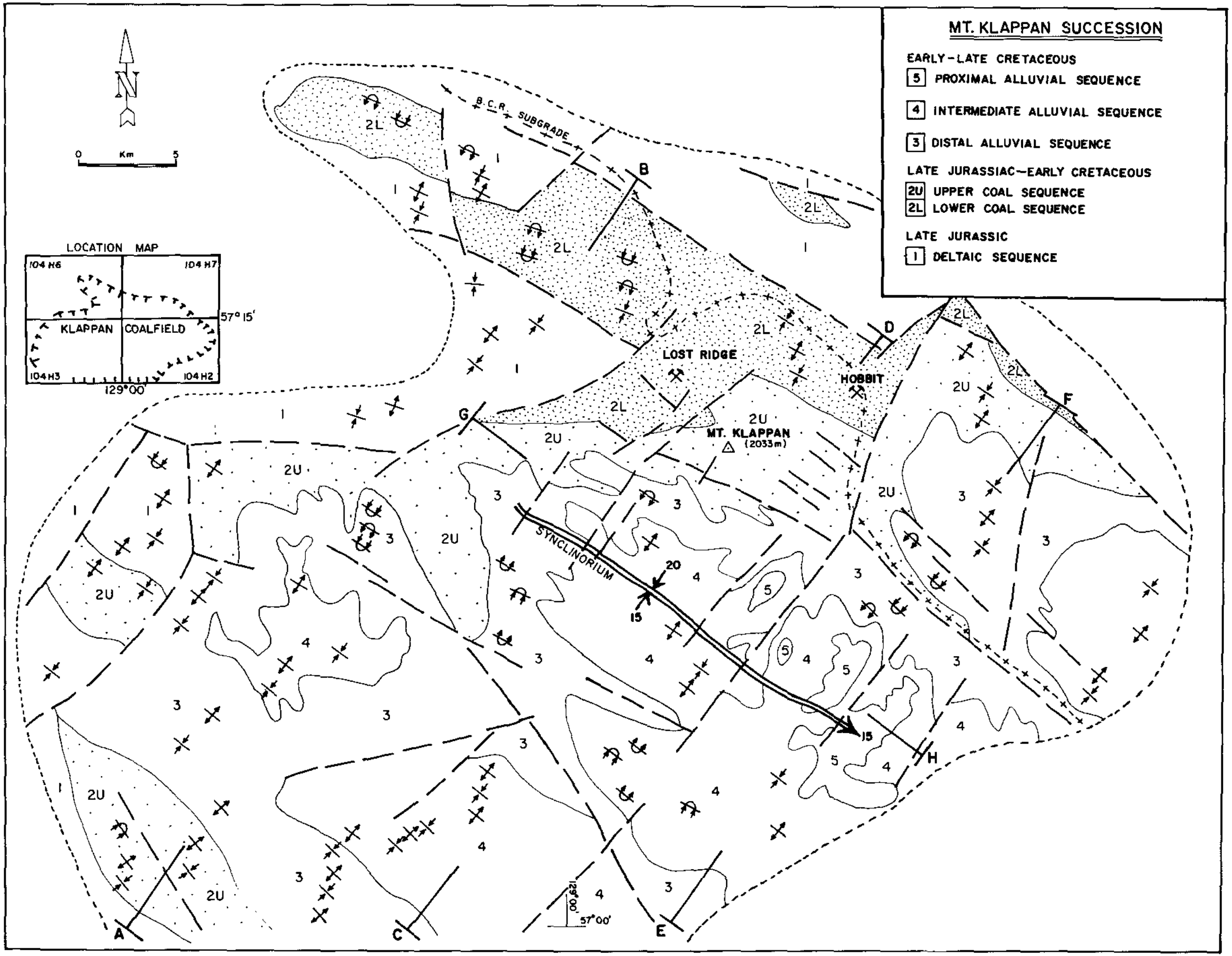

Figure 32-1. Geology of the Klappan Coalfield.

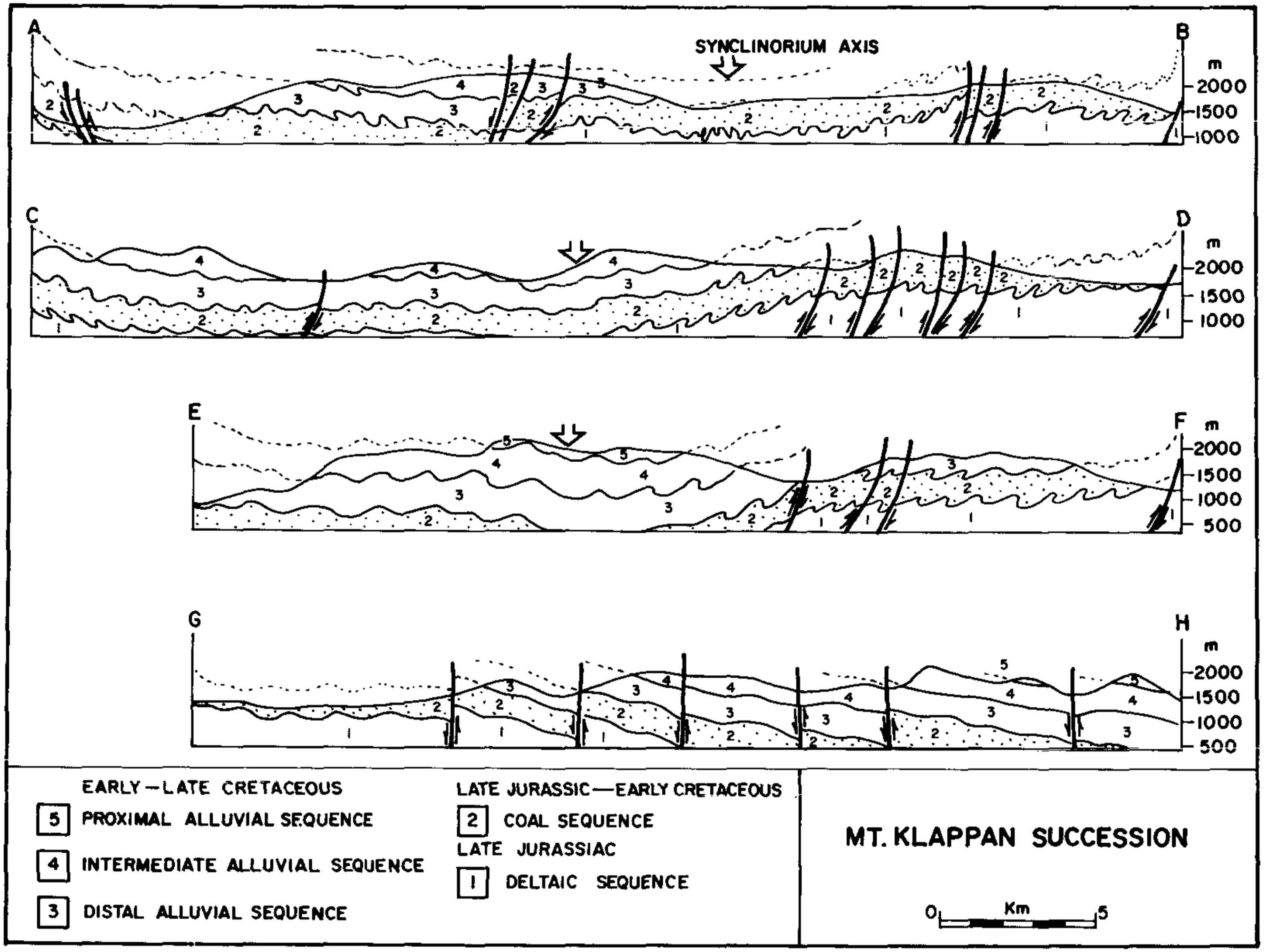

Figure 32-2. Geological cross-sections of the Klappan Coalfield.

incompetent claystone, siltstone, and fine-grained sandstone. In contrast, gently dipping normal limbs of the minor folds occur in the competent stratigraphic intervals that are ruled by conglomerate and coarse to medium-grained sandstone. It is the gently dipping limbs that are the locations of potentially mineable coal seams as well as the foci of economic interest.

In places, the minor folds in units 1, 2, and 3 accompany subsidiary folds. Box-shaped or open symmetric subsidiary folds are present in the layers of competent conglomerate and coarse to medium-grained sandstones, whereas smaller disharmonic subsidiary folds formed in the layers of fine-grained sandstone and mudstone.

Faults and shear zones are developed in some steeply dipping limbs and axial planes of the minor folds in the less competent layers in units 1, 2, and 3. The shear zones, which commonly grade into sets of faults, are up to 300 metres wide. The fault and shear zones strike north 40 to 70 degrees west and dip 40 to 85 degrees either southwest or northeast, depending on which limb of the synclinorium they occur on. Movement on the faults is generally reverse and ranges from a few metres to 300 metres. The faults and shear zones resulted from continued deformation after formation of the synclinorium and its associated minor folds.

Northeasterly or northerly trending faults also cut the northwesterly trending synclinorium, minor folds, faults, and shear zones. Displacements on these later cross-faults are mainly vertical, and locally are up to 500 metres. Cross-folding accompanies these later faults. The folds include a series of southeasterly dipping monoclines in the competent units 4 and 5, and open symmetric to tightly angular chevron folds in the less competent units 1, 2, and 3. Axial surfaces of the later folds strike north 5 to 40 degrees east and dip 40 to 85 degrees northwest. Amplitudes range from 50 to 400 metres; wavelengths from 300 to 2 000 metres. Amplitudes increase and wavelengths decrease toward the northwest part of the Klappan Coalfield. These later folds are superimposed on the northwesterly trending folds; consequently, axial traces of the earlier folds curve and axes are doubly plunging; early fold axes now plunge 10 to 35 degrees either southeast or northwest.

COAL DEPOSITION

Twenty coal seams occur in the lower and upper coal sequences of unit 2 in the Klappan Coalfield. As many as 16 coal seams occur in the lower coal sequence, where individual seams can be 5 metres thick and are 5 to 50 metres apart. Some of the coal seams in the lower interval of the lower coal sequence are associated closely with marine mudstones which typically contain significant amounts of iron sulphides. Gulf's Lost Ridge and Hobbit Creek pits are in coal seams that lie in the upper interval of the lower coal sequence of unit 2.

Four or more coal seams occur in the upper coal sequence of unit 2. They can be 2 metres thick and are 6 to 35 metres apart.

The coal seams formed during the transitional period between deposition of marine and non-marine sequences of the Mount Klappan succession. Seams of the lower coal sequence formed from coal swamps developed under marine deltaic and fluvial conditions. Seams of the upper coal sequence represent swamps developed under entirely non-marine, fluvial conditions. Marine conditions ended at the top of the lower coal sequence of unit 2. This boundary may approximately separate Jurassic and Cretaceous sequences; thus the coal seams may range in age from Late Jurassic to Early Cretaceous. The lower coal sequence correlates with the upper part of the Middle to Late Jurassic Bowser Lake Group. The upper coal sequence may correlate with the lower part of the Early to Late Cretaceous Skeena Group.

Potentially mineable coal seams occur mainly in the gently dipping limbs of the northwesterly trending minor folds in the unit 2 sequence because they are amenable to extraction by surface mining methods. Rocks of unit 2 are exposed in a 375-square-kilometre area in the Klappan Coalfield, and this area should be thoroughly explored for all potentially mineable, near-surface coal seams.

Coal seams in the northwesterly trending faults and shear zones are stretched and dismembered into lenticular bodies. Quartz, carbonate, and sulphide veins are widespread in the intensely deformed coal seams, and the veins are common in most of the fault and shear zones. In places, deformation in unit 2 coal seams is further complicated by the cross-folding and faulting. All the complicating aspects of deformation should be taken into consideration for successful exploration in the Klappan Coalfield.

Unit 2 coal seams consist of semi-anthracite, anthracite, and meta-anthracite; their mean maximum reflectance values of vitrinite in oil range from 2.5 to 5.0 per cent. Similar anthracite and meta-anthracite were produced during thermal metamorphism of Early Cretaceous coal seams by Late to Tertiary granodiorite and quartz monzonite stocks in the southern Bowser Basin. Late Cretaceous to Tertiary rocks are widespread in the Stikine Terrane, and many are also exposed north and south of the Bowser Basin. Although no stocks are exposed in the Klappan Coalfield, the high ranks of the coal seams must have been achieved due to high heat flows; perhaps these heat flows originated from buried intrusions under the coalfield.

CONCLUSIONS

The Klappan Coalfield is underlain by five mappable stratigraphic units of the Mount Klappan succession. The succession is an accretional, coarsening upward cycle that resulted from a major marine regression in the Klappan Basin. Facies in the Mount Klappan succession reflect a gradual change from marine deltaic through fluvial to alluvial environments. The potentially economic coal seams occur in the transitional unit between the marine and non-marine units. The thickest, more continuous coal seams were developed during the transitional period between deposition of marine deltaic and non-marine fluvial sequences within the coal-bearing unit.

Two major phases of post-sedimentary deformation resulted in folding, faulting, cross-folding, and cross-faulting of the Mount Klappan succession. Deformation was most intense in the coal-bearing unit because it is less competent than all other units in the Mount Klappan succession. Nevertheless, locally, low angle, near-surface fold limbs provide favourable potential sites for surface mining of contained coal seams.

Coal ranks range from semi-anthracite to meta-anthracite indicative of high heat flows responsible for coalification in the Klappan Coalfield.

ACKNOWLEDGMENTS

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Resource Data and Analysis

MINFILE

By A. F. Wilcox and C. Borsholm

INTRODUCTION

In the fall of 1984 a decision was made to redesign MINFILE; the project was given a high priority by the Chief Geologist. A management committee consisting of the Chief Geologist, the Managers of Resource Data and Analysis and Geoscience Projects, and the Director of Data Services was established to oversee the project. Trygve Höy, Cindy Borsholm, and Allan Wilcox (project leader) were selected for the working project team. Their responsibilities included supervision of contractors and the daily progress of the redesign.

MINFILE REDESIGN OBJECTIVES

MINFILE has undergone a redesign to serve five main functions:

(1) In conjunction with the Ministry's five-year plan to provide a better inquiry base for mineral inventory data for Ministry and industry use.

(2) To eliminate long-term problems caused by the previous conversion of the database from Honeywell to IBM.

(3) To enable downloading of sections of the database onto personal computers for use by individual geologists. Project and district geologists will be able to update and add new information directly.

(4) To provide graphic output capabilities.

(5) To provide a lead in to "expert" systems.

MINFILE REDESIGN ADVANTAGES

The redesign of MINFILE brings several advantages with it, both from a computerization standpoint and a geological standpoint.

(1) The new MINFILE is a relational database as compared to a hierarchial one.

(2) The system is table driven.

(3) Improved search capabilities allow retrievals on all data fields. Complicated searches using Boolean logic with nested inquiries will be possible.

(4) A fourth generation software/database management system is used to manipulate the data.

COMPUTER HARDWARE

MINFILE resides on a VAX 11-750 minicomputer at the British Columbia Systems Corporation (BCSC). The VAX 11-730 computer installed in Mineral Titles Branch is dedicated to graphics at the present time and does not have the capacity to handle both systems efficiently. Access to the data is via one VT 240, one VT 102 and two VT 220 terminals. Hard copy is produced on a DEC LA210 local printer.

COMPUTER SOFTWARE

When the hardware choice was finalized, the following database management systems were considered:

Focus
Powerhouse
DBase II/III
R:Base 4000/6000
ORACLE
ULTRA

The software product had to meet four basic requirements:

(a) be operational on a VAX.
(b) be a relational database.
(c) allow fourth generation access.
(d) support multi-users.

An in-depth test of ORACLE was performed using the IBM PC version of the software. Results of this test were compared against ULTRA (on a VAX 11-750). Certain factors were taken into consideration in choosing the ULTRA software. These factors were (1) referential integrity, (2) data independence, (3) backup/recovery facilities, (4) security, (5) end-user queries, (6) report writing, (7) system support, (8) micro computer compatabilities, (9) file management, (10) ease of screen design, (11) amount of third generation programming required beyond systems fourth generation features, (12) graphics interface, (13) on-line directory, (14) multithreading, (15) database physical design, and (16) lock-out management.

ULTRA

ULTRA is a directory driven database and information management system designed for the VAX environment that uses the VMS operating system.

ULTRA provides data management for database administrators, application programmers, and end-users. Figure 33-1 illustrates the way data flows within the system and how each component fits into ULTRA.

The ULTRA Directory is the central point of control for the system. Its integration with the Logical User View (LUV) insulates all users from the physical structure of the database which is maintained by the ULTRA DBMS (database management system). The Database Administrator (DBA), with access to the directory, controls how data is used as well as the users. For example, LUV allows the DBA to define logical views of the database for particular users.

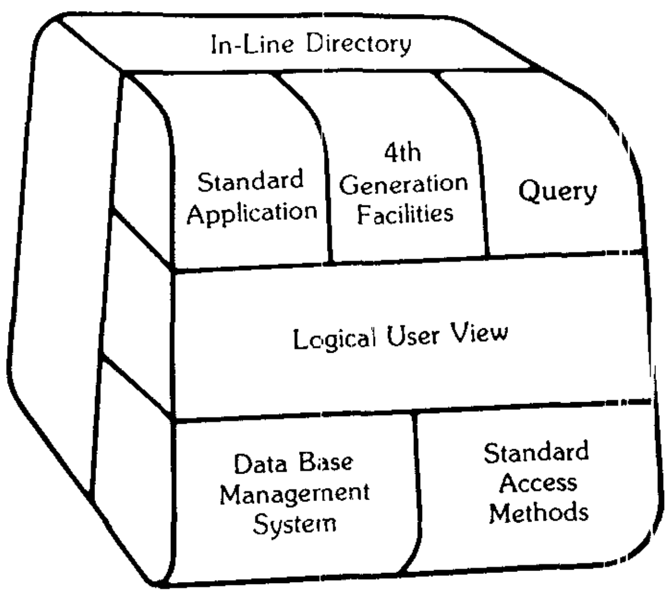

Figure 33.1. ULTRA's integrated architecture.

British Columbia Ministry of Energy, Mines and Petroleum Resources, Geological Fieldwork, 1985, Paper 1986-1.

TABLE 33-2. MINFILE — NEW DATA FIELDS

IDENTIFICATION

MINFILE No.
National Mineral Inventory Number
Mindep No.
Name
Status: Open Pit
        Underground
NTS
Mining Division
Latitude/Longitude/UTM
Location Accuracy

HOST ROCK

Dominant Rock Type
Stratigraphic Units: Group
        Formation
        Member
        Igneous/Metamorphic
        Informal/Other

Stratigraphic Age/Isotopic Age

GEOLOGICAL SETTING

Tectonic Belt
Terrane
Physiographic Region
Metamorphism: Type
        Grade
        Relationship

MINERAL OCCURRENCE

Commodity
Minerals: Economic
        Gangue
        Alteration
Alteration Type
Deposit Type
Genetic Type
Age of Mineralization/Isotopic Age
Structural Attributes: Shape
        Shape Modifier
        Dimension
        Attitude: Strike/Dip
                Trend/Plunge

ECONOMIC ATTRIBUTES

Reserves: Ore Zones and
        Total Deposit
        Grade/Cut-off
        Quantity
        Date
        References
Best Assay-Sampling Method

Production: Year
        Commodity
        Quantity mined/milled/recovered

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Bibliography
Work History: Link to Assessment Report System

These logical views may then be used by an applications programmer in a number of programs. A subsequent change to a logical view usually does not require programs to be changed or recompiled. The Directory stores the updated logical view so that wherever it is used, data are accessed in the current format.

ULTRA allows standard application programs written in COBOL, FORTRAN, or BASIC to access the ULTRA DBMS without including logic to physically navigate the DBMS. The programmer simply accesses a logical view of the data needed. LUV performs the database navigation to retrieve the data.

A fourth generation language called MANTIS is able to interact directly with LUV and the DBMS. The programs for the redesign of MINFILE have been written in MANTIS, with the exception of several FORTRAN sub-routines.

Intelligent Query (IQ) allows non-data processing professionals to use the computer for day-to-day information needs. The IQ language consists of simple commands used to retrieve data, calculate from the data, and derive statistical summaries. Queries can be written, named, and stored, so that they can be used repeatedly without retyping the entire query.

CINCOM Systems of Canada Ltd. chose the Ministry as a Beta Test site for a new product called Advanced Query (AQ) which they hope will replace IQ. The main advantage of AQ is that it works directly against the DBMS, whereas, in IQ all your views have to be redefined to IQ. An important advantage of AQ is that you can create your own personal files for downloading to a micro computer.

MANTIS

MANTIS is a fourth generation programming language allowing users with diverse backgrounds to solve application development problems simply and quickly using a display terminal. It accomplishes this by removing the necessity of coding sheets, job control statements, source decks, and, most importantly, the waiting usually associated with the development and implementation of a new program or system.

MANTIS is an interpreter. Among other things, it enables you to:

(1) Create and test programs interactively using structured programming concepts.

(2) Design and create permanent files for data storage and manipulation.

(3) Design and create formatted screens to enable full use of all the facilities available on today's terminals to display data attractively.

TABLE 33-1. MINFILE — EXISTING DATA FIELDS

DEPOSIT IDENTIFICATION	GEOLOGICAL
*NTS	*Commodity
Latitude/Longitude/UTM	*Minerals
Elevation	*Deposit Type
*Mining Division	Capsule Geology
*MINFILE No.	
Name	
Status	
ECONOMIC	**BIBLIOGRAPHY/ MISCELLANEOUS**
*Reserves	References
*Production	Comments
	NMI No.
	MINDEP No.
	Revision Date

* Retrievable

INFORMATION RESIDING IN MINFILE

Old MINFILE data were divided into four main categories: Deposit Identification, Geology, Economic Attributes, and Bibliography/Miscellaneous. The data elements contained in these are illustrated in Table 33-1. The data fields for the new MINFILE are illustrated in Table 33-2. The new database contains more geological information. To capture this new data all staff geologists have been asked to code and rewrite properties that they visit during the course of their field studies. Coding forms and a coding manual were developed before the start of the 1985 field season. The coding forms will be modified based on the experience of staff using them during this season as well as the addition of a few new data fields.

INFORMATION AVAILABLE

Complete MINFILE is available in the following formats:

(1) Paper.

(2) Microfiche.

(3) Computer tape (ASCII or EBCDIC).

(4) MS-DOS diskette — whole province or by individual map sheet (when the redesign is completed).

A number of reports and indexes are also available. These include:

(1) Alphabetical listing of deposit names.

(2) Commodity index.

(3) Numeric list of MINFILE numbers.

Other selective searches are performed using a user pay cost recovery formula.

Further information is available by telephone or mail from either of the authors at the address below:

Geological Branch
Mineral Resources Division
Ministry of Energy, Mines and Petroleum Resources
Parliament Buildings
Victoria, B.C.
V8V 1X4
(604) 387-1301 or 387-5975

FUTURE PLANS FOR MINFILE

Graphic capabilities will be developed for MINFILE. Direct links with the following Ministry databases are planned; Mineral Titles, Inspection and Engineering, and Mineral Policy. These additional features will provide further output capabilities.

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COALFILE

By Candace E. Kenyon

BACKGROUND

COALFILE is a computer-based data storage and retrieval system for coal exploration information. It provides an index to data contained in coal assessment reports and the updating and maintenance of this file is an ongoing project; the history of the project is outlined by Kenyon (1985). In the spring of 1985, an internal committee was appointed to undertake an in-depth project review of COALFILE.

PROJECT REVIEW

Following are the terms of reference for the project review of COALFILE:

(1) To determine and document the usage of COALFILE by industry and government.
(2) To assess the relevance of the information in the files to the various users.
(3) To assess the timeliness, relevance, and quality of output.
(4) To assess the technical aspects of the data management system as well as the application capabilities and identify problem areas.
(5) To determine the costs of maintaining COALFILE as well as the income received from sales of output.
(6) To recommend changes to make the database most effective.

Four techniques were utilized in the project evaluation: file research, questionnaires (a random sampling of industry), interviews, and observation.

It was determined that COALFILE provided a valuable catalogue of accurate, up-to-date, exploration summary data but to a limited user market. Industry most commonly used the file as an index to further information searches. In some cases there were false expectations of the data due to a lack of understanding and exposure of the information contained in the file. Those who utilized COALFILE were not interested in the analytical data which comprised a major portion of the database because most individuals wished to review the actual assessment report when interpreting analytical information. Output from the existing file was satisfactory, but the cost structure was not yet developed.

An assessment of the technical aspects of the project revealed some problems. The British Columbia Systems Corporation (BCSC) provided all of the technical assistance for the computer file. COALFILE had undergone three major conversions on mainframe systems in a five-year period. This involved changes in operating systems, programming languages, database systems, and a lack of continuity in computer personnel. Because of this control of technical aspects by BCSC, the database manager had no read or write access to the operating software and the system was costly to maintain and inflexible concerning editing and retrieval capabilities. Complicated programs were necessary to produce customized reports as well as statistical and graphic output. A disproportionate amount of time and resources were being spent on machines and consultants.

The in-depth evaluation of COALFILE resulted in the following recommendations:

(1) COALFILE should be restricted to information dealing with exploration work as compared to results from exploration work. This would mean elimination of analytical data capture.
(2) A property summary file for the coal deposits in the province should be created, independent of COALFILE.
(3) Other unique projects, independent of COALFILE should deal with the data falling into the 'Results of Exploration Work' category.
(4) COALFILE should not be stored on the mainframe at BCSC but should reside on a dedicated disk in the microcomputer environment. Basic utility programs on the mainframe would continue to be utilized.
(5) The database manager should take a PL/1 programming course to provide the Geological Branch with more autonomy in regards to COALFILE.
(6) COALFILE should have a higher profile. It should be included in government publication lists and other forms of distribution should be devised. A price structure for data output should be established.

REVISIONS TO COALFILE

Upon completion of the project review, a COALFILE Management Committee was formed in order to decide the future direction of the database. The database manager was appointed project leader and considered the following options in a detailed cost-benefit analysis study:

(1) To carry out the revisions as recommended by the Evaluation Committee (downloading COALFILE to the IBM PC XT Microcomputer).
(2) To adapt new coding forms to the old files, retaining the record structures, but dropping the analytical information (the data would be downloaded for this option also).
(3) To leave COALFILE as is and keep collecting data on the old coding forms.

The operating costs for each option were detailed for 1985/86 and then projected over a five-year period. The first option proved to be more economical and the project leader then presented an implementation plan to carry out the necessary revisions to COALFILE.

The object of this plan was to have the project completed by the end of January 1986. Industry could then have a hands on demonstration at the Cordilleran Round-up in Vancouver.

The implementation plan called for major programming changes and testing, including a complete conversion of the old files to new record structures and a rewrite of all the load/edit programs. Software that was to be retained on the mainframe had to be modified. Complete instruction and maintenance manuals had to be written. All the data in the new format was downloaded to the microcomputer (IBM PC XT) and the files were then defined to a fourth generation language (FOCUS). Further testing was done at this level to determine the type of output available.

The following benefits resulted from revisions to the old database:

(1) Data storage now resides on the microcomputer. This eliminates disk storage costs on the mainframe system. Routine maintenance can be done at the micro level.
(2) Basic utility programs on the mainframe can still be accessed.
(3) Shorter record structures allow for interactive editing capabilities and these newly designed files incorporated data field changes suggested by the internal committee. The entire database can reside on a 5 megabyte disk.

British Columbia Ministry of Energy, Mines and Petroleum Resources, Geological Fieldwork, 1985, Paper 1986-1.

(4) FOCUS generates reports using multiple retrieval parameters as well as statistical charts and graphics on the microcomputer. The language is user friendly and will encourage hands on experience.
(5) The use of both the mainframe and the microcomputer will allow for a variety of output products.
(6) Reliance on BCSC for database management no longer exists.

PRESENT STATUS OF COALFILE

COMPUTER ASPECTS

COALFILE presently resides on floppy diskettes and is accessed on an IBM PC XT. Six sequential files, each record 230 characters in length, comprise the database. WYLBUR software is used for editing purposes. FOCUS (a fourth generation language) is used for generating reports, statistics, and graphs. An Epsom printer and an HP7475A plotter produce hardcopy. The IBM PC XT contains an IRMA board which allows data transfer to and from the IBM 3081 Model K mainframe at BCSC.

Calcomp software for producing x, y coordinate plots resides on the mainframe and operates in TSO foreground. Hardcopy is produced on a flat bed plotter at the Ministry of Transportation and Highways. Basic utilities written in PL/1 reside on the mainframe and are run using menu driven Wylbur exec programs. These utilities are used to load new data, create subset files, restore tapes, back up data, sort files, manipulate tapes and disks, and provide a help facility. The mainframe is more efficient than the micro for running and printing batch jobs. To assure data security, COALFILE is backed up onto tape at BCSC on a regular basis. The old database and all associated utilities are archived on tape (*see* Geological Fieldwork, 1984, Fig. 130, which illustrates computer hook ups for the Geological Branch).

TYPE OF DATA (Table 34-1)

COALFILE is updated with information extracted from assessment reports on a yearly basis. Each report can have as many as six files of associated data. The following record types comprise the database:

(1) **Explore record:** Contains general information such as property ownership, operators, location, work summary, licence area, and types of analyses done. Each coal property in the province has a unique identifier. Detailed information for each report is found in the following record types.
(2) **Comment record:** This is reserved for text concerning the assessment report (for example, title of report, comments, completeness of information).
(3) **Map record:** Indicates the type of maps, including scale and area mapped, that were submitted with the assessment report.
(4) **Trench record:** Provides location data for each trench. It contains the seam name(s) that the trench intersects and the types of sampling done.
(5) **Bulk record:** Contains location information concerning bulk samples (whether from pits or adits). It indicates the seam name, the position of the sample in the seam, type of testing, and sample size.
(6) **Borehole record:** Provides location data, type of borehole, depth drilled, inclination, number of coal intersections, number of analyses, contractor, geophysical log types, and core storage information.

TABLE 34-1. SUMMARY OF RECORDS STORED IN COALFILE

Record Type	Total No. Records
Explore	621
Comment	627
Map	540
Trench	3 076
Bulk	631
Borehole	6 442

INFORMATION AVAILABLE

Output from COALFILE is available as hardcopy or on diskettes or tape. Information is available as raw data or as customized requests. All output in raw data format is accompanied by a description of the structure of the record(s) and the associated code tables. Costs for output have not yet been determined, but they will be reasonable and will vary according to the type of request.

RAW DATA

Obtaining data in raw format allows the user to utilize whatever software is available to access the information.

(1) **Hardcopy printouts:** This can be either an entire file(s) or specific information, such as all the boreholes on Vancouver Island.
(2) **Diskettes** (5 1/4 inch): This could involve one or more file types on a diskette, depending on the request. One diskette can hold 1 500 records.
(3) **Tapes:** A complete file or the entire database could be copied onto a tape at BCSC. The archived borehole analysis data are best purchased as a tape.

CUSTOMIZED RETRIEVALS

Customized data retrievals are available in a variety of formats:

(1) **FOCUS-generated reports:** These customized reports are easy to read with headings, selected information, specific retrieval parameters, summary data if required, and many other features. Codes are replaced by words.
(2) **Statistical and graphic output:** Data can be summarized and presented in one of these formats. An example would be a graph illustrating borehole drilling over a 10-year period. This is an alternative to a report format.
(3) **Plots, x y coordinates:** These are hardcopy location maps on a UTM grid system at any desired scale. The plot can illustrate borehole, trench, or bulk sample locations. Up to eight pieces of information can be printed beside the location point. A printout of the raw data accompanies the plot.

OTHER INFORMATION

(1) **Open file listing:** This is a customized report providing an index summary of exploration data for all non-confidential assessment reports on file with the Ministry. The charge for this listing is $5.00.
(2) **Information pamphlet:** Detailed data descriptions for each record type are listed here as well as examples of output available from COALFILE. There is no charge for this pamphlet.

PLANS FOR COALFILE

COALFILE will be updated on a regular basis. The data are presently residing on floppy diskettes, but an alternative storage method should be available soon, either a fixed dedicated hard disk or a removable cartridge (that is, a Bernoulli box with two removable 10-megabyte cartridges).

For further information, please contact Candace Kenyon at (604) 387-1301; mailing address: Ministry of Energy, Mines and Petroleum Resources, Mineral Resources Division, Coal Resources, Parliament Buildings, Victoria, B.C., V8V 1X4.

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NEW DEVELOPMENTS IN INDUSTRIAL MINERALS

By Z. D. Hora

INTRODUCTION

During the past three years several new centres of production of industrial minerals started to operate in various parts of the province. While some are temporary, rather unsuccessful ventures, other will remain contributers to the British Columbia economy in the years to come.

RED LAKE (MI 92I/NE-81)

Since 1984 a devitrified volcanic ash bed from a site approximately 3 kilometres north of the Red Lake school house has been processed into industrial and domestic absorbent. D.E.M. Resource Processors Ltd. is selectively open-pit mining an approximately 5-metre-thick layer of a massive, fine-grained, white to beige coloured, very lightweight rock — 'fuller's earth'. The deposit is part of the Tranquille Formation of the Eocene Kamloops Group (Church, *et al.*, 1983).

According to X-ray diffraction analysis the matrix is a poorly crystalline montmori lonitic mixed layer clay, with quartz, cristobalite, and K-feldspar as minor components. Under the microscope, cells and fragments of diatomaceous earth material comprise up to 25 per cent of the rock. Testing was done on randomly collected, but typical, samples from the quarry.

The material has the following physical properties:

Density: 0.61 g/cc
Absorption (ASTM): 111.4 per cent
Physical strength: 4.8 to 7.9 MPa

The quarry site exposed the following section:

Metres	
1.5–3.0	till
0.9–1.5	devitrified white to beige volcanic ash
0.6–1.2	dark brown and grey clayey layer
3.0	devitrified beige volcanic ash
0 –0.6	devitrified beige volcanic ash with frequent coal fragments and veinlets of jarosite
0.3	coarse, andesitic lapilli tuff
basement	massive, vesicular, fine-grained volcanic rock (andesite ?)

With the exception of the clayey layer all devitrified volcanic ash is mined and processed.

BENSON LAKE (MI 92L-295)

A quarry in white limestone has been developed at a site located approximately 3 kilometres southwest of Benson Lake, near the intersection of the road from Benson Lake to Port Alice and the main logging road system. The International Marble and Stone Co. is producing a white, massive, fine-grained (1 to 2-millimetre) limestone which is processed in the company's Surrey plant into different grades of fillers and extenders.

Randomly collected samples of typical material from the quarry site have the following, average composition:

	Per Cent
CaO	55.1
MgO	2.49
SiO_2	0.27
Al_22O_3	0.05
Fe_22O_3	<0.09
LOI	43.97
TiO_2	<0.01
MnO	<0.003

The company reports the brightness of the ground product as 95.5 per cent.

Very little overburden developed in the quarry area; fresh clean rock, uncontaminated by earthy soil, occurs between 0.5 metre to 1.0 metre below the surface. Three aplitic dykes, 30 centimetres, 50 centimetres, and 80 centimetres thick, crosscut the limestone at the quarry site with different directions and varied dips. The limestone beds strike 120 degrees and dip 30 degrees northeast. About one-third of the exposed limestone beds are highly fractured and disintegrate into fragments of less than 0.3 cubic metre; the rest is more massive and blocky.

The white limestone is part of a thick section of generally grey coloured carbonate rocks of the Upper Triassic Quatsino Formation (McCammon, 1968).

BAKER CREEK (MI 93P-003)

Agricultural lime and other crushed and sized limestone products are processed from a new quarry located 80 kilometres south of Chetwynd. Prime Lime and Marble Ltd. started this operation in 1984 at the confluence of the Sukunka River and Baker Creek; the site can be reached by the Sukunka River Forestry Road.

The chemical composition of a crushed and screened sample collected from the stockpile is:

	Per Cent
CaO	55.7
MgO	0.58
SiO_2	0.98
Al_2O_3	0.30
Fe_2O_3	<0.07
LOI	43.36
TiO_2	0.02
MnO	0.004

The limestone is very fine grained (0.2 to 0.5 millimetre), massive but highly fractured, and dark grey and brownish grey in colour. The quarry has opened the western limb of a northwest-trending syncline in limestone of the Lower Carboniferous Rundle Group (Stott, 1975).

BONANZA LAKE (MI 92L-280)

A bed of massive, white crystalline limestone was opened during 1983-84 by a 65-metre-long horizontal adit at the north end of Bonanza Lake. The site is on the eastern side of the valley, adjacent to the main logging road. The limestone is fine grained (1 to 2 millimetres), mostly white with occasional greyish streaks and mottled bands. The International Marble and Stone Co. tried to develop the site as a source of white limestone.

British Columbia Ministry of Energy, Mines and Petroleum Resources, Geological Fieldwork, 1985, Paper 1986-1.

Rock exposed in the adit strikes at 80 degrees and dips 20 degrees south. The limestone contains numerous small sills and irregularly distributed lenticular blocks of aplitic rock together with similarly distributed zones of amphibolite. Because of these silicate rock impurities the site was abandoned.

The limestone belongs to the Upper Triassic Quatsino Formation (McCammon, 1968).

BOWRON RIVER (MI 93H-073)

Medium to coarse-grained limestone was processed at Bowron River during the summer of 1983 into agricultural-grade soil conditioner. The material came from the face of the cliff east of the Giscome logging road, 32 kilometres south of its intersection with Highway 16 at Purden Lake. Light to dark grey marble with a grain size between 3 and 5 millimetres and no apparent impurities was mined and processed by Western Lime and Marble Inc. The chemical composition of a sample taken from the 0.5-centimetre-size stockpile is as follows:

	Per Cent
CaO	46.8
MgO	7.6
SiO_2	0.34
Al_2O_3	0.08
Fe_2O_3	0.11
LOI	44.6

The bluff is part of a major northwest-trending belt of limestone that belongs to the Lower Cambrian Mural Formation (Campbell *et al.*, 1973).

GRAND FORKS (MI 82E/SE-036)

A small dolomite quarry has been active since 1983 on the northern side of Highway 3 approximately 5 kilometres east of Grand Forks. Ground dolomite for agricultural applications and crushed rock for landscaping and other similar uses are being produced by VTS Quarry Ltd.

The rock is a medium-grained dolomite (2 to 4 millimetres) with phlogopite, diopside, spinel, and serpentinite as common impurities. The rock colour is yellowish, greenish, and brownish white.

A sample of approximately 1 kilogram of 1 to 2-centimetre chips collected from the stockpile has the following chemical composition:

	Per Cent
CaO	31.2
MgO	20.52
SiO_2	3.94
Al_2O_3	0.67
Fe_2O_3	0.48
LOI	42.59

The dolomite forms two parallel lenses with thickness varying from 10 to 30 metres. They strike east-west with a vertical dip. The dolomite is part of the Proterozoic Grand Forks Gneiss Series (Gunter, 1984).

LOST CREEK (MI 82F/SW-307)

White, fine-grained (1 millimetre) crystalline limestone of a sugary texture, which is mottled in places by a slightly yellow colour, is mined underground on the western side of Lost Creek, 3 kilometres north of Highway 3 between Salmo and Creston.

The mine was opened in 1982 by the International Marble and Stone Co. as a horizontal adit in a massive limestone band. Here, the limestone strikes 60 degrees and dips 45 degrees southeast. The end part of the 60-metre-long adit intersects zones light grey in colour and others with dark grey streaks. The mined rock is trucked to Sirdar, where it is ground into a variety of industrial limestone products. The composition of typical fragments collected from the freshly opened face is as follows:

	Per Cent
CaO	52.8
MgO	0.82
SiO_2	1.31
Al_2O_3	1.29
Fe_2O_3	0.15
LOI	43.25
TiO_2	0.02
MnO	0.055

The company reports the brightness of the ground product as 94.85 per cent.

The limestone is within the Reeves Member of the Cambrian Laib Formation (Fyles and Hewlett, 1959).

REDROCKY CREEK (MI 93J-015)

Dark grey to buff oolitic limestone, in places partially recrystallized, was processed into agricultural soil conditioner during 1983. On the site of a small, old quarry, Tri-Lime Resources Ltd. started a new operation to provide agricultural lime for the northeastern part of British Columbia and adjacent agricultural areas in Alberta. The material comprises fine to medium-grained (1 to 3-millimetre) oolitic limestone and contains, in places, a matrix of brown-weathering cement. The chemical composition of a 1.5-kilogram sample taken from the 1.5-centimetre-sized stockpile is:

	Per Cent
CaO	54.9
MgO	0.76
SiO_2	2.36
Al_2O_3	0.29
Fe_2O_3	0.31
LOI	42.92
TiO_2	<0.01
MnO	<0.014

The limestone forms an elliptical bluff approximately 750 metres long and up to 250 metres wide. The rock is massive and is part of the Upper Ordovician to Middle Silurian Sandpile Group (McCammon, 1969).

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ANOMALOUS RARE EARTH ELEMENTS (REE) IN THE DEEP PURPLE AND CANDY CLAIMS (82J/3E)

By Z. D. Hora and Y. T. J. Kwong

In late August, 1985, one of the authors (Z. D. Hora) made a reconnaissance visit to the fluorite property (Deep Purple and Candy claims, MI 082J/SW-018) along Rock Canyon Creek in the East Kootenays (Fig. 37-1). On this property, fluorspar is abundant in float boulders and a few scattered outcrops over an area of some 2 000 by 3 000 metres. The boulders are of two main types: (1) large fluorspar fragments, and (2) brown, crystalline carbonate rocks with disseminations, patches, or veinlets of fluorspar. In this area the outcrop is sparse and soils have a characteristic gossan-like red colour. Previous trenching revealed heavy overburden in several localities. In the adjacent sedimentary carbonate rocks of Ordovician and Devonian age, fluorite occurs as replacement impregnations and local breccia-type veins and zones. The fluorite associated with the brown carbonate is mostly dark blue to dark purple, while in the surrounding sedimentary rocks it is either colourless or bright purplish and pink.

Because of a close resemblance of the brown carbonate to rauhaugite — a ferroan dolomite which occurs in some carbonatite localities (Mountain Pass, St. Honore) — several float samples collected this summer were semi-quantitatively analysed by an emission spectrographic method and the corresponding mineralogy ascertained by powder diffractometry. The results are summarized in Table 37-1.

Four of seven samples analysed show an anomalous total rare earth element (REE) content in excess of 0.5 per cent. Bastnaesite [Ce^*CO_3F] and gorceixite [$(Ba, Ca, Ce^*)Al_3(PO_4)_2(OH)_5{\cdot}H_2O$] have been identified as the primary hosts of the REE's. Bastnaesite shows a positive correlation with crystalline dolomite, which could be iron-rich, whereas gorceixite can occur independently of the carbonate minerals; it is associated with massive fluorite in sample No. RC-85-D1. Although the abundance of fluorite in these rocks is itself intriguing, it is possible that the fluorspar mineralization is an integral part of a major intrusive carbonatite that carries a significant amount of REE's. Further laboratory and field studies are being planned to assess the plausibility of this hypothesis.

ACKNOWLEDGMENTS

We thank Mr. M. A. Chaudhry of the Analytical Laboratory for his prompt effort to produce the emission spectrographic data for us to finish this note before the publication deadline. We also thank Mr. C. Graf for the introduction to the property geology.

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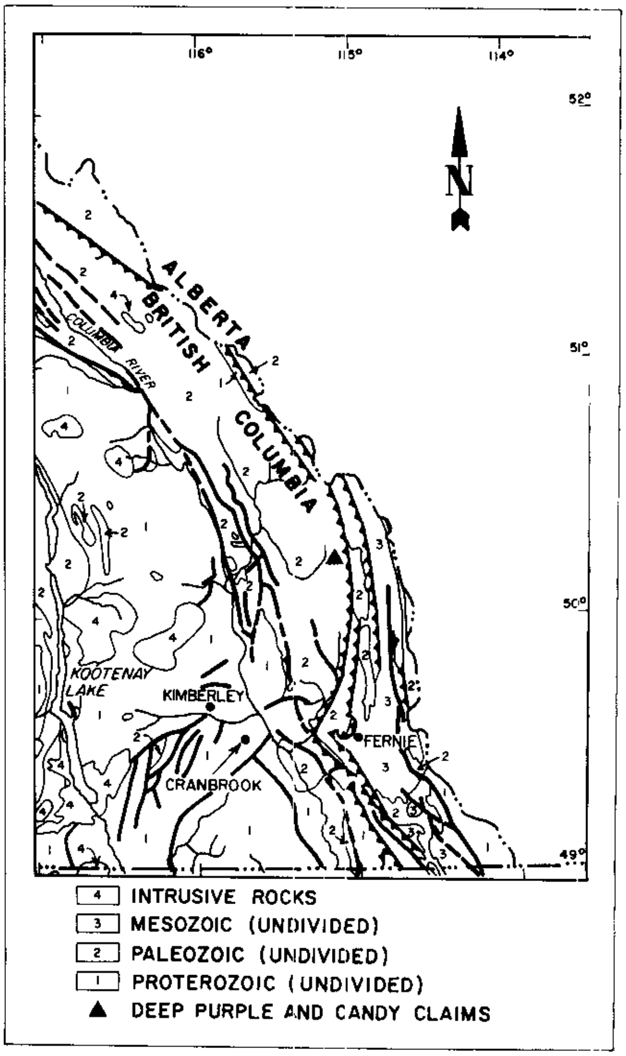

Figure 37-1. Location map for the Deep Purple and Candy claims (82J/3E).

* Usually accompanied by other lanthanide group elements.

TABLE 37-1
CHEMISTRY* AND MINERALOGY OF SELECTED FLOAT SAMPLES FROM THE DEEP PURPLE AND CANDY CLAIMS

SAMPLE No.	BRIEF DESCRIPTION	CHEMISTRY (ABUNDANCE IN PER CENT)	MINERALOGY
RC-85-A1	Dark brown carbonate with patches and veinlets of fluorite	Si <1.0, Al <1.0, Ti 0.03, Na <0.3, K <0.3, Mg 5.0, Ca 10.0, Fe 4.5, Mn 1.0, La 0.5, Ce 0.5, Nd 0.1, Nb 0.02, Y 0.05, Sr 0.1, Ba 0.5, Mo 0.02 trace Pb, Cu, V, Zr, Be, Pr, Sm, Gd, Dy, Yb, Th	Dolomite >> fluorite >> minor bastnaesite > calcite > limonite ± trace pyrite ± gorceixite
RC-85-A2	Light brown carbonate with streaks and veinlets of fluorite	Si <1.0, Al 2.5, Ti 0.02, Na <0.3, K <0.3, Mg >5.0, Ca >10.0, Fe 3.0, Mn 0.8, La >0.5, Ce >0.5, Nd 0.1, Nb 0.01, Y 0.03, Sr >0.5, Ba >1.0, Mo 0.01, P 0.5 trace Pb, Cu, V, Zr, Be, Pr, Sm, Gd, Dy, Yb, Th	Dolomite >> fluorite >> minor barite, gorceixite, calcite, talc(?) ± trace bastnaesite
RC-85-B1	Medium brown carbonate with streaks of fluorite	Si 5.0, Al 1.2, Ti 0.01, Na 0.4, K 1.2, Mg 5.0, Ca 4.0, Fe 5.0, Mn 0.5, La 0.25, Ce 0.25, Nd 0.07, Nb 0.02, Y 0.01, Sr 0.1, Ba >1.0, P >0.5 trace Pb, Cu, V, Ni, Mo, Ga, Zr, Be, Pr, Sm, Gd, Dy, Yb, Th	Dolomite >> fluorite > K-feldspar > barite > minor gorceixite, calcite, illite, talc(?), pyrite ± bastnaesite
RC-85-B2	Light-coloured carbonate with purple fluorite	Si 4.0, Al 1.5, Ti 0.03, Na 0.3, K 0.5, Mg 3.0, Ca >10.0, Fe 1.2, Nb 0.01, Ba 0.06 trace Mn, Cu, V, Ni, Sr, Y, Be	Calcite — dolomite > fluorite > quartz > K-feldspar >> trace illite ± gorceixite
RC-85-C1	Light grey, laminated carbonate with brown clots of limonite	Si 3.0, Al <1.0, Ti 0.01, Na <0.3, K <0.3, Mg 1.2, Ca >10.0, Fe 0.7 trace Mn, Cu, Ni, Sr	Bulk sample: calcite >> dolomite >> minor fluorite, quartz and K-feldspar Brown clots: dolomite >> calcite > minor quartz, K-feldspar, pyrite, and limonite
RC-85-D1	Fine-grained purplish grey massive fluorite with abundant pyrite	Si <1.0, Al 3.0, Ti 0.5, Na <0.3, K <0.3, Mg <0.1, Ca >10.0, Fe 4.0, Be 0.03, V 0.12, La 0.25, Ce 0.3, Nd 0.1, Nb 0.14, Sr >1.0, Ba >1.0, P >1.0, Mo 0.01 trace Mn, Pb, Cu, Ni, Co, Sn, Zr, W, Cr, B, Pr, Sm, Gd, Dy, Th	Fluorite >> gorceixite > pyrite > minor barite, calcite, rutile ± trace K-feldspar
RC-85-D2	Coarse purple fluorite	Si 1.0, Al 5.0, Na 0.3, K <0.3, Mg <0.1, Ca >10.0, Fe 0.4, Ba >0.5 trace Ti, Mn, Cu, Sr, Be	Fluorite > prosopite [$CaAl_2(F,OH)_8$] >> minor kaolinite

* Semi-quantitative emission spectrographic analyses performed by M. A. Chaudhry of the Analytical Laboratory.

DIATREME BRECCIAS IN BRITISH COLUMBIA* (82G, J, N; 83C; 94B)

By Jennifer Pell
Post-doctorate Fellow, The University of British Columbia**

INTRODUCTION

Over the last decade considerable interest has been expressed in diatreme breccias of possible kimberlitic affinity in British Columbia (Fipke, 1983; Fipke and Capell, 1983; Grieve, 1981 and 1982; Roberts, *et al.*, 1980; Woodcock, 1978; etc.). This interest has been heightened by the reported recent discovery of diamonds in pipes north of Golden (Dummet, *et al.*, 1985; Northcote, 1983a and 1983b).

There are three main areas in which diatreme breccias are known to occur: the Cranbrook-Invermere area, the Columbia Icefield area north of Golden, and the Williston Lake area north of Mackenzie (Fig. 38-1). In all but one case (the Cross diatreme) these breccia pipes occur in a zone within the Western and Main Ranges of the Rocky Mountains which is between 20 and 50 kilometres east of the Rocky Mountain Trench. The diatremes in British Columbia intruded the miogeoclinal sequence of platformal carbonate and clastic rocks prior to deformation. With one notable exception (the Cross diatreme) all are hosted in Cambrian to Devonian sedimentary rocks which are unconformably capped by Middle to Upper Devonian strata (Grieve, 1981; Leech, 1979; Roberts, *et al.*, 1980). The Cross diatreme is located approximately 60 kilometres east of the Rocky Mountain Trench and is hosted by Pennsylvanian sedimentary rocks.

CRANBROOK-INVERMERE AREA (82G and 82J)

Forty or more breccia pipes and related dyke rocks are known to occur within the Bull, White and Palliser River drainages, east of Cranbrook and Invermere (Pighin, Fipke, personal communication). A number were visited for this study; four were mapped in detail and will be described here.

THE SUMMER 1 DIATREME (82G/11)

The Summer 1 diatreme is one of two small intrusive bodies found at the intersection of Galbraith and Summer Creeks, approximately 40 kilometres northeast of Cranbrook. It has previously been reported on by Grieve (1981). The Summer diatreme forms a rusty weathering, 50-metre-high resistant knoll hosted in rocks mapped by Leech (1960) as Late Cambrian McKay Group. In the vicinity of the diatreme the McKay Group consists of thin-bedded grey micritic limestone, argillaceous limestone, and intraformational limestone conglomerate. In only one place is the contact between the limestones and the diatreme exposed (Fig. 38-2) and there the contact is subparallel to bedding in the limestones. This is *most likely a locally developed phenomenon, as the overall outcrop* pattern (Fig. 38-2) indicates that the body must be discordant. The limestones within 0.5 metre of the exposed contact are highly brecciated and material similar to the diatreme matrix forms veinlets in the limestone breccia. No thermal metamorphic effects are evident.

The diatreme itself is a breccia throughout. It consists of angular to subrounded clasts in a medium green to grey matrix which is locally calcareous. The matrix is foliated, with the foliation striking southerly to southwesterly and/or west to northwesterly. The matrix is predominantly chlorite and serpentine (Grieve, 1981) with or without carbonate. Rare chrome diopside xenocrysts were noted. The clast:matrix ratio is in the order of 50:50, with clasts ranging from granule to cobble size. The largest and most numerous are angular limestone, limestone conglomerate, and shale fragments up to 70 centimetres in size; these comprise 90 per cent of all the clasts. The remaining 10 per cent are buff dolostones, crinoidal limestones, red-weathering thinly laminated dolostones, granites, granitic gneisses, phlogopite-chrome diopside-marbles, fine-grained intermediate to felsic volcanic rocks, and autobreccia fragments. Resistant (silicified ?) reaction rims were noted around many clasts.

Adjacent to the main diatreme (Fig. 38-2) are possibly related dykes (and sills ?). These dykes have a very fine-grained light to medium green matrix with dark green serpentine-filled ocelli. Subrounded quartzitic and granitic clasts, up to 2 centimetres in size, are locally present.

The majority of the clasts present in the main diatreme are limestones similar to, and likely derived from, the host McKay Group. Crinoidal limestone clasts are also present. Crinoidal limestones are not characteristic of the Cambrian McKay limestones and are most likely derived from younger formations. The Summer diatreme is itself deformed (foliated) and is therefore likely to have intruded the original miogeoclinal succession prior to deformation.

If this is the case, the Summer diatreme must have intruded crinoidal limestone-bearing formations which overlay the McKay Group, and blocks of these younger rocks collapsed into the breccia pipe. This suggests that the diatreme is considerably younger than its host rocks.

THE BLACKFOOT DIATREME (82G/14)

The Blackfoot diatreme crops out at 2 650 metres elevation on ridges east of the headwaters of Blackfoot Creek, approximately 65 kilometres northeast of Cranbrook. It is a recessive, green-weathering body discordant with rocks mapped by Leech (1960) as Ordovician to Silurian Beaverfoot-Brisco Formation. Folds are evident in the host rocks in the vicinity of the diatreme, where there is a deviation from the regional steep westerly dips (Fig. 38-3). The Beaverfoot-Brisco Formation in the hangingwall is characterized by thick-bedded, massive, medium grey limestones containing rugosan corals and light grey limestones in which chain corals (favosites and halosites type) are present. Thin-bedded to laminated, non-fossiliferous, purplish weathering limestones and shaly *limestones are present in the footwall. The contacts between the* diatreme and the limestones are well exposed (Fig. 38-3). As with the Summer diatreme, no thermal metamorphic effects are evident

The Blackfoot diatreme is a composite or branching pipe-like body consisting of pale green breccia with generally small (up to 10 centimetres) subrounded to subangular clasts. The largest xenoliths present are purple-grey to buff-weathering limestones likely derived from the Beaverfoot-Brisco Formation. The clasts generally comprise up to 50 per cent of the diatreme and are predominantly

* This project is a contribution to the Canada/British Columbia Mineral Development Agreement.

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NEPHELINE SYENITE GNEISS COMPLEXES IN BRITISH COLUMBIA* (82M, N; 83D; 93I)

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INTRODUCTION

Nepheline and sodalite syenites in British Columbia can be divided into two main categories. The first comprises pre-orogenic, generally peralkaline agpaitic (agpaitic rocks have Na + K:Al ratio of >1:1, in miaskitic rocks Na + K:Al<1:1) syenites and/or nephelinites which may or may not be associated with carbonatites. Syenites of the Perry River (McMillan and Moore, 1974) and the Mount Copeland areas (Currie, 1975a; 1976) are of this type. The second group consists of miaskitic syenites which are generally post orogenic and not commonly associated with carbonatites. Miaskitic syenites are described by Currie (1976) as 'normal' alkaline rocks. The syenites at Kruger Mountain, Copper Mountain, and Galore Creek (*see* Currie, 1976) are in this class. This study deals with the agpaitic types as part of a project assessing the industrial mineral potential of carbonatites and related rocks throughout the province.

GEOLOGICAL SETTING

A northwest-trending belt, approximately 150 kilometres wide and encompassing the Rocky Mountain Trench, contains all known occurrences of peralkaline syenites in British Columbia (Fig. 39-1). Within this belt, carbonatites and diatreme breccias of possible kimberlitic affinity are also found (Pell, 1985; Pell, this volume; Hoy and Pell, this volume).

Many of the syenite gneisses occur west of the trench and are contained in high-grade multi-deformed metasedimentary rocks. In the Monashee Complex, north of Revelstoke, syenites occur at Mount Copeland (Fyles, 1970; Currie, 1975a) and in the Perry River area (McMillan, 1970; McMillan and Moore, 1974; Hoy and Pell, 1986). In both these areas the syenites occur within a pelitic and calcsilicate, paragneiss succession, the autochthonous mantling gneisses of the Frenchmans Cap dome. The age of this succession is not strictly known; however a U/Pb date of 773 Ma (Okulitch *et al.*, 1981) was obtained from the syenite gneisses at Mount Copeland. At Perry River syenites occur both with and without associated carbonatites. The syenite gneisses at Mount Copeland have no recognized associated carbonatites.

In the Northern Monashee Mountains alkalic rocks intrude metasedimentary rocks of the Hadrynian Horsethief Creek Group, marginal to the Shuswap Metamorphic Complex.

Northeast of Blue River, near Paradise Lake, nepheline syenite gneisses are associated with carbonatites (Pell, 1985) which have been dated at 325 Ma (U/Pb zircon date, Parrish and White, personal communication). On Trident Mountain, southeast of Mica Creek, very similar nepheline and sodalite syenites crop out but significant carbonatites have not been found.

East of the Rocky Mountain Trench there are three main areas in which nepheline syenites are found: the Ice River Complex, southeast of Golden (Currie, 1975b); the Kinbasket Lake/Sullivan River area, east of Trident Mountain (Fyles, 1959; Currie, 1976); and on Bearpaw Ridge, east of Prince George (Pell, 1985; Taylor and Stott, 1980). In these areas the syenites are hosted in Cambrian to Silurian sedimentary rocks which have been weakly to moderately metamorphosed and deformed. The only age dates available for these rocks are from the Ice River Complex. K/Ar dates range from 220 to 390 Ma, while whole rock Rb/Sr dates range from 220 to 280 Ma (*see* Currie 1975b). Currie (1975b) favours an age of approximately 245 Ma. Recently, a U/Pb zircon date of 380 Ma (Parrish, personal communication) was obtained. This latter date most likely represents the true age of the Ice River Complex.

A minor amount of carbonatite is present in the Ice River Complex. The sodalite syenite on Bearpaw Ridge is not associated with carbonatite. Syenites in the Sullivan River area have been poorly documented and the presence of carbonatites has not, as yet, been verified. Fyles (1959) reports "Geiger counter field tests (of the syenites) gave counts only as high as twice the normal background count. Highest counts were obtained from altered limestones near the syenite . . .". The possibility exists that the 'altered limestones' could in fact be carbonatites.

GEOLOGY AND PETROLOGY OF THE SYENITIC ROCKS

The syenitic gneisses in the Mount Copeland (Fyles, 1970; Currie, 1975a), Perry River (McMillan, 1970; McMillan and Moore, 1974), and Ice River (Currie, 1975b) areas have been described in detail and need not be reviewed here. The first two areas have been sampled for zircon extraction, additional geochemistry, and detailed petrography (scanning electron microscopy) but results are not yet available. Fieldwork was concentrated in the Trident Mountain area (1985 field season) and at Paradise Lake and Bearpaw Ridge (1984 field season).

TRIDENT MOUNTAIN (82M/16)

Nepheline syenites were first recognized in the Trident Mountain area by Wheeler (1965) and subsequently mapped by Perkins (1982). A few days were spent sampling and remapping these syenitic gneisses during the field season. The area is very rugged, the syenites are exposed on cliffs at 2 200 to 3 000 metres elevation adjacent to large icefields.

The syenite gneisses at Trident Mountain (Fig. 39-2) are white to grey weathering, medium grained and composed of pink and white feldspars (orthoclase and plagioclase), nepheline and biotite with locally abundant amphibole, sodalite, sphene, ilmenite, apatite, and zircon (crystals up to 1.5 centimetres in size). Very coarse-grained pegmatitic segregations are sporadically developed. They are concordant with hosting psammitic and kyanite-bearing pelitic schists of the Hadrynian Horsethief Creek Group and are exposed in the core of an early isoclinal antiform which is refolded by later upright to overturned structures (Perkins, 1982). The syenites have compositional layering and a foliation parallel to the margins of the body and also parallel to the axial plane of the antiform and the

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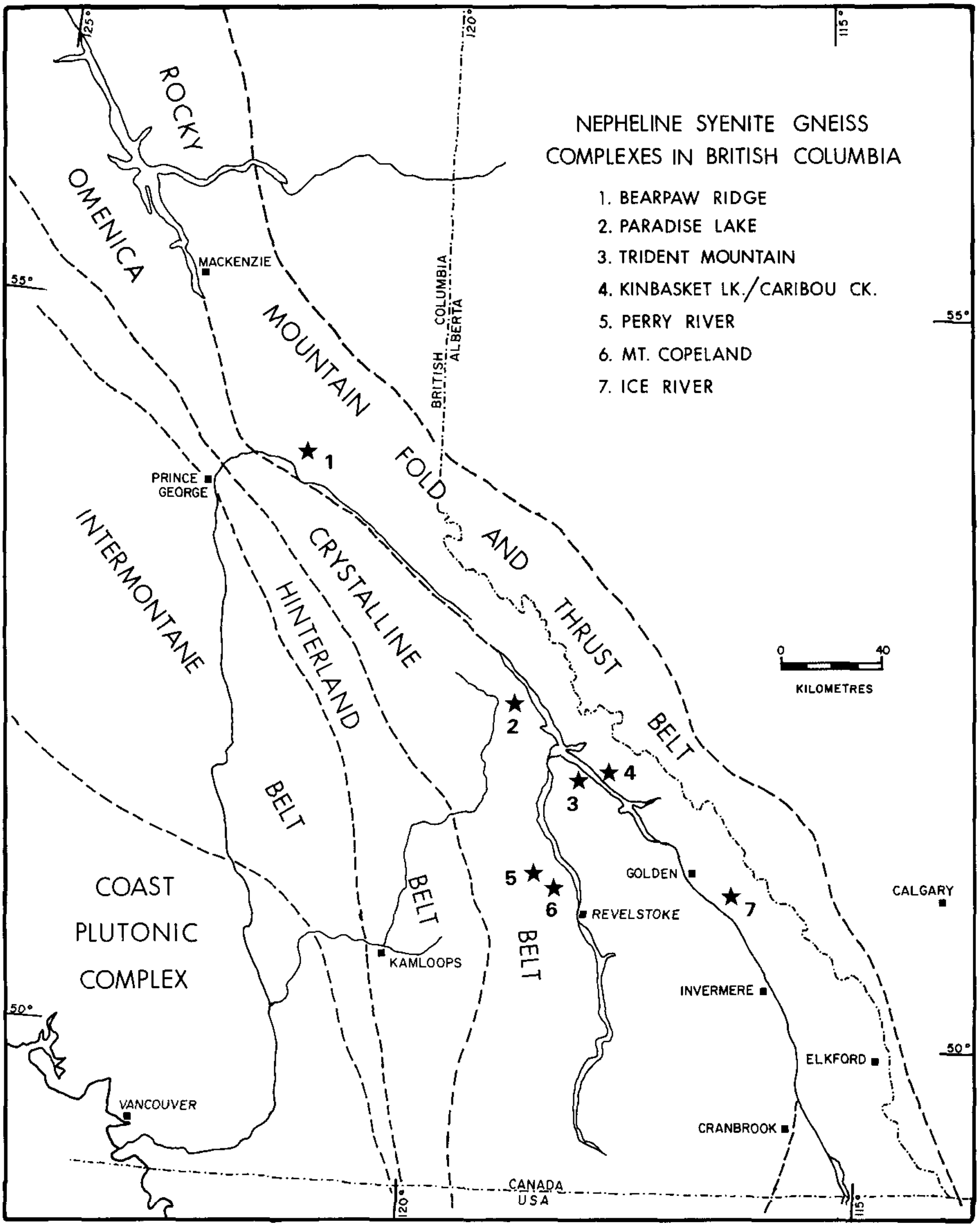

Figure 39-1. Distribution of nepheline syenites and related rocks in British Columbia.

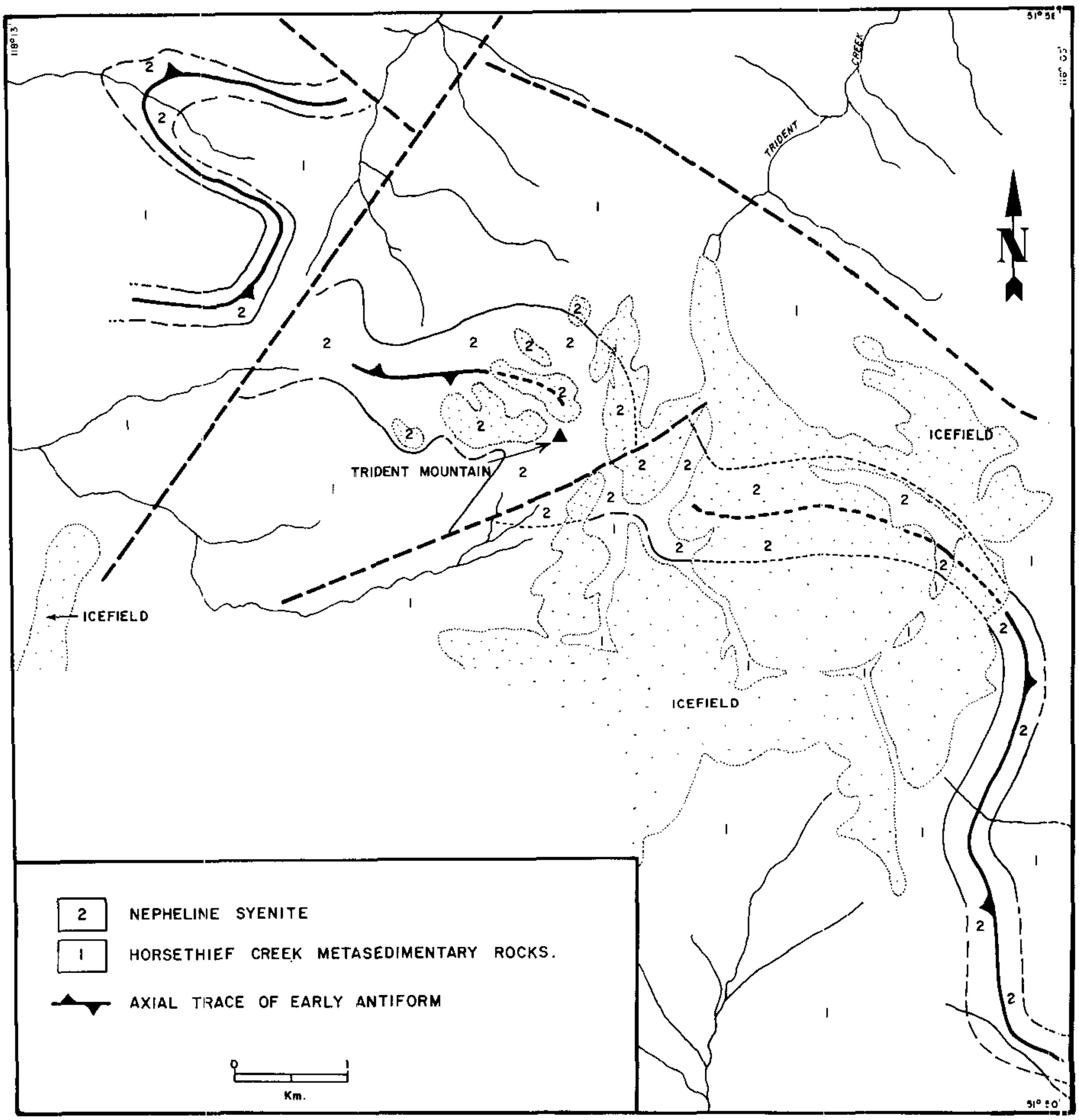

Figure 39-2. Geology of the Trident Mountain area, Selkirk Mountains, British Columbia (modified from Perkins, 1983).

Plate 39-1. Trident Mountain, banded syenite.

Plate 39-2. Trident Mountain, leucocratic syenite cutting more masfic phase.

Plate 39-3. Mafic inclusions in a biotite-rich phase of the Trident Mountain syenite.

bedding in the metasedimentary rocks. The layering (Plate 39-1) is defined by leucocratic (biotite approximately 10 per cent) and melanocratic (biotite approximately 40 per cent) phases with occasional calcareous layers (sovite sweats ?). Mafic gneisses rich in amphibole, biotite, and sphene are also present at Trident Mountain but were not observed in outcrop. These mafic gneisses are cut by dykes of leucosyenite (Plate 39-2). Contacts between mafic gneisses and syenite dykes are sharp. Xenoliths of country rock or mafic gneisses were also observed (Plate 39-3). They have very diffuse borders suggesting reaction with or partial digestion by the syenitic magma. Neither dykes nor syenite crosscutting host metasedimentary rocks were observed.

The nepheline and sodalite syenite gneisses at Trident Mountain are very similar to those at Paradise Lake (Pell, 1985), 90 kilometres to the northwest; however, at Trident Mountain they intrude a slightly lower part of the Horsethief Creek Group stratigraphic succession.

PARADISE LAKE (83D/6)

The syenite gneisses at Paradise Lake have been described previously (Pell, 1985) so only a brief review and some additional notes on their petrography will be presented here. The Paradise Lake syenites are white to grey-weathering, medium-grained, layered and foliated gneisses concordant with hosting Hadrynian Horsethief Creek Group rocks. Layering and foliation are parallel to the margins of the gneiss, to bedding in surrounding metasedimentary rocks, and to the regional foliation. The contact between the syenite and metasedimentary rocks is, in places, gradational.

The syenites are typically composed of 25-35 per cent plagioclase (An_30-40), 25-35 per cent orthoclase, 15-30 per cent nepheline, 7-15 per cent biotite, and 1-10 per cent muscovite. Accessory minerals may include calcite, pyrrhotite, ilmenite, magnetite, cancrinite, sodalite, zircon, pyrochlore [$(Na,Ca,Ce)_2(Nb,Ti,Ta)_2O_6(OH,F)$] and uranopyrochlore.

BEARPAW RIDGE (93I/4)

Sodalite syenite on the northwest end of Bearpaw Ridge intruded volcaniclastic rocks of the Silurian Nonda Formation prior to the Jura-Cretaceous Orogeny. It was first mapped by Taylor (1980) and subsequently remapped by Pell (1985). During the 1985 field season the syenite was sampled to allow separation of zircons for age determinations.

The syenite occurs in low rounded outcrops on the crest of Bearpaw Ridge north of Sinclair Mills. It is a medium-grained rock with a white to grey fresh surface. It is composed of 40-50 per cent plagioclase, 30-40 per cent orthoclase, 5-10 per cent mafic minerals (either secondary chlorite after biotite and epidote or amphibole and aegirine and biotite), 2-5 per cent magnetite and local ilmenite. Accessory minerals include sodalite, muscovite, zircon, allanite, apatite, monazite, thorite ($ThSiO_4$), and pyrochlore.

A second, distinctly different and clearly post-orogenic syenite crops out on the lower slopes of Bearpaw Ridge along an old logging road north of Sinclair Mills. It is pink to white weathering and has a pink fresh surface. The primary constituents are randomly oriented coarse feldspars, often greater than 5 millimetres in size, which make up 70-80 per cent of the rock (20-25 per cent plagioclase, 30-35 per cent orthoclase, and 10-20 per cent microperthite). Other phases present are aegirine-augite (10 per cent), hornblende (5-10 per cent) rimmed by a prussian blue sodic amphibole, and magnetite (5-8 per cent). Accessory minerals include apatite, biotite, ilmenite, pyrite, arsenopyrite, sphalerite, barite, and monazite. This syenite is lithologically similar to Cretaceous alkaline intrusions and dissimilar to the pre-orogenic sodalite syenite on the crest of Bearpaw Ridge.

CONCLUSION

There are many lithologic similarities between the various syenites included in this study. Biotite is the most commonly developed mafic mineral, except at Ice River and in some phases of the Mount Copeland gneisses where pyroxenes dominate. Peralkaline minerals such as sodalite are common. Accessory phases often include zircon, sphene, and pyrochlore.

There were apparently at least two periods during which the intrusion of peralkine and carbonatite-related syenites occurred. The first is around 770 Ma but is based on a single U/Pb age; it may be related to a Hadrynian rifting or extensional episode. The second is apparently much younger, 380-325 Ma and suggests that extensional tectonics were active along the western North American continental margin during Devonian to Mississippian times. Further work will include detailed petrography, geochemistry, and age dating in order to assess the economic potential of syenite complexes.

ACKNOWLEDGMENTS

I would like to thank the Ministry for providing me with capable field assistant (Olga Ijewliw) and the logistic support for this project. I would also like to acknowledge the Canada/British Columbia Mineral Development Agreement and the Natural Science and Engineering Research Council for additional financial support.

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PRELIMINARY REPORT LANG BAY GERMANIUM PROSPECT* (92F/16W)

By G. V. White

INTRODUCTION

The Lang Bay germanium prospect (MI 92F-137) is located 15 kilometres southeast of Powell River. Renewed industry interest prompted the Geological Branch to re-evaluate this property. The purpose of our seven-day program was to map the area underlain by this small sedimentary outlier and examine the beds with reported anomalous germanium values; the aim was to assess the germanium potential at Long Bay and to suggest other areas with possible germanium concentrations. With the documentation and sampling of available exposures now completed, a further study will concentrate on:

(1) age determination and detailed petrographic composition of Lang Bay sediments;

(2) a study of silicate mineral alteration and distribution of germanium within the Lang Bay basin.

PROPERTY HISTORY

In 1949, the British Columbia Ministry of Mines reported results of a reconnaissance examination of coal samples from Lang Bay; germanium values in ash were reported as high as 1 per cent. This report led Dr. F. C. Buckland of Taiga Mines Ltd. to stake 136 claims in the Lang Creek area. Subsequently, the company drilled 7 auger holes and 19 churn holes near the northeast edge of the property to examine the coal strata at depth, and excavated 6 trenches and a few small pits.

Reported results (Skerl, 1959) indicated intersections of:

1.4 metres with 68 grams GeO_2 per tonne,
1.4 metres with 136 grams GeO_2 per tonne,
0.6 metres with 139 grams GeO_2 per tonne,
0.7 metres with 90 grams GeO_2 per tonne.

Fargo Oil Corporation of Vancouver acquired the property in 1981 and has carried out laboratory studies and benefication tests on samples recovered from two re-opened trenches (Fig. 40-1).

REGIONAL GEOLOGICAL SETTING

The Lang Bay germanium prospect is in a small outlier of sedimentary rocks on the western edge of the Coast Plutonic Complex. The sediments consist of poorly to well-indurated mudstones, siltstones, shales, sandstones, conglomerates and coal. The outlier forms a small basin approximately 3 kilometres wide by 6 kilometres long; thickness is undetermined. The sedimentary rocks are relatively undisturbed; beds strike northwest and dip up to 20 degrees to the southwest.

Preliminary examination of palynomorphs extracted from Lang Bay mudstones suggests the sediments are Late Cretaceous in age (personal communication, Dr. G. E. Rouse), and may be equivalent to the Chuckanut Formation of the Fraser Lowland. The basin is surrounded and underlain by granitoid intrusives of the Coast Plutonic Complex of Jurassic-Cretaceous age.

PROPERTY GEOLOGY

Except along Lang Creek almost all of the claim area is covered by glacial overburden. A traverse along Lang Creek from Highway 101 to the power transmission line, located 1.6 kilometres to the north, provided the best outcrop exposure on the property. A generalized section illustrating the section exposed along this portion of the creek is shown on Figure 40-2. The following sediments were examined along Lang Creek.

(1) Argillaceous mudstones to siltstones are dark brown to black, form beds up to 5 metres thick, and are moderately to well consolidated. They are calcareous and in places contain thin wisps of coal. Contacts with other units are conformable and well defined. The sediments are crossbedded and often interbedded with medium to coarse sandstones. No remnant fossils or worm burrows were observed in the mudstone or siltstone beds.

(2) Arkosic sandstones are medium to coarse grained (0.5 to 2.0 millimetres) and consist of re-worked quartz and feldspar. They are moderately to well indurated and form beds up to 5 metres thick. Layers are crossbedded, exhibit soft sediment slumping in places and contain coalified wood fragments. Contacts between beds of sandstone and other, more pelitic units are sharp and conformable. No marine fossils, worm burrows, or remnant grasses were observed in the sandstones.

(3) Conglomerates form several 2 to 3-metre thick layers approximately halfway between Highway 101 and the powerline along Lang Creek. Chert and quartzite pebbles in the conglomerate are randomly oriented and lenticular to rounded. The largest pebbles measure 15 centimetres long by 3 centimetres wide. The matrix consists of moderately to well-consolidated, medium to coarse-grained, feldspathic brown sandstone.

(4) Coal comprises infrequent and isolated lenses observed in coarse sandstone and argillaceous siltstone units along Lang Creek. The lenses are generally less than 3 metres in length and range from 1 to 4 centimetres in width. Petrographic determinations using the minimum-maximum reflectance of vitrinite in oil technique established the coal as lignite. Individual coal lenses are probably remnants of isolated logs or branches which were washed into unconsolidated sand and siltstone units and later coalified. According to previous reports, coal is the main carrier of high germanium values (*Minister of Mines, B.C.*, Ann. Rept., 1949).

SUMMARY

The Lang Bay outlier consists of interbedded chert-quartzite conglomerates, arkosic sandstones, siltstones, mudstones, and coals. The sediments were deposited in a fluvial environment of varying intensity which is reflected in the generalized geological section illustrated on Figure 40-2.

* This project is a contribution to the Canada/British Columbia Mineral Development Agreement.
British Columbia Ministry of Energy, Mines and Petroleum Resources, Geological Fieldwork, 1985, Paper 1986- .

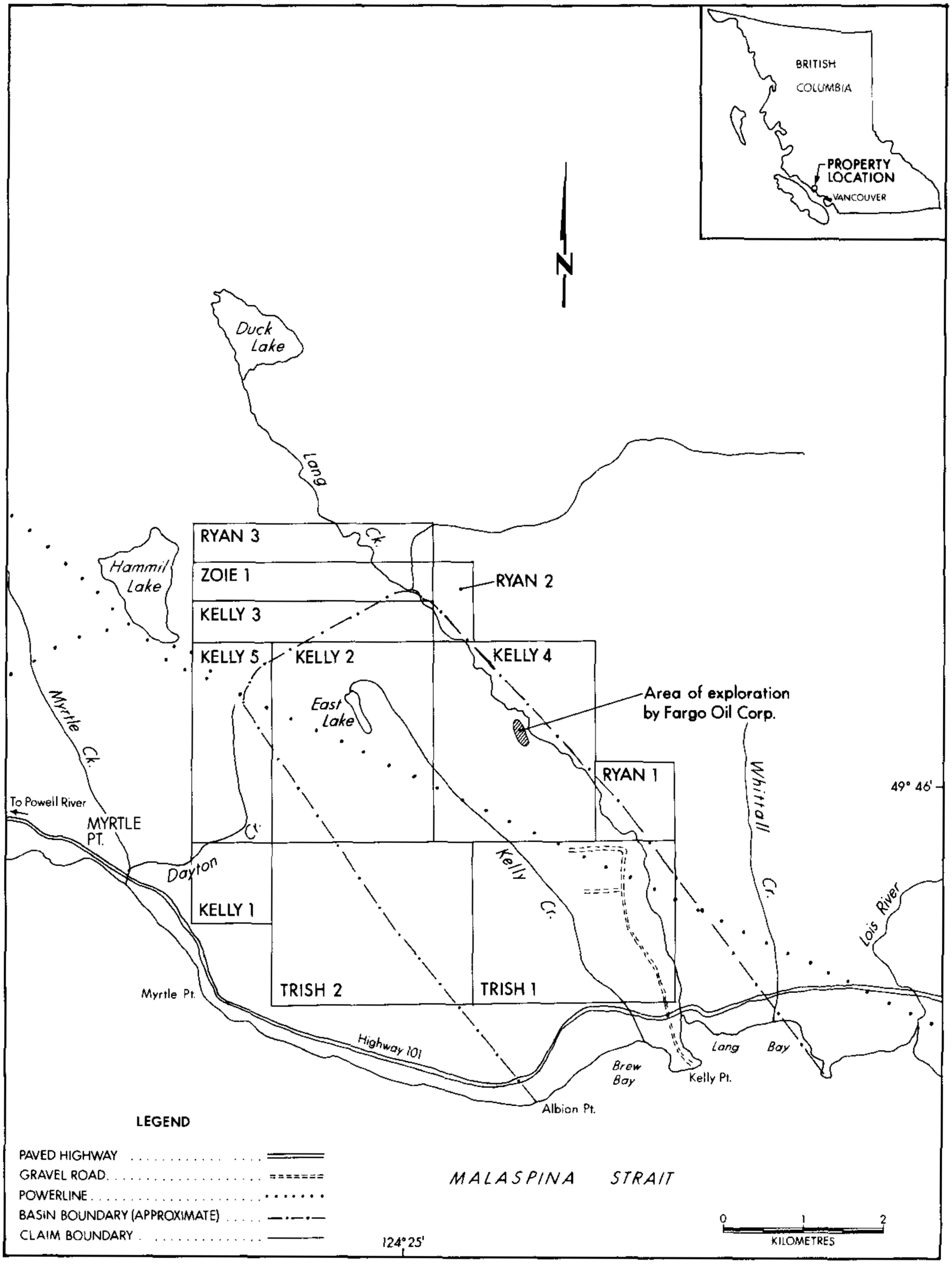

Figure 40-1. Lang Bay germanium prospect.

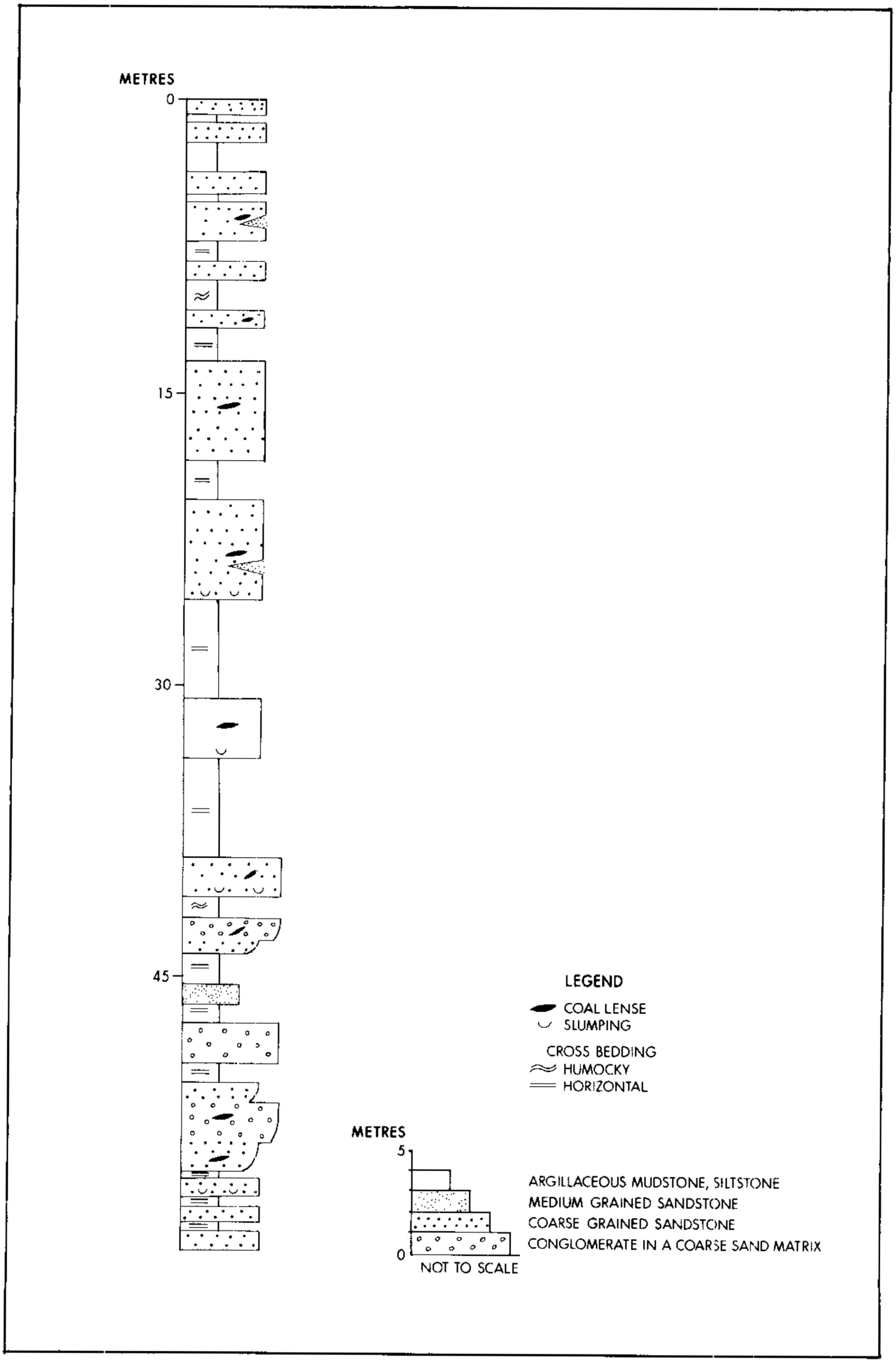

Figure 40-2. Lang Creek, generalized section.

Past exploration near the northeast edge of the outlier has identified coal-bearing sediments of variable thickness, which have anomalous germanium values, and which extend over at least a 350-metre distance.

These beds which lie immediately above basement rocks belonging to the Coast Plutonic Complex have been the main exploration target. If the beds host economic grades of germanium and a successful recovery process can be developed, then excellent potential for expanding the reserves westward exists. Coal-bearing sediments situated stratigraphically above these beds may host significant germanium values as well, although further investigation is required to assess their potential.

Other sedimentary outliers and basins in British Columbia having a similar depositional environment to Lang Bay may also contain sediments anomalous in germanium.

ACKNOWLEDGMENTS

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GEOLOGY AND MINERAL POTENTIAL OF THE CHILKO-TASEKO LAKES AREA* (92O/4,5; 92J/13; 92K/16; 92N/1)

By G. P. McLaren

INTRODUCTION

The Chilko-Taseko Lakes area covers a section of rugged, mountainous terrain located 230 kilometres north of Vancouver. The mineral potential of this area is largely undefined at present, but significant gold, copper, and molybdenum mineralization in adjacent areas of similar geology suggests the potential might be high. Sporadic exploration attempts have been made in the area in recent years, with localized successes. In order to better define the mineral potential, an eight-week field project, conducted in July and August 1985, consisted of 1:50 000-scale geological mapping, lithogeochemical sampling, and geochemical stream silt sampling of all minor and major drainages. A four-person crew, operating in a mobile fly camp mode and utilizing considerable helicopter time, was required to complete the project.

The stream silt sampling program covered an area of 1 200 square kilometres. Mapping and lithogeochemistry within this area varied in detail according to accessibility, complexity of geology, and indications of mineralization. All geological and geochemical data are being compiled for release as an open file series of maps as a guide to the mineral potential and future prospecting of the area.

PREVIOUS WORK AND REGIONAL GEOLOGY

Regional geologic compilations in the Taseko Lakes map sheet (92O; Tipper, 1978) and the Mount Waddington map sheet (92N; Roddick and Tipper, 1985) reveal a sequence of Middle Triassic to Upper Cretaceous volcanics and sediments lying along the northeastern margin of the Coast Plutonic Complex. The stratified rocks are cut by numerous, northwesterly trending, right lateral transcurrent faults, some of which have displacements in excess of 100 kilometres (Tipper, 1969).

Jeletzky and Tipper (1968) defined the Jurassic and Cretaceous stratigraphy in the Taseko Lakes map-area on the basis of fossil and lithologic correlations. They concluded that these rocks have been deposited in the northwest-trending Tyaughton Trough and that the trough was bounded by intermittent landmasses on the southwest and northeast. The study area is underlain by a sequence of Lower and Upper Cretaceous volcanics and sediments that accumulated on the southwestern flank of the Tyaughton Trough and that are now in contact with the Coast Plutonic Complex. The stratified rocks have been correlated in part with the Relay Mountain, Taylor Creek, and Kingsvale Groups.

Regional geochemical stream water and silt surveys, conducted by the Ministry, have been completed for map sheets 92O (1979) and 92J (1981). Sample site density of these surveys averaged one per 14 square kilometres.

GENERAL GEOLOGY

Figure 41-1 outlines the general geology in the Chilko-Taseko Lakes area mapped in this study. A limited amount of data from assessment reports and Geological Survey of Canada mapping has been incorporated into this map. In the following discussion, rock units are defined on a lithological basis alone; possible correlations are discussed afterwards. This stratigraphy may be subject to revision, pending identification of marine fossil collections obtained from at least four different units.

STRATIFIED ROCKS

UNIT 1

Exposures of Unit 1 occur in a thin, discontinuous horizon south of Rufous Mountain, where they are cut by quartz diorite of the Coast Plutonic Complex. This clastic sedimentary section consists of interbedded, dark-grey argillite, quartz-rich greywacke, and chert pebble conglomerate. The greywackes have yielded a limited collection of marine pelecypods and belemnites. The sediments are interbedded with overlying tuffs to the north and are cut by quartz diorite to the south. A sediment horizon mapped by Tipper (1978) south of Mount Goddard is likely correlative with this unit (Fig. 41-1).

UNIT 2

Conformably overlying Unit 1 is a section of volcanic pyroclastics and flows that are very poorly bedded and contain no extensive sedimentary horizons. Purple, grey, and green, generally matrix-supported fragmental tuffs containing angular to subrounded clasts up to 25 centimetres across, form massive, thick horizons that are intercalated with finer lapilli and crystal tuffs as well as some vesicular flows. Crystal-rich tuffaceous material comprises the matrix in the fragmental rocks. The pyroclastics are dominantly composed of feldspar, plus hornblende or augite, crystal tuffs of andesitic to basaltic composition. Fragmental units are intraformational. Chlorite and epidote alteration is common, often being associated with carbonate-quartz veining that weathers a distinctive brown colour. Also present in this unit are felsic tuff and dacitic-rhyolitic members, locally with quartz eyes. A prominent gossan containing considerable pyrite and pyrrhotite has developed at one such locality, 7 kilometres south of Mount Goddard.

A thrust sheet of this volcanic unit overlies Unit 5 in the Mount Goddard area. Here the fragmentals include irregular bodies of white, laharic deposits which consist of a chaotic mixture of subangular to rounded volcanic debris dispersed through a white, muddy, ash-like matrix. Horizons of well-bedded waterlain tuffs are also present in this area.

The upper contact of Unit 2 was only observed in the Tchaikazan Valley where it appears to conformably pass into clastic sediments and volcanics of Unit 5.

UNIT 3

Unit 3 occurs in a fault-bounded, northwesterly trending belt from the lower Tchaikazan River to the Yohetta Lake area. It is dominated by purple-weathering lapilli and heterolithic fragmental pyroclastics. Poorly sorted lithic fragments, up to 25 centimetres in size, include dark grey to purple, hornblende-feldspar crystal tuff, dark grey feldspar porphyry flows, green chloritic hornblende porphyry, and some green, strongly epidotized tuff. Argillaceous to arkosic sedimentary fragments and dioritic intrusive fragments are also present. The matrix material is a feldspar-rich crystal tuff containing sufficient finely disseminated hematite to give the over-

* This project is a contribution to the Canada/British Columbia Mineral Development Agreement.

British Columbia Ministry of Energy, Mines and Petroleum Resources, Geological Fieldwork, 1985, Paper 1986-1.

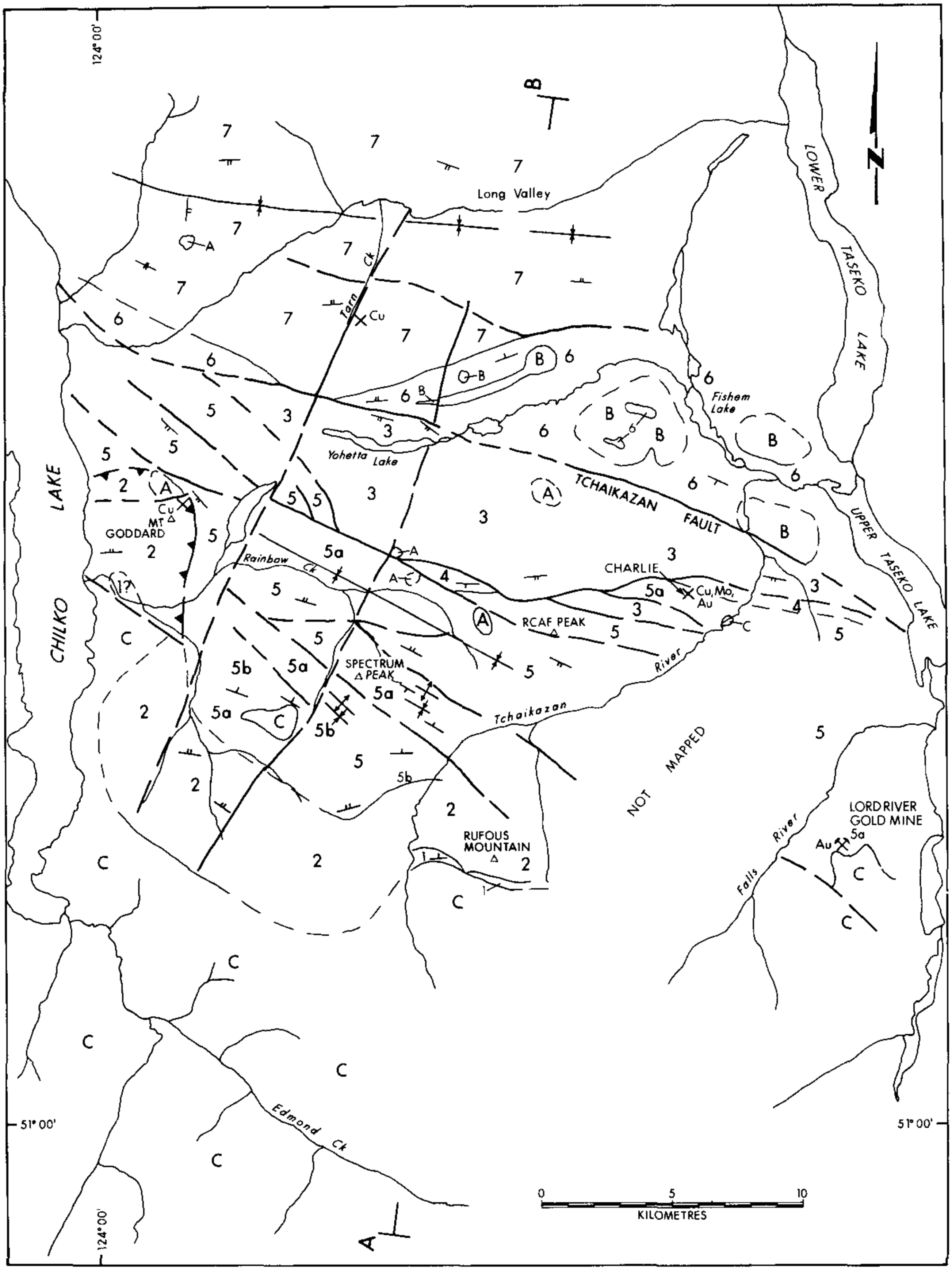

Figure 41-1. Geology of the Chilko-Taseko Lakes area (for legend, *see* Fig. 41-2).

LEGEND

STRATIFIED ROCKS

7	ANDESITIC TO BASALTIC PYROCLASTICS, FLOWS, AND VOLCANIC SEDIMENTS
6	ARGILLITE, QUARTZ SANDSTONE, ARKOSE, CONGLOMERATE; MINOR VOLCANIC FLOWS AND TUFFS
5a	DACITIC TO BASALTIC PYROCLASTICS, FLOWS, BRECCIAS, AND VOLCANIC SEDIMENTS
5b	ARGILLITE, SILTSTONE, SANDSTONE, CONGLOMERATE
5	UNDIFFERENTIATED 5a, 5b
4	BLACK ARGILLITE, SILTSTONE, SANDSTONE, MINOR TUFFS AND FLOWS
3	PURPLE ANDESITIC PYROCLASTICS AND BRECCIAS; MINOR FLOWS
2	DACITIC TO BASALTIC PYROCLASTICS AND FLOWS; MINOR RHYOLITE TUFFS
1	ARGILLITE, GREYWACKE, CONGLOMERATE, MINOR TUFFS

INTRUSIVE ROCKS

A	DIORITE STOCKS: HORNBLENDE DIORITE
B	FELSITES: FELDSPAR AND BIOTITE FELDSPAR PORPHYRY
C	COAST PLUTONIC COMPLEX: GRANODIORITE, QUARTZ DIORITE

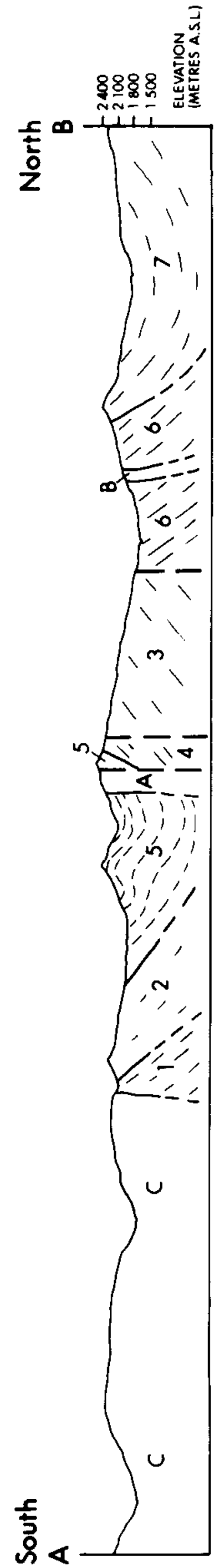

Figure 41-2. Geological cross-section, A-B, in Figure 41-1.

Plate 41-1. Volcanic breccia/conglomerate overlain by andesitic lithic fragmental tuff, Unit 5a (hammer 40 centimetres long).

Plate 41-2. Crossbedded quartzose sandstone, Unit 5b (hammer head 13 centimetres long).

all purple colour to the unit. Brown-weathering hornblende feldspar porphyry flows of andesitic to basaltic composition form resistant ridges within the pyroclastics. These flows are typically fine grained and vesicular. The faults bounding this unit appear to be major transcurrent structures. The southern boundary fault is exposed in two locations: one is a strongly sheared fault breccia consisting of altered volcanic fragments and lithic blocks set in a white carbonate matrix; the second is a gossanous shear zone 25 metres wide containing silicified and bleached volcanic fragments with vuggy quartz-carbonate veins carrying pyrite, pyrrhotite, and minor chalcopyrite. The northern bounding fault has been called the Tchaikazan fault by Tipper (1978).

Unit 3, appears to be correlative with similar Lower Cretaceous volcanics in the Mount Waddington map-area (Unit 13; Tipper 1969), however the fault-bounded and unfossiliferous nature of these rocks renders their position in the straatigraphy uncertain at present. They may represent a subaerial facies equivalent of the volcanics of Unit 2.

UNIT 4

The fine clastic sediments of Unit 4 are distinctive for their rich marine fossil fauna, evident in at least six locations within the narrow wedges of exposed strata. Sedimentary facies are closely interbedded and include thinly laminated grey siltstone to black argillite as well as concretionary brown siltstones to arkosic sandstones in beds often a few metres thick. Limy sections or impure limestones are common. Tuffaceous volcanic horizons are present, particularly adjacent to the contact with the overlying volcanics of Unit 5. Hornblende-feldspar crystal and lapilli tuffs comprise the volcanics, and epiclastic volcanic material, including volcanic derived conglomerate, is mixed with the sediments.

The contact with overlying Unit 5 rocks is seen to be a fault in some locations but elsewhere Unit 4 sediments appear to pass into a coarse volcanic conglomerate with interbedded concretionary greywacke which in turn passes into fragmental volcanics of Unit 5. Hence this unit may conformably underlie Unit 5. For the most part the contact is not exposed due to faulting. If the contact is conformable, Unit 4 would be correlative with volcanics in the upper part of Unit 2.

Unit 4 sediments are richly fossiliferous with a diversity of shelly fauna present, including brachiopods, belemnites, ammonites, and bivalves. Some fossilized wood fragments are also present.

UNIT 5

Unit 5 is composed of intimately interbedded volcanic and volcaniclastic rocks (Unit 5a) and clastic sedimentary rocks (Unit 5b). There are regular gradations from tuffaceous volcanics to epiclastics to greywackes, hence Units 5a or 5b are mapped according to the dominant lithology present. Rapid facies changes inhibit the definition of extensive stratigraphic horizons.

UNIT 5a

The volcanic members of Unit 5 comprise multi-coloured dacitic to basaltic pyroclastics, vesicular flows, and flow breccias. Crystal, lapilli, and lithic tuffs predominate. Lithic fragments are generally intraformational and are set in a fine, feldspar crystal tuff matrix. These rocks are often layered, but are generally poorly sorted. Flow rocks are fine grained, green to grey, and commonly contain calcareous or chloritic amygdules and epidote knots. Chalcedonic amygdules and red or green jasperoidal lenses are also present in some flows. A distinctive grey vesicular flow horizon, extending from the Tchaikazan Valley to southwest of Spectrum Peak, locally contains 1-3 per cent pyrite or pyrrhotite in silicified and fractured sections. Interflow breccias are common in this horizon. A prominent blocky assemblage of flows, flow breccias, and epiclastics overlies the vesicular flow unit (Plate 41-1). Felsic members of the unit tend to be fine grained, pale grey tuffs that are moderately siliceous and contain thin horizons with fine quartz eyes; however, they comprise a small proportion of the total volcanic section.

UNIT 5b

Sedimentary lithologies in Unit 5 include dark grey argillites, siltstones, brown greywackes, and chert pebble conglomerate as well as minor quartzose sandstone and impure limestone. The base of Unit 5 in the Tchaikazan Valley is marked by conglomerate and arkosic sediments from 2 to 20 metres thick that conformably overlie volcaniclastics of Unit 2. The conglomerates are white to pale grey and composed of cherty or siliceous pebbles set in a calcareous, sandy matrix. Argillaceous and volcanic pebbles become more common as this layer grades into the overlying or underlying volcanics. Carbonized tree trunk fragments have been recovered from within the conglomerate.

Elsewhere in Unit 5, dark grey argillites and grey to brown siltstone and greywacke are typically well bedded and locally display grading or cross-bedding. A cross-bedded quartzose sandstone with interbedded conglomerate layers (Plate 41-2) located 4 kilometres west of Spectrum Peak gives an upright attitude and a westerly source direction. Approximately 80 per cent of the clasts in the conglomerate are cherty or quartzose pebbles, while the remaining 20 per cent are split between other sedimentary and volcanic lithologies. This is a distinctive member of Unit 5; it is not derived locally, but likely records an erosional event to the west in the Coast Mountain plutonics.

An extensive marine fossil collection of ammonites, belemnites, brachiopods, and gastropods, plus fossilized wood fragments, were collected from Unit 5 sediments north of Mount Goddard. A solitary gastropod was collected from an argillite-felsic volcanic contact in the Tchaikazan Valley. Two thin limestone members were also sampled for microfossil analysis.

UNIT 6

Unit 6 comprises a sequence of interbedded argillite, greywacke, quartzose sandstone, and pebble conglomerate that is exposed from the lower Tchaikazan Valley to the Yohetta Valley. Impure limy sections are common and large limy concretionary boulders weather out of the sandstone and conglomerate. Conglomeratic members range from clast to matrix supported, with clasts being dominated by quartzose or cherty lithologies but argillite, greywacke, and minor volcanic pebbles are also present. The upper members of the unit in Yohetta Valley are well bedded, displaying grading, cross-bedding, and channel scour marks that indicate an upright sequence with a westerly source. A suite of marine bivalves, gastropods, and belemnites was collected from an argillaceous horizon north of Yohetta Lake. Thin volcanic horizons are present within the sediments, forming resistant ridges of grey-green feldspar-hornblende porphyry flows with minor tuffs.

This unit has an abrupt but apparently conformable contact with overlying Unit 7 rocks, however it is bounded on the south by the Tchaikazan fault. Strongly opposing dips in Units 6 and 3 across this fault suggests a significant displacement may have occurred relative to other faults in the area.

UNIT 7

Volcanic lithologies of Unit 7 include a variety of multi-coloured andesitic to basaltic pyroclastics and flows. No extensive sedimentary units were mapped, but a few layered waterlain tuffs and volcanic epiclastics are present. Andesitic volcanic breccias and tuffs, generally purple, brown, or green in colour, dominate the section. Lithic tuffs are intraformational. Flow rocks are grey to brown, massive, feldspar-hornblende porphyries of andesitic to basaltic composition. Magnetite and carbonates are common accessories. Individual flows are normally less than 5 metres thick and interflow breccias are common.

In the northwest corner of the study area, a relatively flat-lying volcanic conglomerate, with well-rounded boulders up to 1 metre across, forms a distinctive, thickly bedded member of Unit 7. The clasts are derived from the surrounding volcanics or from sub-volcanic intrusives of similar composition. Interbedded tuffaceous members, including some very finely laminated waterlain tuffs, occur in discontinuous horizons.

STRATIGRAPHIC CORRELATIONS

The rocks of the Chilko-Taseko Lakes area, as previously mapped by Tipper (1978), were correlated in part with Cretaceous strata of the Relay Mountain, Taylor Creek, and Kingsvale Groups. Relay Mountain and Taylor Creek rocks are essentially sedimentary units that accumulated in the Early Cretaceous Tyaughton Trough. Extensive volcanics of the Late Cretaceous Kingsvale Group marked an end to the period of dominantly sedimentary deposition. Similar units were mapped to the northwest in the Mount Waddington map-area (Tipper, 1969).

The preponderance of volcanic lithologies interbedded with the sediments between Chilko and Taseko Lakes has long posed a problem in correlating these rocks with the dominantly sedimentary formations to the southeast that accumulated in the axial regions of the Tyaughton Trough.

Portions of the Cretaceous stratigraphy in the Chilko-Taseko Lakes area are lithologically similar to rocks exposed in the Mount Raleigh pendant, 45 kilometres to the southwest (Woodsworth, 1979). Woodsworth has suggested correlations of the Mount Raleigh area lithologies with rocks of the Chilko-Taseko area as well as with rocks of the Gambier Group (Roddick, 1965) and the Cheakamus Formation (Mathews, 1958) in the southern Coast Mountains. Even though correlations based on lithologic similarities across these distances may be tenuous, they do provide useful comparative stratigraphic frameworks.

The Mount Eurydice Formation in the Mount Raleigh strata includes andesitic to dacitic tuff and breccia, conglomerate, and lesser pelitic schist, and feldspar porphyry. Plutonic clasts in the conglomerates record an episode of exposure and erosion of granitoid rocks to the west. The overlying Styx Formation consists of graphitic arenaceous and pelitic rocks.

The Gambier Group has been broadly divided into three units (Roddick, 1965): (1) a lowest unit of andesitic flows and pyroclastics with granitic cobble conglomerate and breccia, (2) a middle unit of argillite, slate, arkose, and quartzite, and (3) an upper unit of interbedded andesite and slaty tuff, although there is some evidence to suggest that the upper unit is a repetition, by thrusting, over the lowest (Woodsworth, personal communication). The Cheakamus Formation is a Lower Cretaceous sedimentary unit with a basal plutonic-clast conglomerate overlain by a thick succession of greywacke, sandstone, and argillite.

Proposed correlations of units mapped in the study area with Cretaceous stratigraphy elsewhere in parts of southwestern British Columbia are summarized in Table 41-1.

In the Chilko-Taseko Lakes area, the lowest exposed rocks (Units 1, 2, 3) comprise a basal clastic unit overlain by dacitic to basaltic pyroclastics and flows. Based on similar lithologies and fossil descriptions, these units appear to be correlative with Hauterivian (mid-Early Cretaceous) and (?) younger volcanics and sediments in the Mount Waddington map-area (Units 12-15; Tipper, 1969). Hauterivian fossils have previously been obtained from the clastic sedimentary rocks of Unit 4 (Jeletzky and Tipper, 1968), confirming the Early Cretaceous age of this section. Units 1-4 are possibly correlative with the lower Gambier unit and the Mount Eurydice Formation. An Early Cretaceous age (Hauterivian-Barremian) is indicated for the Cheakamus Formation (Woodsworth, personal communication), hence these clastic rocks may be correlative with Unit 4 and with the lower Gambier Group. The plutonic-clast conglomerates were not observed in the Chilko-Taseko Lakes area, however quartz-rich sandstone and chert pebble conglomerate derived from a westerly source are present. Also note that only a tiny portion of the basal clastic unit is preserved along the Coast Mountain intrusive contact in the study area.

TABLE 41-1. CRETACEOUS STRATIGRAPHIC CORRELATIONS

	Age	Lithologies	This Paper 920	Tipper 1978 920	Tipper 1969 92N	Woodsworth 1979 Mount Raleigh	Roddick 1965 (Southern Coast Mountains)	Mathews 1958 (Southern Coast Mountains)
		volcanics	7		19			
Late Cretaceous	Cenomanian			Kingsvale Group				
		sediments	6		18			
	Aptian							
		volcanics	5a	Taylor Creek Group				
	Albian	and						
		sediments	5b		16	Styx Formation	Middle Gambier Group	
Early Cretaceous	Barremian	sediments	4	Relay Mountain Group	9			Cheakamus Formation
	Hauterivian	volcanics	2, 3	1kv	15 ↕	Mount Eurydice Formation	Lower Gambier Group	
		sediments	1		12			

Ammonites collected from Unit 5 appear to be Albian (late Early Cretaceous) in age (Tipper, personal communication) suggesting that these rocks are equivalent to the middle Gambier Group and the Styx Formation. Taylor Creek Group sediments also appear to be time equivalent with the Unit 5 lithologies. The increased proportion of volcanics of this age in the Chilko-Taseko Lakes area may represent the evolution of a volcanic island arc chain separating sedimentary basins to the east and west.

Units 6 and 7 record a progression from a marine sedimentary sequence to a terrestrial volcanic sequence and are likely correlative with the Upper Cretaceous Kingsvale Group. Jeletzky and Tipper (1968) assigned an Albian (latest Early Cretaceous) to Cenomanian (Late Cretaceous) age to these rocks in the Chilko-Taseko Lakes area. Marine fossils from Unit 6 may provide further evidence for this age. Final correlation of all units based on fossil evidence collected in this project will have to await detailed analysis of the fossil suites.

Therefore, the rocks of the Chilko-Taseko Lakes area appear to record a mid-late Early Cretaceous, dominantly volcanic and marine environment with lesser sub-aerial deposition, probably representing an intermediate volcanic island arc situation. This continued at least into early Late Cretaceous, but the beginning of extensive uplift and erosion of volcanics is indicated at this time. This environment is punctuated locally by incursions of a westerly derived, quartz-rich sediment, probably representing uplift and erosion of intrusive rocks in the continually evolving Coast Plutonic Complex.

INTRUSIVE ROCKS

UNIT A — DIORITE STOCKS

A number of hornblende diorite stocks of unknown age intrude the volcanics and sediments, generally with minimal contact metamorphic effects. The intrusives contain hornblende and plagioclase phenocrysts up to 2 centimetres across set in a fine, mottled grey-white matrix. Accessory quartz, biotite, and magnetite are common, as is chlorite-epidote-carbonate alteration. A series of these stocks follow a northwesterly trend between RCAF Peak and Mount Goddard, and may be related to the faulting in this direction. The numerous diorite dykes present in Tarn Valley north of Yohetta Lake are thought to represent the root of a larger dioritic stock below. Copper mineralization, accompanied by fracturing, hornfelsing, and propylitic alteration of surrounding rocks, is present at this locality, and adjacent to the Mount Goddard intrusion.

UNIT B — FELSITES

A group of distinctive white-weathering intrusive stocks occur within a fault-bounded wedge of volcanics and sediments between the lower Tchaikazan and Yohetta Valleys. These rocks include feldspar, and biotite-feldspar, porphyries with considerable variation in percentage, size, and crowding of phenocrysts. Intense quartz-carbonate alteration may be present in adjacent rocks. Tipper (1978) assigned an Eocene age to these intrusives. No mineralization was noted with them, however the government regional geochemical survey (BC RGS-3, 1979) produced a number of anomalous silt geochemistry values from creeks in this area.

UNIT C — COAST MOUNTAINS INTRUSIVES

The massive equigranular granodiorite and quartz diorite intrusives of the Coast Mountains form the southern and southwestern borders of the map-area. No attempt was made to map these in detail. Strong fracturing, often accompanied by silicification and pyrite-pyrrhotite mineralization, are locally common in the adjacent stratified rocks. An outlying stock of granodiorite, located 4 kilometres southwest of Spectrum Peak, has had minimal contact metamorphic effects on the surrounding sedimentary lithologies. No roof pendants were located during a brief reconnaissance survey of the Edmond Creek area.

UNIT D — DYKES

A wide variety of dykes are present in the map-area, but are to small to show on Figure 41-1. The most common are mafic-feldspar porphyry, often with nodular or spherulitic textures developed along chill margins, that are likely subvolcanic in origin. Pale-grey, fine-grained, feldspar and carbonate-rich dykes are also common. Brown-weathering carbonate alteration zones are often associated with these dykes. A number of biotite or hornblende-rich lamprophyre dykes are also present.

STRUCTURE

The area is dominated by a series of northwesterly trending transcurrent faults that are closely spaced and have numerous splays between them (Plate 41-3). Displacements, where visible, are right lateral. The Tchaikazan fault (Tipper 1978, 1969) is poorly exposed but is clearly present, based on the juxtaposition of rock units in the Yohetta Valley. This structure is believed to have more than 30 kilometres of right-lateral displacement in the Tatlayoko Lake area to the west.

A number of north-northeasterly trending faults form prominent lineaments on both landsat imagery and aerial photography of the area. Prominent fractures in ridge crests or silicified and quartz-carbonate-altered fault breccias attest to the presence of these faults on the ground. The felsite sill in Yohetta Valley is not truncated, but is reduced substantially in width, by a northeasterly fault, thereby suggesting a vertical motion on these structures. As these faults appear to cross the northwesterly trending transcurrent faults with little displacement, they are considered to be younger. Tipper (1969) recognized similar northeasterly trending normal faults as late structural features to the west of Chilko Lake.

In the Mount Goddard area, massive volcanics of Unit 2 have been thrust northeastward over volcanics and sediments of Unit 5 (Plate 41-4), possibly recording an episode of thrusting during emplacement and uplift of the Coast Mountains plutons. The sole of this thrust is marked, in part, by a gossanous zone directly beneath Mount Goddard. The intrusive at Mount Goddard appears to cut the thrust fault however this is uncertain at present due to the relations of topography and outcrop pattern. The sense of this thrusting is similar to that south of the Tchaikazan fault in the Tatlayoko Lake area to the west (Tipper, 1969)

Folds in the study area tend to be broad open structures, as shown by the synclinal folds with axial traces in the Rainbow and Long Valleys. These folds are only identified by opposing dips across the valleys. In the northwest border of the area mapped bedding attitudes swing from vertical to relatively flat in a short distance, and suggest a pronounced northeasterly fold vergence in this area. Further mapping is required to define this and to determine the relationship, if any, between the northeasterly directed thrust faulting and folding on the east side of Chilko Lake.

Minor folds with tighter closures are locally present in the map area, but tend to be sheared out parallel to axial planes. Southwest of Spectrum Peak, a distinct anticline-syncline pair that is cut by a shear zone illustrates this structural style.

MINERALIZATION

Copper and gold mineralization has been known within the map area since the 1930's at the Lord River Gold mine, (MI 92O-045: H, Do, Pellaire) located in Falls River, and at the Charlie (Warren) Crown grants (MI 92O-043 — Eggs, Tchaikazan, Charlie; MI 92O-076 — Warren, Charlie) in the Tchaikazan Valley (Fig. 41-1). Exploration on both these properties has continued into the 1980's

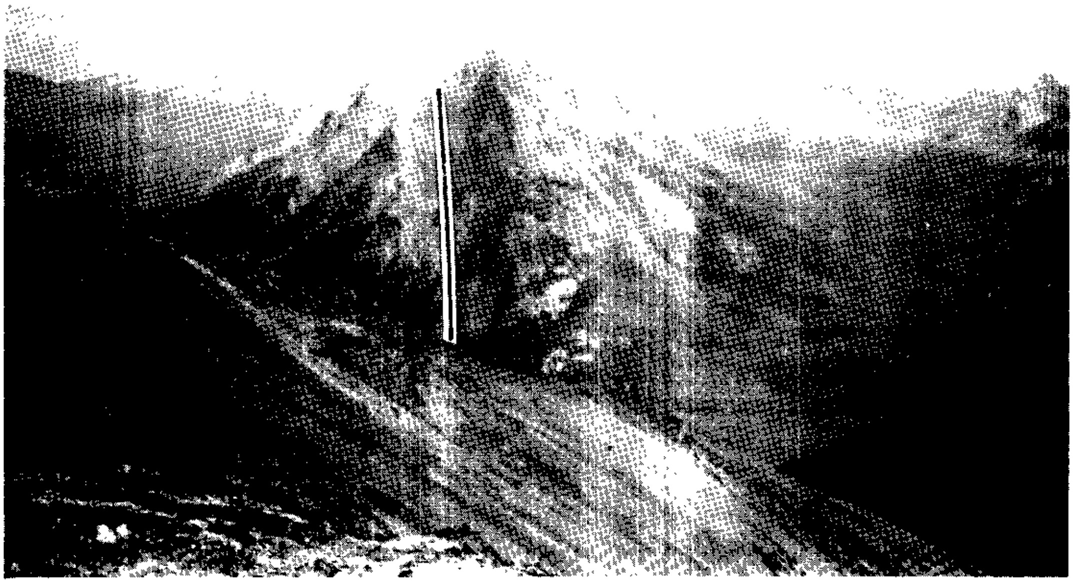

Plate 41-3. Northwest-trending transcurrent fault (looking east from Mount Goddard).

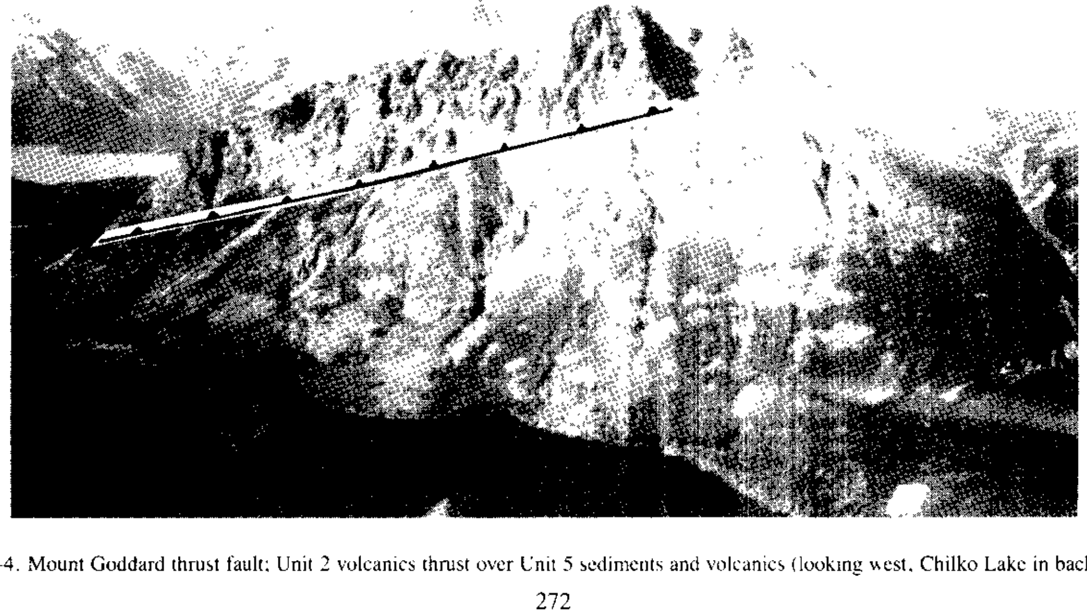

Plate 41-4. Mount Goddard thrust fault; Unit 2 volcanics thrust over Unit 5 sediments and volcanics (looking west, Chilko Lake in background).

with inconclusive results. Twenty kilometres to the northeast, the Fish Lake porphyry copper deposit (MI 92O-042 — Fish Lake), with inferred reserves of 180 million tonnes grading 0.24 per cent copper, 0.57 gram per tonne gold, and 1.25 grams per tonne silver (Northern Miner, February, 10, 1983), provides a further model for the style of mineralization that might be found in the Chilko-Taseko Lakes map-area.

The Lord River deposit consists of a series of quartz veins cutting Unit 5 metavolcanics where they form a sizeable, fault-controlled embayment into granodiorite of the Coast Plutonic Complex. High gold values are associated with limonitic, brecciated quartz veins, and silicified wallrocks. Reserves are reported to be 31 000 tonnes grading 25 grams per tonne gold plus approximately 75 grams per tonne silver (George Cross Newsletter, No. 183, September 22, 1980).

The Charlie (Warren) showings have been included in extensive claim holdings recently being explored for a possible porphyry system containing copper, molybdenum, and gold mineralization. The area between Yohetta and Tchaikazan Valleys and RCAF Peak to Fishem Lake contains numerous small copper and molybdenum showings in a well-fractured sequence of volcanics and sediments. Anomalous gold values have been located as well. Gold-bearing tellurides in quartz veins carrying relatively small percentages of metallic minerals were the original prospecting target in this area (Warren, 1947). Granodiorite intrusives exposed in the Tchaikazan Valley may underlie other portions of the stratigraphy and may be responsible for the widespread zone of porphyry style mineralization.

Alternately, the Charlie area may be viewed as a precious metal epithermal vein system related to the predominantly volcanic lithologies and the large area of fracturing. Rocks in the vicinity of the prospect have been juxtaposed along numerous splays of an extensive northwesterly trending fault. Silicification and mineralization have developed in the fractures, possibly due to the underlying intrusive. However traces of mineralization have been located over an area that is significantly broader than that near the intrusive, and the main northwesterly fault contains traces of silicification and mineralization up to 10 kilometres away. Considerable work is required to evaluate such dispersed showings over this large area.

A previously undocumented zone of mineralization was located during this project in Tarn Creek, 4 kilometres north-northeast of the west end of Yohetta Lake (Fig. 41-1). In this area numerous dykes and irregularly shaped intrusive bodies of hornblende diorite porphyry have intruded and hornfelsed the enclosing volcanic fragmentals and flows. All rocks are intensely fractured and veined by quartz. A gossanous zone extending approximately 400 metres by 150 metres contains chalcopyrite, bornite, pyrrhotite, and pyrite mineralization in veinlets and as disseminations through both the volcanics and intrusives. Magnetite and chlorite alteration is also present. Elsewhere in this valley, pockets of skarn-type mineralization, including bornite, epidote, garnets, and hematite, have developed within calcareous tuffs along intrusive contacts. The area is interpreted as being the roof of an intrusive porphyry system and at present has a significant untested potential.

In the Mount Goddard area, copper mineralization is present adjacent to another hornblende diorite intrusive in an area of complex faulting. A number of pyrite-pyrrhotite-bearing gossans related either to hornfelsed contacts or faults are present.

Traces of copper mineralization in calcareous nodules were noted within black argillites adjacent to the granodiorite stock southwest of Spectrum Peak. A float sample containing sphalerite, galena, chalcopyrite, and pyrite was located on the south side of this intrusive stock, but no source of the mineralization was found.

A prominent gossan is well exposed on a ridge crest, 7 kilometres south of Mount Goddard. A fine-grained highly siliceous (possibly rhyolitic) volcanic unit contains extensive pyrite and pyrrhotite mineralization at this locality. The sulphides occur as fine disseminations, in veinlets, and surrounding fragments in what appears to be a tuff with indistinct crystal and fragmental textures. Rocks immediately adjacent to the gossan are felsic tuffs, hosted within a broader assemblage of intermediate volcanics.

Numerous other gossans of limited extent occur in the study area and are generally related to hornfels or fracture zones. Zones of brown-weathering carbonate alteration are also common but are generally devoid of any significant sulphide mineralization.

GEOCHEMISTRY

A total of 355 stream sites were silt sampled during the project covering a drainage area of approximately 1 200 square kilometres. The density of sampling within the volcanic and sedimentary units is approximately 1 sample site per 2.5 square kilometres. All samples are being analysed for 30 elements using an inductively coupled plasma (ICP) technique, as well as for gold using a fire assay and neutron activation analysis. These analyses will provide quantitative data for 15 elements and semi-quantitative results for the remainder.

Rock chip samples were collected from all locations found that contain mineralization or alteration assemblages potentially related to mineralization. A total of 131 rock samples are being analysed for 14 elements, including base metals, precious metals, and precious metal indicators.

All of the geochemical data is being compiled in conjunction with the geological mapping to produce a mineral potential map of the study area. The data will be released in an open file series, with the geology and geochemistry coordinated on 1:50 000-scale topographic base maps.

SUMMARY: MINERAL POTENTIAL

The rocks of the Chilko-Taseko Lakes area comprise a Lower to Upper Cretaceous sequence of volcanics and sediments that likely accumulated in an island arc type setting bordering a sedimentary trough to the east. Coast Mountain intrusives have truncated these rocks on the southwest. The stratified rocks are known to contain significant indications of gold and copper mineralization, but have undergone little intensive prospecting, largely due to the relative inaccessibility of the area in the past.

This survey has identified one new zone of mineralization related to intrusive activity and has documented the presence of a number of previously unmapped intrusive stocks. The possibility for further intrusive/hydrothermal systems being present beneath the extensive talus and glacial drift covering the area is high.

If the volcanic stratigraphy in this area is in part correlative with Gambier Group stratigraphy in the southern Coast Mountains, the potential for volcanic related sulphide deposits must be considered. The Britannia mine, that produced 50 million tonnes of ore grading 1.1 per cent copper, 0.65 per cent zinc, 7.5 grams per tonne silver, and 0.75 gram per tonne gold between 1905 and 1974, is hosted by rocks correlated with the Gambier Group (Payne, *et al.*, 1980). Gossanous zones related to felsic volcanism are present in the Chilko-Taseko Lakes area, however in field observations mineralization appears limited to pyrite and pyrrhotite.

Any further encouragement for mineralization must come from the compilation of analyses of the lithogeochemical and stream silt geochemical samples. A final mineral potential map will be drawn when this compilation is complete.

ACKNOWLEDGMENTS

Competent and cheerful field assistance was provided by Paul Fagerlund, John Bradford, and Kerry Curtis. Mr. Tom Bugg, Highland Helicopters, is thanked for experienced and congenial helicopter support. Dr. Howard Tipper of the Geological Survey of Canada provided an informed introduction to the area, plus identification of fossils and discussion of results. Dr. Glenn Woodsworth of the Geological Survey of Canada introduced the author to correlative stratigraphy and suggested many improvements in a review of the manuscript. Landsat imagery of the area was kindly provided by Mr. Paul Hawkins, Suncor Inc., Calgary.

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British Columbia Geological Survey
Geological Fieldwork 1985

CARBONATITES IN BRITISH COLUMBIA: THE ALEY PROPERTY*
(94B/5)

By Jennifer Pell
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INTRODUCTION

In many areas of the world carbonatites are commercial sources of niobium, phosphates, rare earth elements, vermiculite, copper, and fluorspar. Carbonatites in British Columbia occur in a broad belt parallel to and encompassing the Rocky Mountain Trench. Those from the Manson Creek, Blue River, and Three Valley Gap areas were reported on last year (Pell, 1985; White, 1985). Additional localities were visited during the 1985 field season in the Frenchman Cap area, where both intrusive and extrusive carbonatites are preserved (*see* Höy and Pell, this volume) and near Williston Lake where a previous unreported carbonatite exists. This paper discusses this newly discovered carbonatite complex.

The Aley property was staked by Cominco Ltd. in 1982. It is located approximately 140 kilometres north-northwest of Mackenzie on the east side of Williston Lake between Peace Reach and the Ospika River. The area has excellent exposure and is generally above tree line (1 450 to 2 200 metres). It is fairly remote; access is by helicopter from Mackenzie.

GENERAL GEOLOGY

The Aley Creek area is underlain by Cambro-Ordovician to Middle Devonian carbonate and clastic rocks of the Kechika, Skoki, and Road River Groups (Pride, 1983; Thompson, 1978). This miogeoclinal succession was intruded by the Aley carbonatite complex prior to the main Late Jurassic-Early Cretaceous orogenic event.

The carbonatite complex and surrounding sedimentary rocks were subjected to sub-greenschist facies regional metamorphism. The Aley complex is, however, essentially undeformed; it appears to have behaved as a rigid body during deformation and was rotated and/or transported eastward in a thrust slice.

GEOLOGY OF THE ALEY CARBONATITE COMPLEX

RAUHAUGITE CORE ZONE

The core of the Aley Complex is approximately 2 kilometres in diameter. It comprises more than 50 per cent of the exposed complex and consists of dolomite (80 to 95 per cent) and apatite (5 to 15 per cent) with minor amounts of phlogopite, pyrite, magnetite, and zircon (Pride, 1983). It is generally a massive and homogeneous unit, weathering buff to brownish.

Pyrochlore [$(Na,Ca,Ce)_2(Nb,Ta,Ti)_2O_6(OH,F)$] and/or columbite [$(Fe,Mn(Nb,Ta)_2O_6$] may be developed near the margin of this zone.

SOVITE ZONES

Sovite zones (dykes ?) occur locally near the margin of the rauhaugite core zone and in the surrounding amphibolite zone. The sovites exhibit a more varied mineralogy than the rauhaugites. Calcite with or without dolomite dominates and there are accessory amounts of apatite, sodic pyroxenes and amphiboles, magnetite, pyrochlore (Pride, 1983), and fersmite [$(Ca,Ce,Na)(Nb,Ta,Ti)_2(O,OH,F)_6$] (Pride, personal communication, 1985).

AMPHIBOLITIC MARGIN

An amphibolitic margin approximately 1 kilometre in width encircles and complexly interfingers with the rauhaugite core of the Aley complex. The marginal zone includes massive and breccia phases. No distinct pattern to the spatial distribution of the two phases is evident. Carbonatite dykes cut both members.

The massive phase is a medium to coarse-grained, dark green rock consisting primarily of sodic amphibole, quartz, and pyroxene (Pride, 1983). It is more extensively developed than the breccia phase and resembles fenites associated with some of the other carbonatite complexes in British Columbia (*see* Pell, 1985). The breccia phase contains subrounded clasts of dominantly orthoquartzite, with some siltstone, albitite, and syenite fragments in a matrix that is similar to the massive member. The clast to matrix ratio is highly variable and locally clast-supported breccias develop. The subrounded nature of the clasts give this unit the appearance of a conglomerate (Plate 42-1). The massive and breccia phases locally grade into one another.

ALTERATION HALO

Sedimentary rocks adjacent to the Aley complex have been altered for a distance of approximately 500 metres beyond the amphibolite margin. This alteration halo is characterized by a colour change from grey to buff which is indicative of a limestone to dolomite transition. The altered rocks can look superficially similar to material from the rauhaugite core zone. Apatite, pyrite, and magnetite are developed in the alteration zone. The degree of alteration decreases outward from the complex.

RARE EARTH-BEARING DYKES

Rare earth element-enriched dykes or 'sweats' occur throughout the complex but are most commonly developed in the outer alteration halo. The dykes weather dark reddish brown, are generally intruded parallel to bedding, and average 0.5 to 1.5 metres in thickness. Their primary component is dolomite. Accessory minerals include purple fluorite, pyrite, barite, bastnaes te [$(Ce,La)CO_3F$], and other rare earth carbonate minerals (K. Pride and U. Mader, personal communication).

PRELIMINARY GEOCHEMISTRY

Preliminary results of geochemical analyses are presented in Table 42-1 and on Figure 42-1. Only four samples have been analysed to date; three lanthanide-enriched dykes and one sample from the amphibolitic margin. All have high rare earth concentrations typical of carbonatites. The three samples of dyke rocks have a much greater light/heavy lanthanide enrichment ratio than does the sample from the amphibolitic margin.

* This project is a contribution to the Canada/British Columbia Mineral Development Agreement.

** Presently at the University of Windsor, Ontario.

Plate 42-1A. Breccia member of the amphibolite zone. Note the subrounded white quartzite clasts.

Plate 42-1B. Breccia member of the amphibolite zone. Here the matrix has weathered away, leaving quartzite clasts standing in relief.

TABLE 42-1. Preliminary Geochemistry

	1 Per Cent	2 Per Cent	3 Per Cent	4 Per Cent
Si	<1.0	<1.0	<1.0	>8.0
Al	<0.5	<0.5	<0.5	3.0
Mg	>5	>5	>5.0	3.0
Cu	>10	>10	>10	>10
Na	<0.3	<0.3	0.3	1.5
K	<0.3	<0.3	<0.3	0.6
Mn	0.7	1.0	2.0	1.0
Fe	4.0	6.0	6.5	2.5
Ti	tr	tr	tr	0.15
	ppm	ppm	ppm	ppm
Sr	1 000	800	5 000	3 000
Ba	300	900	10 000	1 500
Nb	500	100	—	800
Ce	12 100	12 500	4 000	2 070
Th	151.0	105.0	61.5	108.0

Analyses 1-3 are from REE dykes (3 contains fluorite); 4 is a locally developed basic phase of the amphibolitic margin.

The emission spectrographic analyses were performed by the Ministry laboratory. Ce and Th were analysed using induced neutron activation by Bondar-Clegg. *See* also Fig. 42-1.

DISCUSSION

The Aley carbonatite complex lies within the Rocky Mountains in a structural setting similar to that of the Ice River Alkaline Complex. Its setting contrasts with most other British Columbia carbonatites (Pell, 1985) which most frequently occur in high-grade polydeformed metamorphic core complex rocks, west of the Rocky Mountain Trench. Due largely to the lack of intense deformation the Aley deposit is an excellent locality in which to study and attempt to understand the emplacement of these bodies.

Field relationships suggest that amphibolites at Aley were the first to be emplaced, probably as a volatile-rich explosive mix of fenitizing solutions and igneous material. Intrusion must have been violent, ripping up country rock fragments (quartzites, mudstones) and abrading them as well as transporting fragments which may have originated from the initial magma chamber (albitite, syenite). Rauhaugites and sovites were then emplaced, crosscutting and interfingering with the amphibolites. The end of the igneous cycle was marked by intrusion of late stage, volatile-enriched rare earth dykes. The time relationship between the carbonatite complex and the nearby lamprophyres and diatreme breccias is unclear (*see* Pell, this volume).

ACKNOWLEDGMENTS

I would like to thank K. R. Pride and J. M. Hamilton of Cominco Exploration, Vancouver for making my visit to the Aley property possible and for their comments on this text. I would also like to acknowledge the Ministry for providing me with a capable field assistant (Olga Ijewliw) and logistic support for this project, in part through the Canada/British Columbia Mineral Development Agreement.

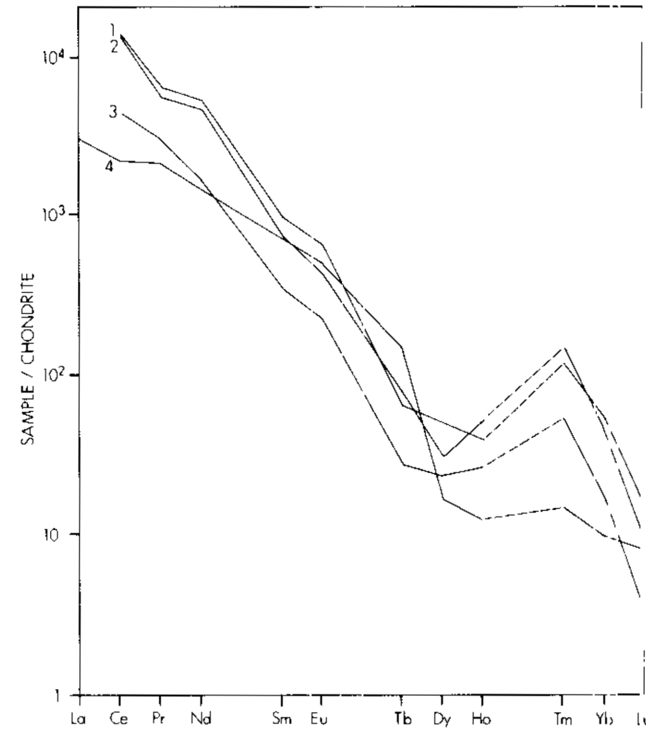

Figure 42-1. Chondrite normalized REE plot, *see* Table 42-1 for sample descriptions (chondrite REE values from Henderson, 1984).

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PRELIMINARY REPORT O'CONNOR RIVER GYPSUM DEPOSIT* (114P/10E)

By G. V. White

INTRODUCTION

During the winter of 1984-85, a proposal to develop the O'Connor River gypsum deposit (MI 114P-005), in northwestern British Columbia was submitted by Haines Gypsum Ltd. of Vancouver. This deposit, which has been known since 1958, was evaluated by industry in 1959 and 1965, but no geological information or report on the work done were ever filed with the Ministry. This study was undertaken to obtain independent information about the location, size, and type of this gypsum occurrence.

Seven field days were spent mapping three gypsum zones and their surroundings. Emphasis was placed on defining the size and the structure of the gypsum deposit.

TOPOGRAPHY

The O'Connor River gypsum deposit is located in a rugged, steep, V-shaped river valley between elevation 850 and 1 220 metres on both sides of the glacier-fed O'Connor River. The river, which flows south, has cut vertical canyons in places and is strewn with large rounded chert and granite boulders that average 1 metre in size. At the time of the property visit, summer run-off was high and the 10-metre-wide river could not be safely forded. Relief on the property is pronounced and slopes steep, so outcrop exposure is good, particularly along the western bank of the river and along an access road on the eastern side of the valley.

REGIONAL GEOLOGICAL SETTING

The O'Connor River gypsum deposit is situated within the Alexander Terrane of the Insular Tectonic Belt. The terrane consists primarily of complexly deformed, Paleozoic sedimentary rocks and Triassic basic submarine flows and related volcaniclastic rocks.

Regionally, the terrane has been moderately metamorphosed and localized intrusives of varying compositions and age have altered host rocks by contact metamorphism. The regional geology and structural setting are illustrated on Figure 43-1.

PROPERTY GEOLOGY

The O'Connor River gypsum deposit consists of three separate zones in a carbonate host (Fig. 43-2). The host rocks were divisible into three separate units with distinctive lithological differences. The Geological Survey of Canada (Open File 926) suggests the carbonates are Early Permian to Late Triassic in age.

UNIT 1

Unit 1 consists of limestone, which is locally argillaceous and/or siliceous, quartzites, and in places skarn. Good exposures of the units are found along a road paralleling the east bank of the O'Connor River and along the banks of the River itself. The limestone is predominantly light to medium grey but colours range from white to black with local variations of pink, buff, and brown. Argillaceous limestone layers are a few centimetres thick whereas purer limestone layers range to tens of metres. Beds strike northwest and dip 20 to 40 degrees to the northeast. Several beds of quartzite were mapped approximately 550 metres north of Zone 1 (Fig. 43-2). The quartzites are grey and fine grained and layers are thin and apparently discontinuous. Rusty skarn outcrops occur 100 metres north of Zone 1 and in Zone 2. This calc-silicate rock contains no visible sulphides; its outcrops are local and small.

UNIT 2

Unit 2, a pink-buff-grey intraformational limestone breccia, is exposed along a road 120 metres north of Zone 1 and along the west side of the O'Connor River 200 metres north of Zone 2 (Fig. 43-2). The unit strikes north to northwest and dips between 25 and 45 degrees easterly. Layers range from a few centimetres to several metres in thickness and are often interbedded with limestone that is not brecciated. Clasts are angular to rounded, ranging between 1 and 5 centimetres in diameter; they are poorly sorted and randomly oriented. The matrix consists of limestone that is similar in composition to the fragments.

UNIT 3

Unit 3 is a dark-grey to black calcareous argillite; it is well exposed along the road on the east side of the O'Connor River 600 metres north of Zone 1. Beds strike north to northwest and dip 25 to 45 degrees easterly. In places, small pyrite crystals were observed in the argillite, although no other sulphides were recognized.

GYPSUM

Three separate gypsum zones are located on the property and these are referred to as Zones 1, 2, and 3, respectively (Fig. 43-2).

ZONE 1

Zone 1 is situated on the east side of the O'Connor River; access is along a road paralleling the river 125 metres above the valley floor.

Zone 1 strikes 120 degrees and dips 70 to 90 degrees northeast. It is irregularly exposed over a strike length of approximately 400 metres. Gypsum exposures are found between 914 metres and 1 036 metres elevation although overburden probably covers gypsum at both lower and higher levels.

The gypsum contains few foreign inclusions and it appears to be pure although a few samples of anhydrite were found. Contact between the wallrock and gypsum is sharp and the gypsum appears to have crosscut the layered sediments. Wallrock on the north side of Zone 1 is sheared and consists of a closely fractured argillaceous limestone (Fig. 43-2).

Sink holes occur between elevations 990 metres and 1 067 metres at the southeast end of Zone 1. These surficial features, which follow the gypsum zone along strike, are often interconnected; they range from 10 and 20 metres in diameter and are 10 to 15 metres deep. Gypsum lines the walls of some of the holes.

* This project is a contribution to the Canada/British Columbia Mineral Development Agreement.

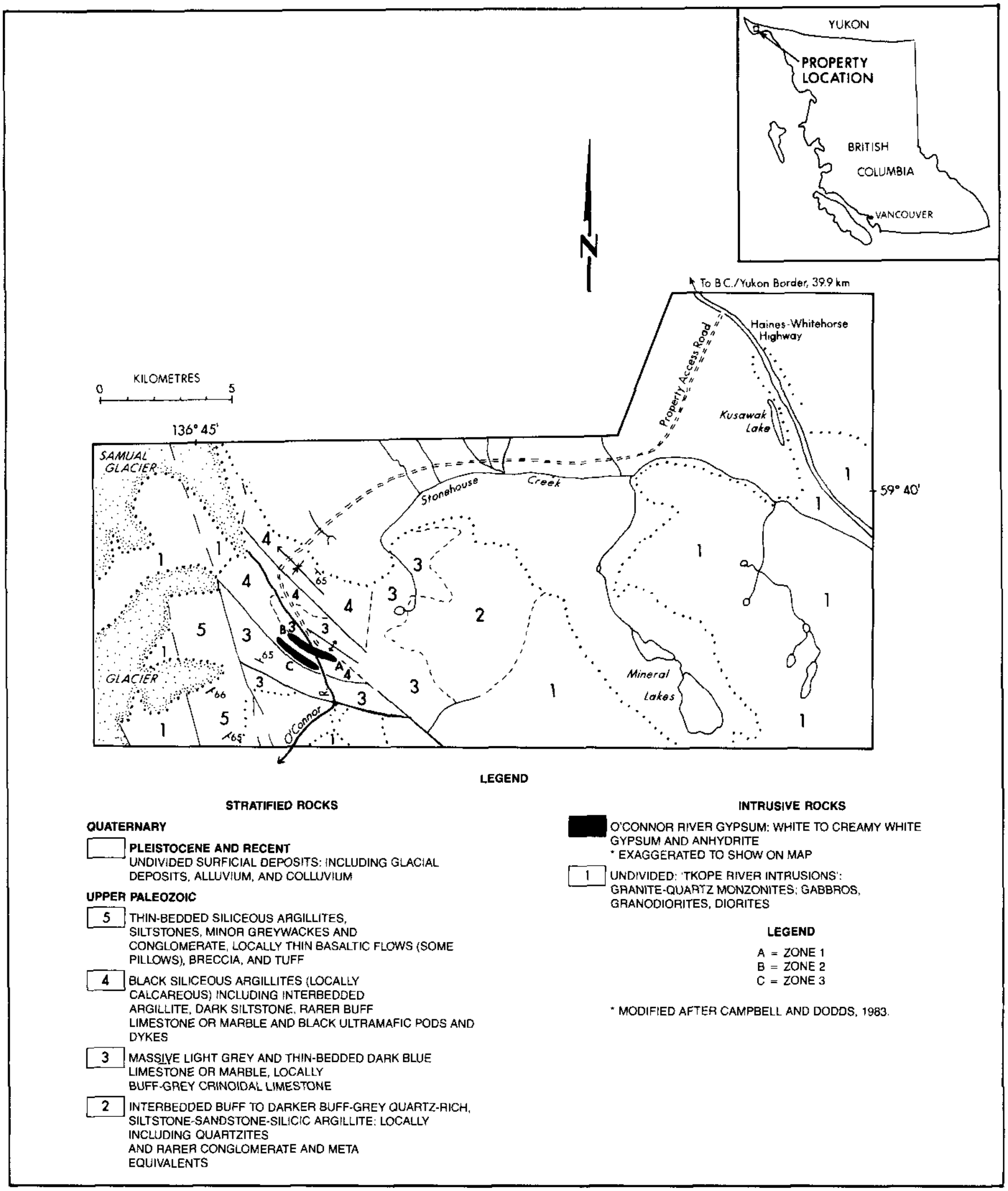

Figure 43-1. Regional geology, O'Connor River gypsum.

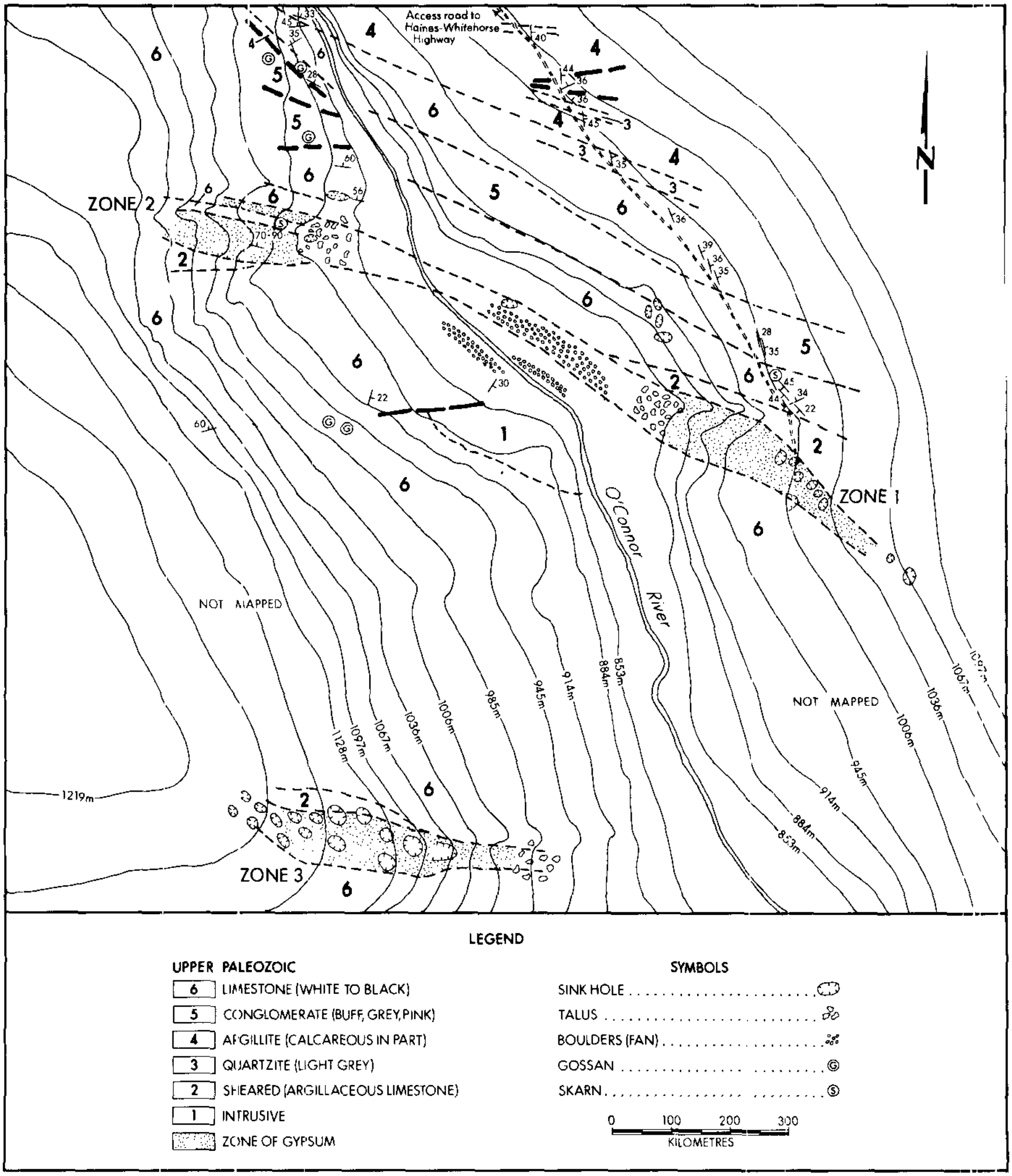

Figure 43-2. The O'Connor River gypsum showing.

ZONE 2

Zone 2, which is west of the O'Connor River, is a northwest extension of Zone 1. Zone 2 can be traced along strike from Zone 1 by following sinkholes. Zone 2 occurs between elevations 868 and 1 067 metres and has a strike length of approximately 220 metres. The zone is irregularly exposed with measured widths ranging between 60 and 100 metres.

Gypsum in Zone 2 is similar in appearance to that in Zone 1; it is white, finely crystalline, and massive. A 30-metre-wide argillaceous limestone unit, which forms a parting in the zone, is well exposed at the lower, southeast end of the zone (Fig. 43-2).

Contacts between the wallrock and the gypsum are sharp and wallrock inclusions in the gypsum are uncommon. The few inclusions are angular, ranging up to 15 centimetres in size, and consist of argillaceous limestone. The wallrock is closely fractured and sheared.

ZONE 3

Zone 3 is on the west side of the O'Connor River approximately 1 200 metres south of Zone 2. The zone strikes east-west and appears to dip steeply toward the north. Gypsum crops out between elevations 1 036 metres and 1 158 metres.

The zone has a strike length of approximately 550 metres and is exposed over a width ranging from 50 to 110 metres. These dimensions are approximate because slopes are steep and largely covered by overburden. Sink holes are 20 and 40 metres wide and 5 to 15 metres deep and often interconnected; they occur along the length of the deposit. The gypsum is white and similar to that sampled in Zones 1 and 2. The deposit intrudes a limestone (locally argillaceous) which strikes northwest and dips moderately to the northeast.

ORIGIN OF THE DEPOSIT

The O'Connor River gypsum deposits, which occur in faulted Early Permian to Late Triassic carbonate rocks, were originally deposited as part of the sedimentary sequence. In each of the three zones exposed, gypsum cuts layered sediments; an indication that the gypsum intruded the sediments. This intrusion probably occurred as a result of tectonic movements in the O'Connor River area when pressure squeezed the calcium sulphate bodies into their present position by plastic flow along a faulted zone.

Haines Gypsum Inc. (1984) reports that the gypsum deposit contains up to 8 per cent anhydrite. Possibly the original anhydrite deposit has hydrated into gypsum by interaction with a combination of meteroic and ground waters. A similar interpretation was suggested by Baird (1984) for the Faulkland gypsum deposit in southern British Columbia (82L/5E). Both gypsum deposits have similarities in their intrusive nature and the presence of anhydrite.

SUMMARY

Three separate gypsum showings designated Zones 1, 2 and 3 are located on both sides of the O'Connor River in northwestern British Columbia. The zones have a strike length of approximately 400 metres, 220 metres, and 550 metres respectively; irregular widths range between 30 and 110 metres. The gypsum on surface appears pure and intrudes Upper Paleozoic carbonates along a northwest-trending shear zone. Zones 2 and 3, located on the west side of the O'Connor River, are not readily accessible; any development of the gypsum in these zones will be difficult.

ACKNOWLEDGMENTS

The author would like to acknowledge Stryker Resources and in particular D. Perkins, Exploration Manager, for hospitality during the mapping project. The author was ably assisted in the field by Bill Turnbull. D. Hora reviewed the paper and offered many useful, constructive criticisms.

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Other Investigations

LITHCHEM: AN INTEGRATED GEOLOGICAL DATABASE FOR MICROCOMPUTERS

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The University of British Columbia
Department of Geological Sciences

INTRODUCTION

Lithchem is a dedicated geologic database system with graphical and statistical support integrated into the basic design. The system was developed with a specific application in mind, storage and manipulation of chemical analyses of igneous rocks. However, because other sets of geologic data have essentially the same types of fields within each record, lithchem can be modified for other applications. Lithchem is currently 2500 lines of source code, which compiles to about 47 kilobytes (Kb) of object code.

Lithchem was written in TURBO Pascal[1] on an IBM XT microcomputer with 576 Kb internal memory and a 10 megabyte (Mb) hard disk. The 8088 microprocessor was augmented with a 8087 numerical co-processor greatly enhancing execution speed of *real* arithmetic and *transcendental* functions, as well as providing extended precision reals and integers. TURBO-87 takes advantage only of the extended precision reals. To use the extended integers of *transcendental* functions one must develop the appropriate assembly language subroutines or await advanced versions of TURBO-87.

DEVELOPMENT CRITERIA

Of the criteria controlling the choice of language and algorithms in this project, time was probably the ultimate one. The end result has numerous areas for improvement and expansion. With time of development being necessarily short, methods and algorithms were the simplest that would do the job. The most elusive bugs were found to be features of the compiler and alternate code was written to avoid these problems. It was anticipated that the system would be used by non-experts with regard to programming and thus prompting for input with menus was used as much as possible. Input that requires data is always assigned a default value if no value is supplied. Range checking and checking membership in a known set are also required to reduce typographic errors that would confuse searches and be difficult to find later. To ensure ease of use for non-expert programmers, a system that would internally pass data between searching, graphical, and statistical procedures was conceived.

The following considerations were given to developing such a system in the microcomputer environment. Choice of the programming language had to meet the following requirements:

(1) The system will require many steps so a compiler, rather than an interpreter, is needed.

(2) The system will become complex and should allow possibilities for expansion, therefore the language should be structured.

(3) The language will be need at least graphics primitives.

(4) The language should utilize dynamic variables to allow the full power of the memory to be used.

(5) The language should have adequate mathematical support and not limit the statistical applications.

(6) The language should be commonly available and able to run on other microcomputers, portability is important.

Given the requirements, any language will fall short somewhere so compromise is inevitable. FORTRAN is reasonably portable and certainly easily available, but it lacks easily accessible dynamic variables and the version available to the writers also lacks graphics. Consequently, FORTRAN and for similar reasons BASIC, were ruled out. The remaining possibilities included C and Pascal with more points in favour of Pascal. While C fits the preceeding description well and is probably the most portable, Pascal is available for most microcomputers in Borland's economical Turbo version. Pascal only falls short in the mathematical support but this could be overcome by using the 8087's powers. Certain features of Turbo Pascal have been of use in the development of this project and they will be mentioned in the appropriate section.

DATA STRUCTURES

Each sample has one record associated with it that contains:

(1) Sample number.

(2) Map area (NTS map sheet, for example, 93G/11).

(3) Assemblage.

(4) Rock unit (general and specific).

(5) Rock type (author's and revised).

(6) Source (number reference to a bibliography).

(7) Twelve main oxides, LOI, CO_2, and S.

(8) Six trace oxides.

The data are found in the form of strings of unknown length, integers, and some fixed point numbers or reals since Pascal does not contain a fixed point type. In some languages namely FORTRAN and BASIC we probably would have to define arrays, of fixed size, for each of these fields of data. With a total of 28 fields we would be lucky to be able to work with one or two thousand samples at one time. With sets of data exceeding the memory's capacity, pages of data, perhaps in smaller amounts to lessen each loading time, would have to be moved on and off the disk. On the IBM XT it took between 2 and 3 minutes to load 1 000 samples this way from the hard disk. We did not use the primitive read procedures and consequently could be made faster; nonetheless it is comparable or better than FORTRAN or BASIC which are notoriously slow with their I/O routines. For a search to go through 3 000 samples, 12 to 18 minutes would be spent on I/O processing alone! A different approach to variable declaration must be taken. Arrays of the type mentioned above have to be defined at the beginning of the system and are of fixed size. Because of the internal structure of the compiler these arrays are usually limited to around 64 kilobytes of memory for all the arrays. If one relieves the compiler of the job of keeping track of the location in memory of the variable (in this case an array), there is no longer the 64-kilobyte limit to the data storage capacity and in this application approximately 5 000 samples can be dealt with at one time! This should remove the need to flip pages on and off the disk for most data sets, and search times will consist only of the time the system takes to work its way through memory.

The next major decision lies in how the data should be stored in each record. Pascal allows the programmer to define a *record* type variable that consists of several fields of similar or different variable types. For instance we could define a record with a field for each of

British Columbia Ministry of Energy, Mines and Petroleum Resources, Geological Fieldwork, 1985, Paper 1986-1.

1. TURBO-87 © 1984 by Borland International, in TURBO PASCAL Version 2.0

the previously mentioned variables of the appropriate type for the data. Closer inspection shows that substantial savings can be made by compressing the data. The real numbers reported for whole rock analyses are never less than 0.01 per cent and never (we hope) more than 99.99 per cent for a single oxide. Real numbers in Turbo require 6 bytes whereas integers only require 2 bytes. The range of a *two's* complement binary integer is as $-(2^{n-1})$ to $2^{n-1}-1$ where n is the number of binary digits. In this case a 16-digit integer will give the range -32 768 to 32 767. Since the per cent oxides are reported with four digits of accuracy an integer of four and one-half digits can contain the data as long as we keep track of the position of the decimal place. This can be done by storing the data as one hundred times the reported values, truncated. Oxide data forms a large part of the record and this method gives us two or three times as much room as would be available using all reals.

The rest of the data is mainly strings, which in Turbo are stored as one byte per character and one preceding byte to specify the length of the string. The source can be recorded as a number reference to a bibliography kept in a separate text file. This text file does not require anything more than the editor to maintain so further discussion of this part of the system is not needed. Sample numbers currently are used to sort out which of the sources samples is being referred to, so an integer will probably suffice in this application. We still have the 'map area', 'assemblage', 'rock unit', and 'rock type' to represent. Turbo requires that we specify the length of the string at the start of the system, so a maximum length that will not cause problems will have to be set. We could use four-letter mnemonics and keep the strings short, but this will result in the system being harder to use by persons not very familiar with it as well as increasing the chance of typographic errors during input. Almost all names we need here can be put into a twelve-character variable, and these names will be repeated many times throughout the samples. We have assumed during development that each of these variables will have less than fifty different names. Some such as 'assemblages' may have fewer but others such as 'map area' may need more than fifty. As the system is used these details can be clarified. Now, if each name is kept in an array of 12-character strings, one array for each variable, then the individual records will only need to keep the integer that represents the position in the array of the appropriate name. The names will be stored in the long, rather than mnemonic form and for each time the name is repeated a saving of ten bytes is made over storing the full name. Ease of use is maintained and in finding the position of each name entered in the array any typographic errors can be queried and the correction made at the time of entry. In the case of rock type and rock unit, two fields have been merged into one by using the eight most significant bits to represent an 8-bit number, and the eight least significant bit *numbers* as a second 8-bit number. These can be separated easily by binary masking using an arithmetic *and* operation. If the upper eight bits are being recovered an 8-bit right shift is also used (equivalent to an integer divide by 128) to recover the data. Note that this has left room in the '*map area*' and '*assemblage*' variables for later addition of new variables.

Thus, we see that all data entries can be reduced to integers and stored in a compressed form. There are four more variables attached to each record that also require note here. These are *next*, *last*, *nexta*, and *nextb*. Dynamic variables are not defined at a particular location by the compiler, so it is the job of the system to keep track of where the record currently being operated on is kept. This record will also need to contain the memory address of the next record, thus building a *linked list* of records. When these records are being examined the user may wish to back up one or more records so a second link to the last record is also maintained resulting in a *doubly linked list*. These addresses are generated and stored in *next* and *last* during the initial setup when the records are recovered from the disk. The two other variables *nexta* and *nextb* are set aside for sorting linked lists by some parameter (for example, by SiO_2 content) and have not yet been used. One last variable used in the record are integers used as flags in the search routines. These integers are also available to the plotting and statistical routines and may be saved on the disk if desired. This variable will be discussed in detail in the next section. The remaining field is not used as a variable but is assigned when a sample is entered and is a unique identifier that remains set and cannot be edited or refused. *Refnum* is also used to identify samples for editing and other such operations of the system.

This results in the following list of variables in each record, using a total of sixty-four bytes per record.

(1) next, last (pointer variables) : linked list.

(2) main[1..28] (array of 28 integers) : compressed data.

(3) samflag (integer) : set membership flags.

(4) nexta, nextb (pointer variables) : for future sorting routines.

(5) refnum (integer) : unique identifier.

MAIN ALGORITHMS

Here we will move through the system in about the same order in which the system would run. The majority of the system has been designed to be *menu driven* with the goal of always prompting the user for instructions. The user is kept aware of what commands are currently valid. A few situations, such as when plotting a composition diagram, are not favourable for showing menus. In these cases the menu is either very simple, or a space or return keystroke will get the program to the next frame or menu. These areas should not cause problems after only limited use of the system.

The records are loaded from and written to the disk using the lowest level procedures available in Pascal, namely *blockread* and *blockwrite*. The advantages of these are speed, smaller disk files, and the fact that the procedures are standard Pascal. They do, however, require that data be transferred in 128-byte blocks and a double sample buffer is used to do this. Notice that one record requires 64 bytes, thus two will fit neatly into 128 with no wasted bytes. When the next record pointer is nil, or in other words there are no more records in the list, the procedure continues on to the next stage.

Samples are entered and edited one at a time in a form mode. Using the IBM special characters for the text screen, a form for the sample entry and editing routines has been designed. The form allows the user to fill in the blanks and, if no data are available, a default is provided. This helps to prevent random values from entering sample data. The form also enhances readability of the data. Editing provides the current value for the default and, if no re-entry is required, then a return keystroke will pass on to the next line. The routines that read in the data are set to allow only valid characters. This helps reduce typographic errors and ensures that data can be compressed correctly (*see* preceding data structures). Individual forms can be printed on the dot matrix printer with the print screen key. While forms are a convenient way to view small amounts of data on the screen, larger sets often need a tabular format. This can be done to the printer by specifying which fields to print per line. The whole sample is considerably larger than a single line.

Searching is a major part of this system and the routine has been kept simple to ensure ease of use. This area of computing has many refinements to offer which have not been used due to lack of time. Every sample has an integer flag associated with it. This is then used as fifteen *set flags* to show which sets, if any, a given sample belongs to. When searching a source and target, flag must be specified. The source, which could also be the whole file, tells the system which of the samples to make the search comparison with. The target, which cannot be the whole file, is a flag that the search will use to mark which samples meet the search criteria. This target can then be used for plotting, listing, or further searching. When a search is made the samples meeting the criteria can be added to the target, removed from the target, or removed from the target if they do not fit the criteria. These operations can only be done one at a time, but they can be sequenced to find the desired set of data. There is also an operation to join two sets. When saving the samples the option is given to save the flags. This allows one to continue with the same sets the next session since otherwise the sets would be lost.

GRAPHICS

The graphics support given by Turbo goes no further than moving or drawing from point to point with the coordinates given in pixels. In the case of the IBM XT the vertical range is 320 and the horizontal 600 pixels. Graphics routines are provided for nine plots which one may select at random. A tenth option sets the symbols to be used and with which flags the symbols are to be associated. This remains set so that several different diagrams may be displayed. Up to six different characters may be assigned to any or all of the fifteen sets defined by the search routines. This was conceived to be useful in the comparison of potentially different sets and in combining sets at the plotting stage for comparison rather than returning to the search facility. Copies of the screen output can be made on the dot matrix printer with the print screen key. Some distortion with respect to the length of the axes will occur when this is done, but this should be of little concern in this situation since the axes are of arbitrary length to begin with.

STATISTICS

This section, while planned for in future expansion, has not been included in the initial version of the system. This is only for time constraint reasons and because the application of the system currently does not require statistical procedures to be useful.

PORTABILITY

Some of the problems of portability have been dealt with in the choice of language. Turbo Pascal is easily available and very reasonably priced so any microcomputer supported by this language will be able to accept a source code version of Lithchem. Any IBM PC or XT should be able to run Lithchem immediately and if they do not have an 8087 numerical processor then a compiled version with the regular Turbo would be directly transferable. Most IBM compatibles will be able to accept the system with very few modifications. The areas of code that are machine dependent have been isolated, whevever possible, to short subroutines, many of which are found in the first few hundred lines of source code. The adjustments needed would amount to one or two days of work.

Should the system be moved to a microcomputer using another version of Pascal the problems will be greater. Care has been taken to keep the code as close to standard Pascal as possible. Again, the majority of changes would be in the sub-routines found at the beginning of the code. If the microcomputer is not IBM compatible but uses the 8088 and 8087 processors a compiled version may be portable.

Perhaps the most important question would be whether the machine has enough memory for the proposed application of the data base and whether a hard disk is essential or not. In its current configuration the size of the Lithchem system's database is limited by the amount of random access memory (RAM) in the host. No capacity for *paging* data on and off the disk has been included. As well as having simplified the development, this strategy has kept the operational speed of the system up.

EXPANSION AND FURTHER DEVELOPMENT

As mentioned previously, one section that can be added with relatively small effort is that for statistical procedures. These would interleave with the graphics since some of the statistical methods would require graphical output. This is the only other set of procedures that should be added internally to the system. To add more would result in the complexity and size of the system becoming unmanageable for future programmers to work with. Thus a method has been used to allow system additions to be made without having to enter the main body of the program. This is the ability in Turbo to *chain* systems so that a second system can be executed with the data left by the first system still accessable in memory, from the first. As long as subsequent programmers know the format of the data further sections can be added as particular needs arise. The main system can be returned to by *chaining* back to a version identical in everything except that it does not initialize variables or load the data from the disk.

Of the many further developments possible one in particular would be most useful. That is a routine to enter a file of data from either MTS (the operating system on the mainframe at the University of British Columbia) or another external source, an analytical laboratory, for instance. Batch entry would remove the most time consuming part of the current system.

The modular form of the Lithchem system and data structure can be modified to work for similar applications. Some of these would only require a revised record structure, while others would need new routines added. Applications of such an integrated system could range from soil geochemical interpretation to working with isotopic data.

ACKNOWLEDGMENTS

This work has been supported by the British Columbia Science Council in cooperation with the Geological Branch, British Columbia Ministry of Energy, Mines and Petroleum Resources.

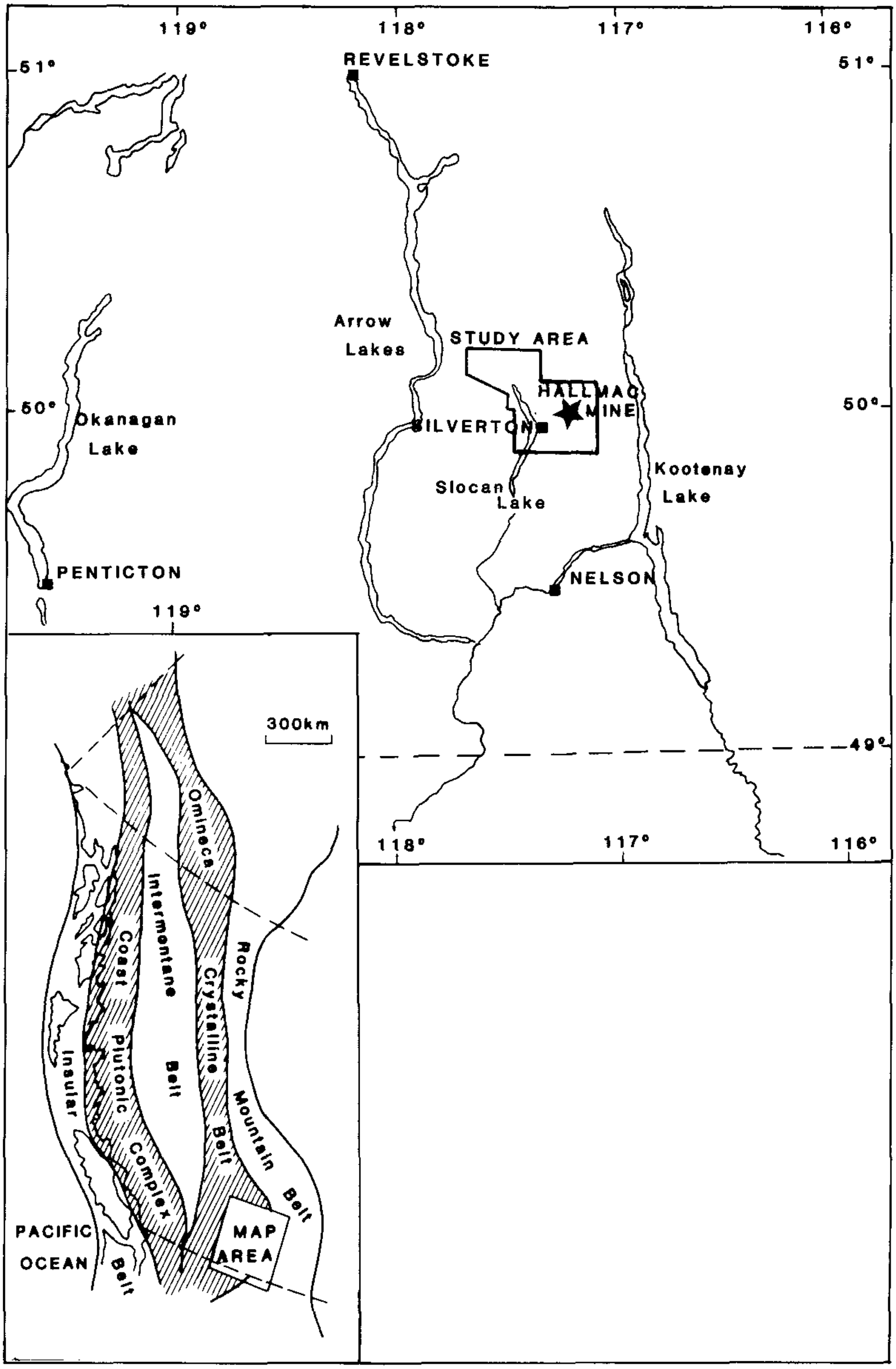

Figure 45-1. Location map of Hallmac mine. Inset map shows location with respect to major physiographic subdivisions of the Canadian Cordillera.

British Columbia Geological Survey
Geological Fieldwork 1985

MINERALOGY AND METAL DISTRIBUTION HALLMAC MINE SANDON (82F/14, 82K/3)

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INTRODUCTION

Silver-lead-zinc ores have been produced from about 140 vein deposits in the Slocan mining camp since the 1890's. Discovery of the Hallmac deposit in August of 1980 marked the first significant discovery in the camp during recent years. The Hallmac mine is 1.7 kilometres north of Sandon in the centre of the camp (82F/14, 82K/3) (Fig. 45-1).

Supergene material accessible from surface pits accounted for early production of high-grade Hallmac ore. Bulk assays reported 127 ounces silver per ton, 72 per cent lead, 1.0 per cent zinc, and 0.02 ounce gold per ton for the initial 45-ton shipment (Goldsmith, 1981). Development continued sporadically for the next three years. The mine is closed at present.

This study was undertaken to examine metal and mineral distribution patterns within that part of the 'lode system' available for study. In addition, a comparative study was made of two spatially distinct mineralized veins, one along the footwall of the lode and the other along the hangingwall.

GENERAL GEOLOGY

The Late Triassic (Orchard, 1985) Slocan Group underlies the Sandon area in a structurally complex belt of typically argillaceous rocks with subordinate quartzite, limestone, and volcanic (tuffaceous) units. The principal structure within the camp is a regional recumbent fold concave to the southwest, referred to as the 'Slocan Syncline' (Hedley, 1952). Intruding the Slocan sediments, generally concordant with the strike of bedding, are dykes and sills related by Cairnes (1934) and Hedley (1952) to the Upper Jurassic Nelson batholith (Nguyen, *et al.*, 1968; Archibald, *et al.*, 1983). Emplacement of this composite, post-tectonic batholith (Duncan, *et al.*, 1979) has been related spatially and temporally by many (Cairnes, 1934; Reynolds and Sinclair, 1971; Cox, 1979; and Andrew, *et al.*, 1984) to the mineralizing event.

Slocan silver-lead-zinc-gold veins are mineralized parts of a system of interconnected and in many cases multistranded breaks or lodes (Robinson, 1950) which trend easterly to northeasterly across the regional fold structure of the enclosing strata. Veins occur along these lodes where dilation coincided in time with the mineralizing event(s).

MINE GEOLOGY

At the time of sampling the Hallmac lode had been developed over a horizontal length of 75 metres and vertical distance of 50 metres. Workings comprised two adit levels with the lode being explored by four subdrifts totalling nearly 250 metres in length (Fig. 45-2).

The predominant lithology encountered underground is massive argillite, in part shaly and thin bedded. Porphyritic dacite has intruded the sedimentary sequence concordant to bedding; dacite also locally occupies the lode structure, where it crosscuts bedding. Within the lode the dacite is typically pyritic; it is locally sheared and altered. Mineralization consists of massive pods and lenses of coarse-grained and local steel galena enclosed in a country rock of limonite-stained clay gouge. Trace amounts of sphalerite are also visible.

Following Cairnes' (1934) definition and classification scheme for mineralized structures in the Slocan camp, Hallmac is a 'shear-vein lode deposit' containing 'wet' ore. It comprises a roughly 10-metre-wide "lode" structure that strikes 075 degrees and is intermittently mineralized with lead, zinc, and silver sulphides. The geometry of the lode system is evident in vertical section A — A' (Fig. 45-3). Below 1735 level mineralization is confined to the walls of the shear zone, so separate hangingwall and footwall veins occur. Between these veins the lode is rarely mineralized and consists of variably sheared country rock. Above 1735 level the footwall is not well defined and the 'veins' appear to merge. Here the entire width of the lode consists of thoroughly sheared, altered country rock that contains relict stringers and pods of galena.

PETROLOGICAL SAMPLING PROCEDURES

Aggregate chip sampling of the mine was carried out during the summer of 1983. Later that same year additional sample rejects were supplied by the operators. Obviously, aggregate chip samples of this nature pose limits on textural and paragenetic studies, though at the outset of the study only a correlation between mineralogy and assay data was sought. In all, a total of 34 polished sections were prepared, 18 samples from the hangingwall vein and 16 from the footwall vein (Fig. 45-4).

A subset of five samples was selected to determine if redistribution of ore minerals during deformation could be related to microstructures. These samples were etched using either Brebrick and Scanlon (1957) etchant (following the technique of McClay, 1977) or a solution of $KMnO_4$ + H_2SO_4 (as outlined in Ramdohr, 1969) for galena and sphalerite respectively.

Mineralogy and paragenesis were established using a reflecting microscope and scanning electron microscope-energy dispersive X-ray emission spectrometer unit. Only a synopsis of the study results is presented here.

VEIN MINERALOGY

In the Hallmac deposit only galena with trace amounts of sphalerite and pyrite are visible mesoscopically. The gangue consists of crushed country rock, quartz, calcite, and siderite, all of which are thoroughly altered by supergene processes. No decrease in the amount of oxidation is evident with depth. Common vein mineralogy is galena, sphalerite, pyrite, freibergite, acanthite, pyrargyrite, chalcopyrite, and freieslebenite.

British Columbia Ministry of Energy, Mines and Petroleum Resources, Geological Fieldwork, 1985, Paper 1986-1.

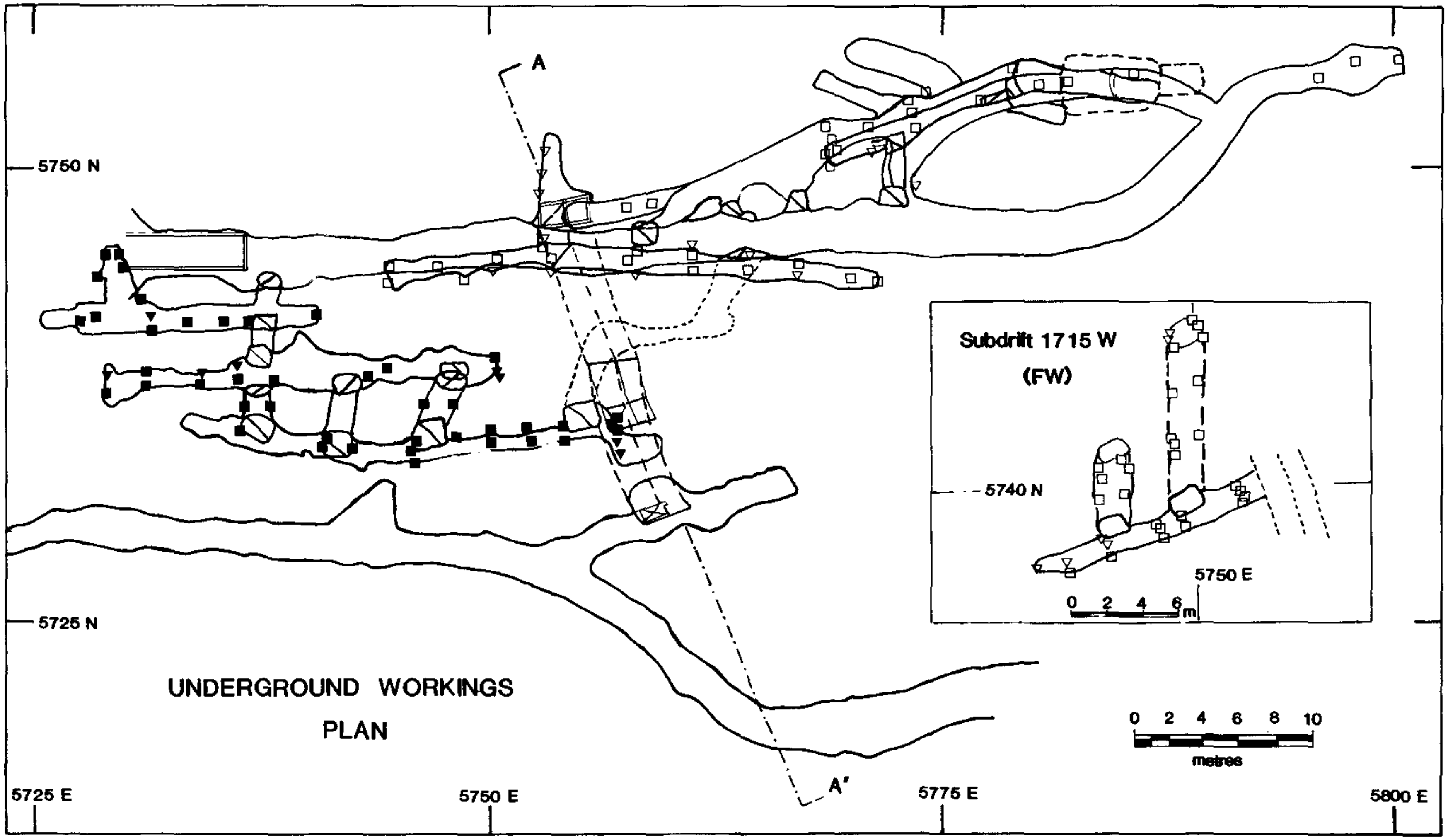

Figure 45-2. Plan view of underground workings, Hallmac mine, Sandon, showing location of single and composite samples. Symbols distinguish hangingwall vein (■) and wallrock (▼) from footwall vein (□) and wallrock (▼) samples.

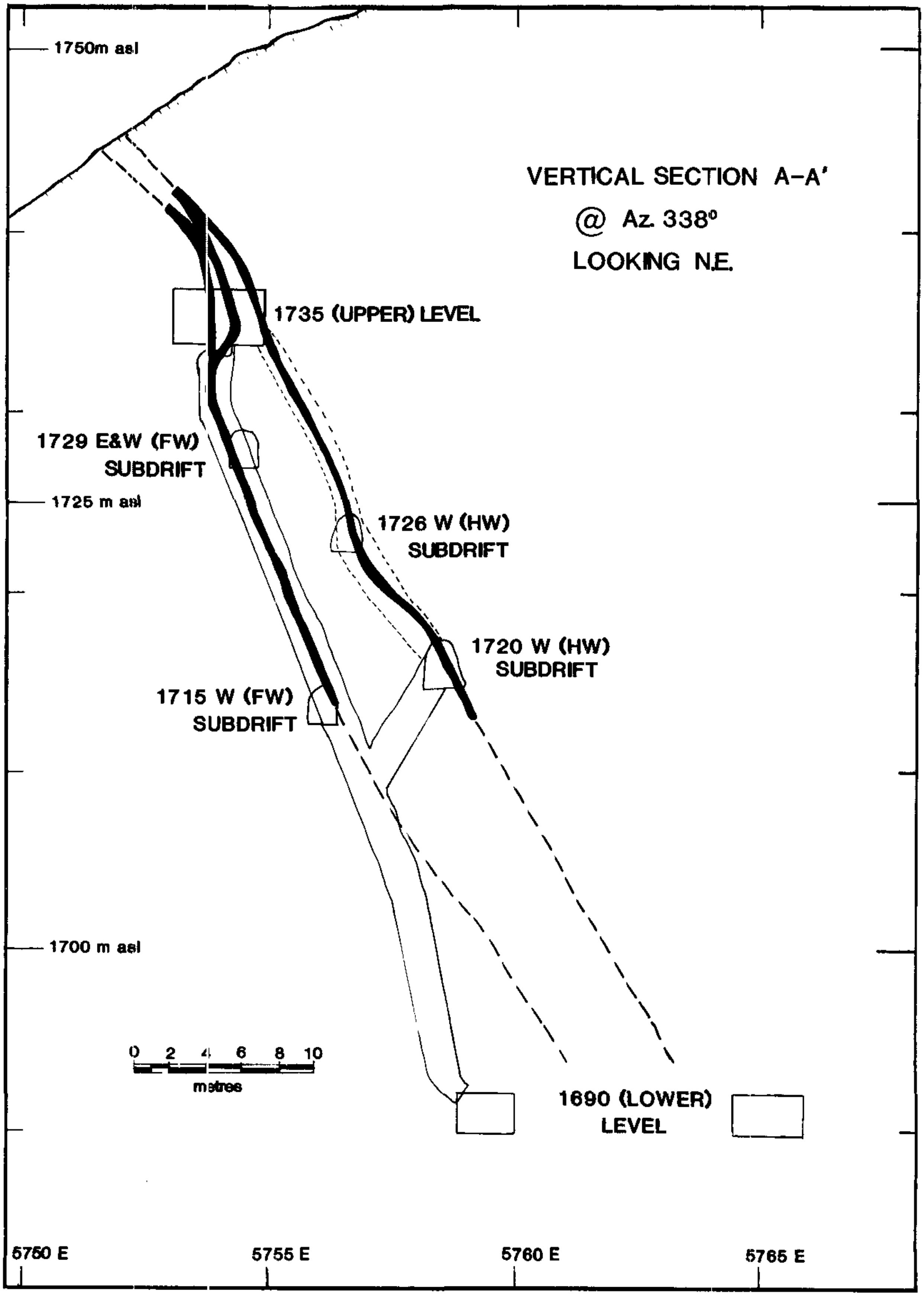

Figure 45-3. Vertical section A-A', Hallmac mine, Sandon, showing structure of lode system. Below the Upper level (1 735 metres above sea level) the structure branches into hangingwall and footwall veins.

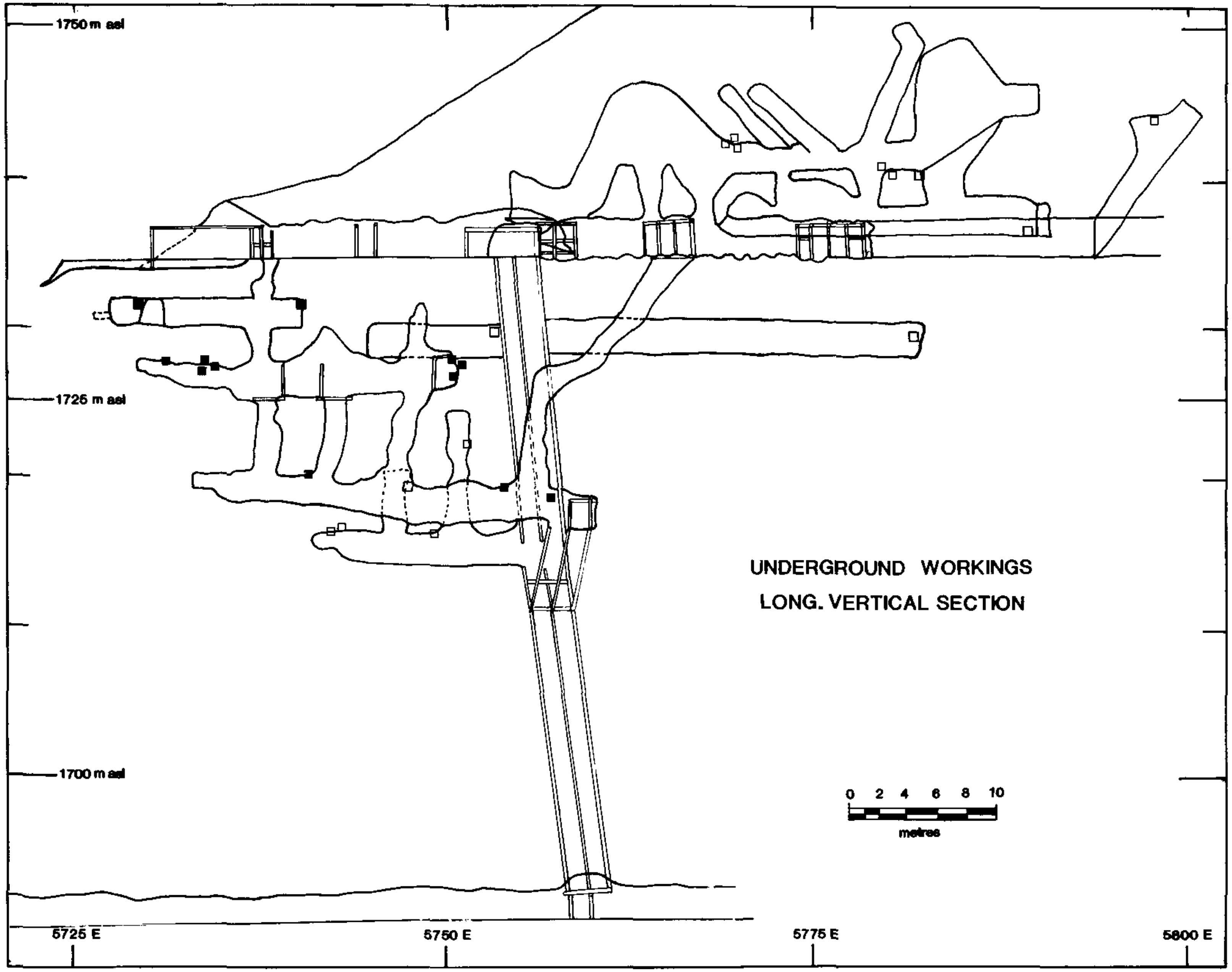

Figure 45-4. Longitudinal vertical section. Hallmac mine, Sandon, showing vertical and horizontal distribution of petrographic samples; hangingwall (■) and footwall (□).

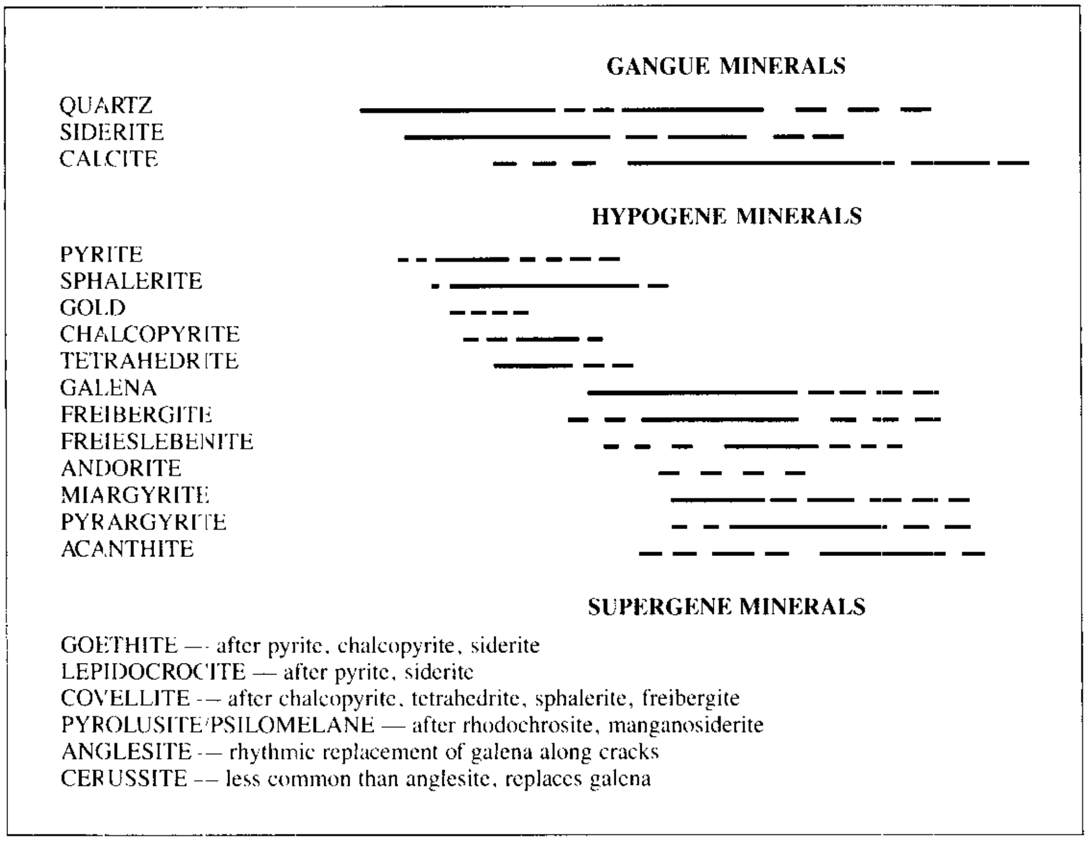

Figure 45-5. Paragenesis Hallmac mine line diagram.

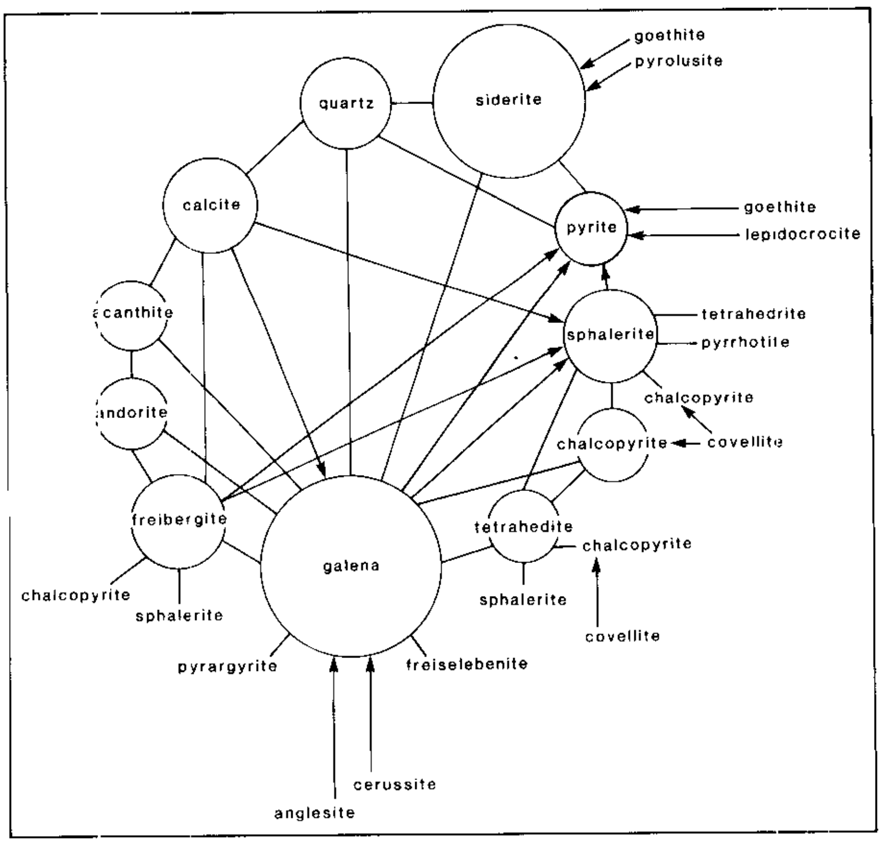

Figure 45-6. Van de Veer paragenetic diagram, Hallmac deposit.

MICROSTRUCTURES

Post-depositional shearing has affected the ore minerals variably, depending upon their respective rheologies and locations within the stress field. Pyrite has deformed by brittle fracture, and granulation has produced porphyroclasts of sphalerite. Where shearing has been operative both minerals are drawn out into parallel strings of granules within a matrix of galena (Plate 45-1).

Shearing has affected galena more noticeably than any of the other ore minerals. Grain size varies from coarsely crystalline (4 by 4-centimetre cubes) in zones isolated from shearing, to foliated steel galena where deformation has produced a variety of superimposed microstructures and textures in addition to grain size reduction. These textures include kink banding, polygonization, dynamic recrystallization and curved {001}cleavages. Kink band boundaries in galena are outlined by a high density of etch pits (= crystal dislocations) localized along slip planes (Plate 45-2b). Where polygonization developed adjacent to pyrite or sphalerite grains, small relict subgrains (Plate 45-2d) are preserved. Greater than 1 millimetre away from these areas of relatively high strain, subgrain size is markedly larger.

Freibergite and silver sulphosalts display different textures and residence following deformation. In samples which have undergone deformation these silver-bearing minerals occur in parallel layers intergrown with sphalerite, interstitial to polygonized galena, and localized along slip planes. In the undeformed samples, exsolution bodies of these minerals are aligned parallel to {100} planes in galena.

An increase in the grain size and relative abundance of freibergite and freieslebenite occur within deformed samples at the expense of oriented exsolution minerals. These 'second phase' inclusions are localized at triple junctions and along elongate grain boundaries coincident with partially annealed kink band boundaries.

PARAGENESIS

Relict depositional relations preserved in sheared samples and primary textures in unsheared samples permit a paragenesis to be determined with confidence, in contrast to the concerns of both Uglow (1917) and Bateman (1925). The paragenetic sequence of ore deposition for Hallmac follows closely that established by Cairnes (1934) for the Slocan camp, 'commencing with the earliest mineral: quartz, pyrite, calcite, siderite, sphalerite, grey copper, galena and argentite, pyrargyrite, silver'. The textural and paragenetic relationships for ore and gangue minerals is summarized in a line diagram (Fig. 45-5) and a Van de Veer diagram (Fig. 45-6).

Shearing and fracturing in not less than two separate events, likely syn and post-ore deposition, have altered the earliest formed textural relations. Uglow (1917) recognized 'gneissic galena' from Slocan ores to be a shear-generated texture and suggested that the *en echelon* distribution of orebodies within a shear zone was related to shearing parallel to an early vein. Ore shoot distribution, geometry, and mineral microstructures suggest a shear fracture origin. More recent studies (Atkinson, 1976; Clark, *et al.*, 1977; McClay and Atkinson, 1977) of the deformation and annealing properties for single galena crystals and polycrystalline aggregates have led to the quantification of deformation mechanisms and recovery processes.

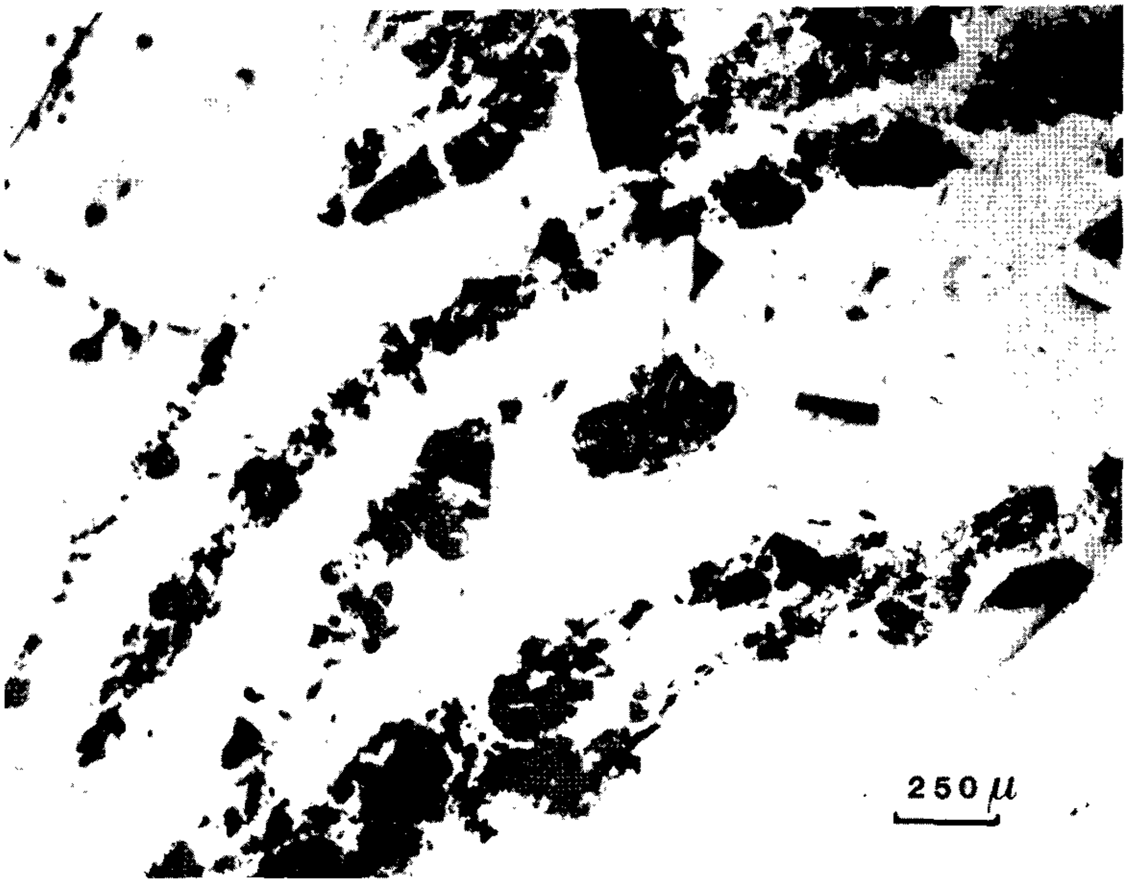

Plate 45-1. Parallel layers (dark) of sphalerite, freibergite, and pyrite granules defining mineral lineation in matrix of recrystallized galena (pale). Reflected plane polarized light.

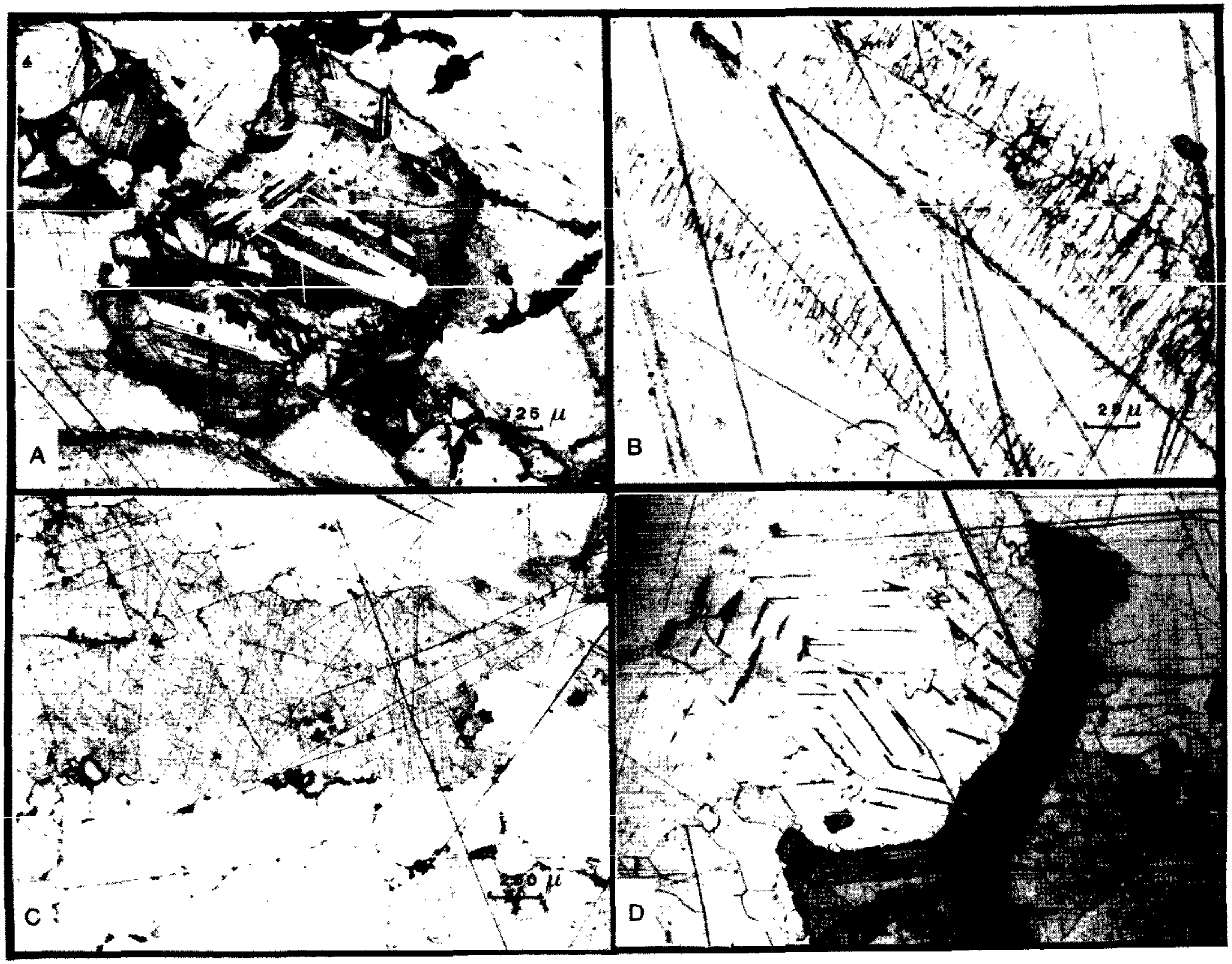

Plate 45-2. Reflected plane polarized light photomicrographs of polished and etched samples. A: Growth-annealing twins in sphalerite porphyroclasts (etched by $KMnO_4$ + H_2SO_4); B: Kink bands defined by etch pits (Brebrick and Scanion etchant); C: Sutured boundaries between elongate galena grains (etchant as in B); D: Sphalerite (centre) in groundmass of annealed galena. Freieslebenite occupies interstitial positions for foam texture. Relict subgrain evident in upper left (both Brebrick and Scanion etchant and $KMnO_4$ + H_2SO_4).

Interpretation of microstructures in light of these experimental studies allows constraints to be placed on the timing and mechanism of the redistribution of ore minerals.

Dynamic recrystallization (sutured boundaries on elongate grains, Plate 45-2c) and polygonization (Plate 45-2d) are common throughout deformed samples. Both are generated by intracrystalline deformation, neither requires later annealing (McClay, 1984). An upper temperature limit of 300 degrees Celsius (dry experimental deformation) is invoked by Clark, *et al.* (1977), as characteristic of 'sutured' kink band boundaries. Much lower temperatures are inferred for a fluid-dominated system such as is envisioned during the vein deposition episode.

Growth-annealing twins in sphalerite, locally pinned grain boundaries (calcite), and foam texture (120 degree triple junctions) in the most sheared samples are all indications of annealing processes. No restriction or systematic distribution between annealing textures versus deformation textures is obvious. Formation of annealed textures coincided with a period of high ambient temperature either metamorphic, hydrothermal, or shearing generated.

Recrystallization and microscopic redistribution of ore minerals occurred within the lode in response to tectonism. A simplistic approach to understanding the distribution of silver-bearing exsolution bodies in deformed samples was achieved by analysing small areas of the sample in terms of single crystal deformation mechanisms. Where the polycrystalline/polymineralic nature of the ore results in substantially more complex behaviour during deformation, this provides a working model for intragrain changes during deformation.

Nucleation sites of exsolution phases are localized at imperfections such as dislocations, twin lamellae, slip planes, and grain boundaries. Galena has two principal slip systems {100} <011> and {110} <110>; the former is operative below 300 degrees Celsius, and dislocation creep and glide are the deformation mechanisms (McClay, 1980). During low temperature deformation therefore, the slip and exsolution planes are coincident for galena. A dislocation climb-type mechanism is envisioned to facilitate migration from this plane of high stress to subgrain boundary locations. These inclusions alternatively may represent primary exsolutions involving no additional deposition.

Secondary or 'deformation induced' exsolution initiated by shear stress likely occurred during dynamic recrystallization and polygonization. This resulted in grain boundary migration and crystalliation of freieslebenite interstitial to galena subgrains. Exsolution minerals are impurities and as such cause deformation to take place at lower temperatures and/or lower stress. Hall and Czamanske (1975) reported similar mobilization and recrystallization of inclusions following gliding and resultant annealing in lead-silver ores from Idaho.

Late groundwater circulation along the lode structures has oxidized, leached, and further obliterated primary structures and produced supergene overprinting.

METAL DISTRIBUTION

ASSAY DATA

Data used to examine metal distribution patterns were collected and supplied to the writer by G. Salzar. The data comprises 150 chip samples distributed roughly equally between footwall and hangingwall veins. Samples were analysed by atomic absorption spectrophotometry at Loring Laboratories Ltd., Calgary, Alberta. The assay data include silver, lead, zinc, copper, and gold values and corresponding width measurements. Initial data were subdivided into hangingwall vein ($n = 61$), footwall vein ($n = 73$), and wallrock of both vein structures ($n = 26$). Assay results are not complete for either gold or copper. Sample coordinates were measured for each sample to permit machine contouring in plan and vertical section. Where more than one sample constitutes the width of the vein (at a single location) the disparity between samples is large in some cases. To facilitate contouring, such data were averaged and the mean replotted. This reduced the data set to $n = 43$ and $n = 30$ for footwall and hangingwalll samples respectively.

STATISTICAL ANALYSIS

Histograms and probability plots of both arithmetic and log values for all variables were computer generated. Silver, lead, and gold consist of mixtures of 3, 2, and 1 log-normal distributions respectively; zinc and copper consist of mixtures of 3 and 1 normal distributions respectively. Width was considered too subjective, considering the nature of these veins, and was not considered further.

Partitioning the data into the subpopulations described earlier was achieved graphically, following the procedure outlined by Sinclair (1976). Figure 45-7 illustrates the probability plot for silver from the hangingwall. Three populations are evident. The upper two with threshold values of 6 and 46 ounces silver per ton, correspond to 'mill-grade' and 'high-grade' ore respectively. The means, standard deviations, and threshold values for partitioned populations of silver, lead, zinc, copper, and gold are presented in Table 45-1. The threshold values provide the contour values which separate and define high-grade ore shoots (population A) and separate mineral zoning patterns.

TRIANGULAR PLOTS

Goldsmith (1984) has shown the usefulness of triangular plots in characterizing metal ratios of deposits in individual mining camps. Here plotting assay data on triangular plots permits recognition of separate data clusters within a single deposit. The most useful triangular plots for examining fundamental differences in metal

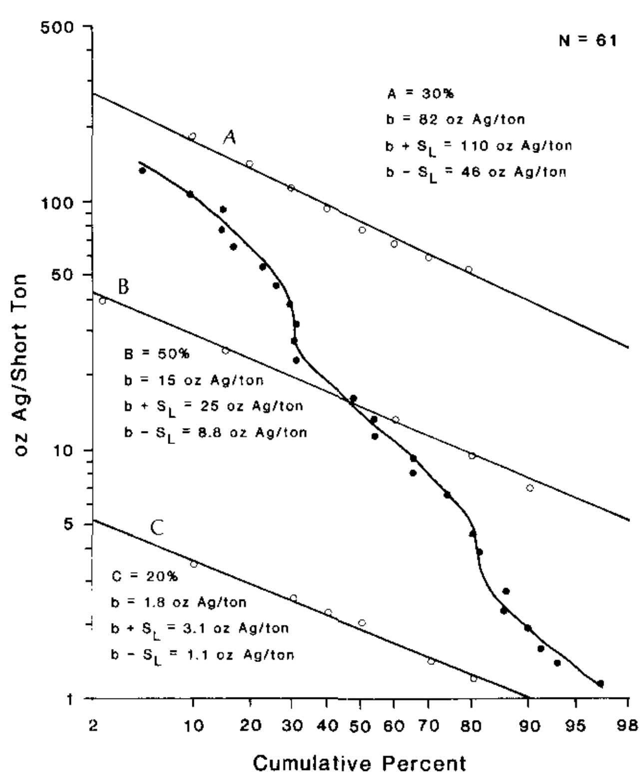

Figure 45-7. Probability graph for 61 silver values from hangingwall vein. Black dots are original data, open circles are estimated partitioning points. Three populations are evident from lognormal distribution of silver values.

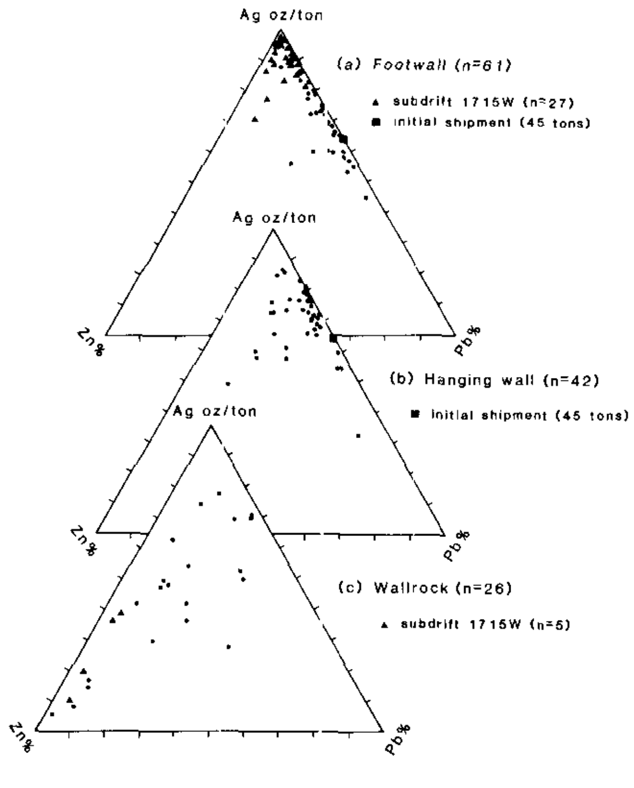

Figure 45-8. Silver-zinc-lead triangular plots of footwall, hangingwall, and wallrock, Hallmac mine.

ratios in Hallmac assay data are silver-zinc-lead and copper-silver-lead. To produce more easily interpreted patterns, copper and gold data were converted to ppm/100. Silver is plotted as ounces per ton and lead and zinc as per cent.

Silver (ounces)-zinc (per cent)-lead (per cent) plots for footwall and hangingwall data sets (Fig. 45-8) indicate that: silver-lead ratios for veins (and wallrock) generally exceed 1 ounce/per cent; zinc is subordinate to lead, as for Trout Lake camp (Goldsmith, 1984); and a subset of the footwall data contains high silver to lead ratios. Comparison of Figure 45-8a with Figure 45-9b indicates a subgroup of 27 samples with silver-lead ratios exceeding 4 ounces silver/1 per cent lead. Examination of samples from subdrift 1715 W shows that 25 of the 29 were collected from this one small area. Once subdrift 1715 W is isolated, distinctions between hangingwall and footwall become less evident. Figure 45-8 indicates slightly higher relative silver and zinc in the hangingwall samples compared with those for the footwall.

Figure 45-8c shows that plots of metal ratios in wallrocks exhibit considerable scatter; a continuous variation in proportions extends from the mineralized vein field to the zinc vertex; and lead is generally subordinate to zinc. A small group of five samples contains similar proportions but lower absolute amounts of silver-zinc-lead than average vein samples. This apparent overlap emphasizes the difficulty in separating vein from wallrock, particularly where post-ore deformation has obscured the contacts. No apparent supergene enrichment of silver values is evident for wallrock from subdrift 1715 W.

The zinc-copper-lead plot (Fig. 45-9a) shows two clusters of data where lead values are subordinate to zinc (a characteristic typical of wallrocks). The cluster near the copper vertex corresponds to a footwall subset representing subdrift 1715 W. A hangingwall copper-zinc-lead plot shows a similar cluster of data, which corresponds to sample sites located in the lowest portions of the hangingwall workings. This area coincides roughly in elevation with subdrift 1715 W.

A silver-copper-lead plot does not produce a clearly defined footwall subset, instead the data tend to spread out close to the silver-copper line in response to the low relative lead abundance of the data (Fig. 45-9b).

PLAN AND VERTICAL CONTOURING

Composite plans, rather than individual level plans, have been constructed for silver, lead, zinc, copper, and gold utilizing the entire assay database. For this, data from all levels including hangingwall, footwall, and wallrock samples (n = 150) were projected to one plane and contoured. Threshold values defined in Table 45-1 were used as the initial contour values. The more common practice of compiling level plans proved unsatisfactory because of small data sets reflecting the limited size of the workings. These plots (not reproduced here) illustrate the general east-west strike of the fissure and the gross geometry of assay-defined ore shoots, the southwesterly rake of which is the most apparent feature.

Simple correlation between elements and zonation patterns are best illustrated on vertical sections. Using respective assay data from either footwall or hangingwall structures, east-west vertical sections for both were constructed. The variables included the same five metals listed previously and, in addition, various metal ratios. Figure 45-10 shows contoured log silver values for the hangingwall workings. Overlaying log 10 × lead (population A) and log 100 × zinc (populations A and B) contours, it is evident that silver and lead are positively correlated. Zinc is peripheral to both silver and lead

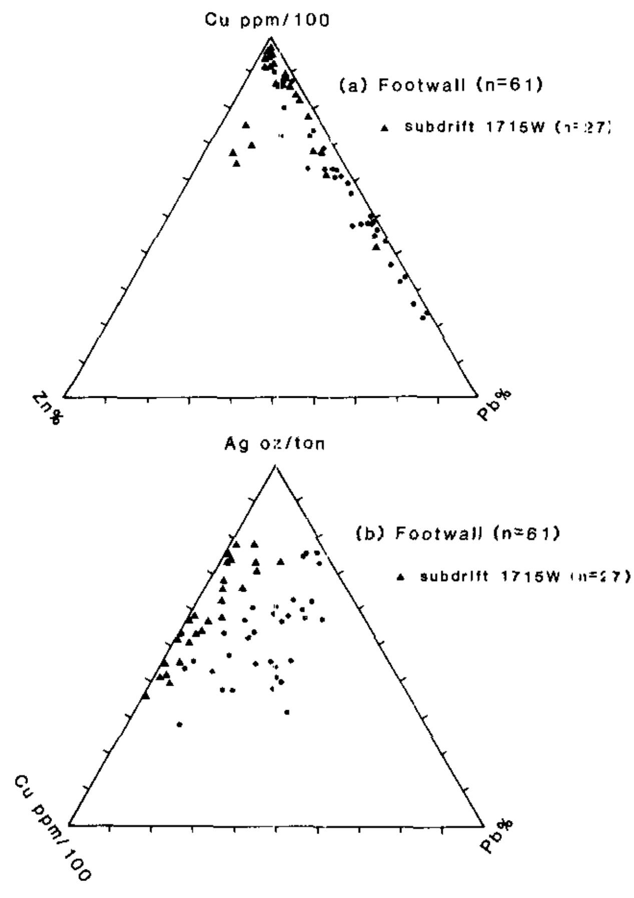

Figure 45-9. Zinc-copper-lead and silver-copper-lead triangular plots of footwall, Hallmac mine.

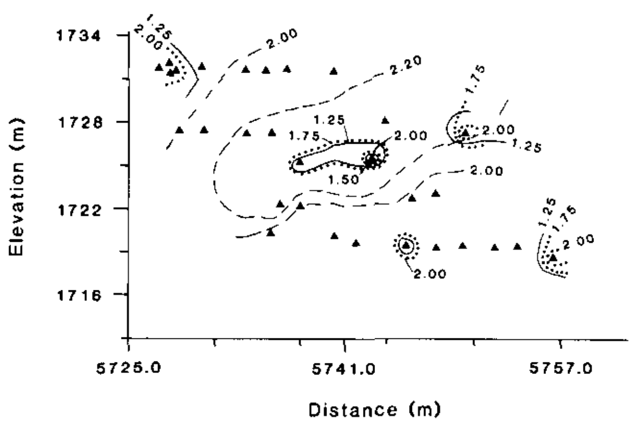

Figure 45-10. Hangingwall vertical section. Dashed contour lines are log (100 × Zn per cent); dotted lines log Ag (ounces per ton); and solid lines log (10 × Pb per cent). Zinc outlines a concentric central zone cored by high-grade silver and lead. Silver and lead show coincident distribution and define ore shoot locations throughout the workings.

and outlines a concentric zone of high values centred on the hangingwall workings. The same pattern for silver and lead is found in the footwall vertical section, though that for zinc is less apparent.

Subdrift 1715 W data, which forms a separable cluster on triangular plots, was isolated from the footwall and contoured separately (Fig. 45-11). Plotting single metals shows that highest silver and lead values coincide with the uppermost sections of both raises and the west end of the subdrift. Contouring silver suggests two >50-ounce-per-ton silver zones raking 30 degrees southeast. Lead values decrease down rake away from the 'silver-defined' shoots. Contour patterns for both zinc and copper are less consistent, showing no systematic distribution. Higher values for both metals coincide in part with the ore shoots, but just as commonly do not.

Contour plots of logged lead to zinc ratios show that values decrease down rake, away from the ore shoots. The reverse is true for logged silver to lead ratios: these values increase by an order of magnitude proceeding from the upper to lower portions of the workings (Fig. 45-11c). Logged silver to zinc ratios (Fig. 45-11d) define a central, westerly raking low perpendicular to the rake of the ore shoots, thus defining limits to the down rake extension of the >50-ounce-per-ton silver ore shoots.

DISCUSSION

Metal zoning patterns in individual ore shoots, noted first by Cairnes (1934), have been the focus of re-interpretation by numerous later studies (Robinson, 1948; Hedley, 1952; Orr, 1971). The pattern is described as a vertical phenomenon characterized by galena and silver minerals in the uppermost sections, surrounded by a sphalerite-rich zone, which gives way successively downward to pyritic and silicic zones. Cairnes (1934) attributed this pattern to a steep geothermal gradient coincident with the present topography. Hedley (1952) and Robinson (1948) suggested mineral precipitation to be a pressure-related phenomena, relating zonation to vein dilation which in turn was related to closeness to the surface. Orr (1971), using production data and elevation of Slocan City deposits to the south, could not identify vertical zoning within individual deposits, although he documented a district zonation for the Slocan City camp.

Traditionally this zoning pattern has been viewed as unidirectional and not concentric. From top to bottom the pattern is identical to the paragenetic sequence for the camp and early workers cited this to support a granitic source for the deposits. Hedley (1952)

TABLE 45-1
MEANS, STANDARD DEVIATIONS, AND THRESHOLDS DETERMINED GRAPHICALLY FOR PARTITIONED METAL VALUES

	FOOTWALL VEIN					HANGINGWALL VEIN				
Element Unit	Populations Per Cent	b[1]	b + s[2]	b − s[3]	Thresholds	Populations Per Cent	b[1]	b + s[2]	b − s[3]	Thresholds
Ag	A(0.59)	60	110	32	45	A(0.30)	82	110	46	46
Oz./ton . . .					25					17
	B(0.33)	12	22	6.8	5.5	B(0.50)	15	25	8.8	6.0
	C(0.08)	3	4.1	2.1		C(0.20)	1.8	3.1	1.1	
Pb...........	A(0.80)	9.8	30	2.8	3.0	A(0.42)	21	36	12	20
Per cent... . .					0.8					7.0
	B(0.20)	0.62	1.3	0.3		B(0.58)	1.8	5.8	0.54	
Zn[4]	A(0.03)	2.37	2.42	2.32	2.2	A(0.05)	2.6	2.7	2.5	2.37
Per cent. ...	B(0.15)	1.72	1.95	1.47	1.7	B(0.57)	1.4	1.8	0.97	1.05
					1.25					0.5
	C(0.82)	0.92	1.3	0.52		C(0.38)	0.55	0.78	0.30	
Cu[4]	A(1.0)	0.175	0.33	0.04	0.45	A(0.08)	0.35	0.39	0.31	0.28
Per cent........						B(0.52)	0.15	0.21	0.09	0.10
										0.03
						C(0.40)	0.08	0.07	0.02	
Au........ . . .	A(1.0)	0.0057	0.022	0.0014	0.08	A(1.0)	0.0076	0.026	0.0023	0.08
Oz./ton										

Per cent of data in population.
[1]Antilog of mean of log-normal population.
[2]Antilog of mean plus one standard deviation of log-normal population.
[3]Antilog of mean minus one standard deviation of log-normal population.
[4]Normal distribution.

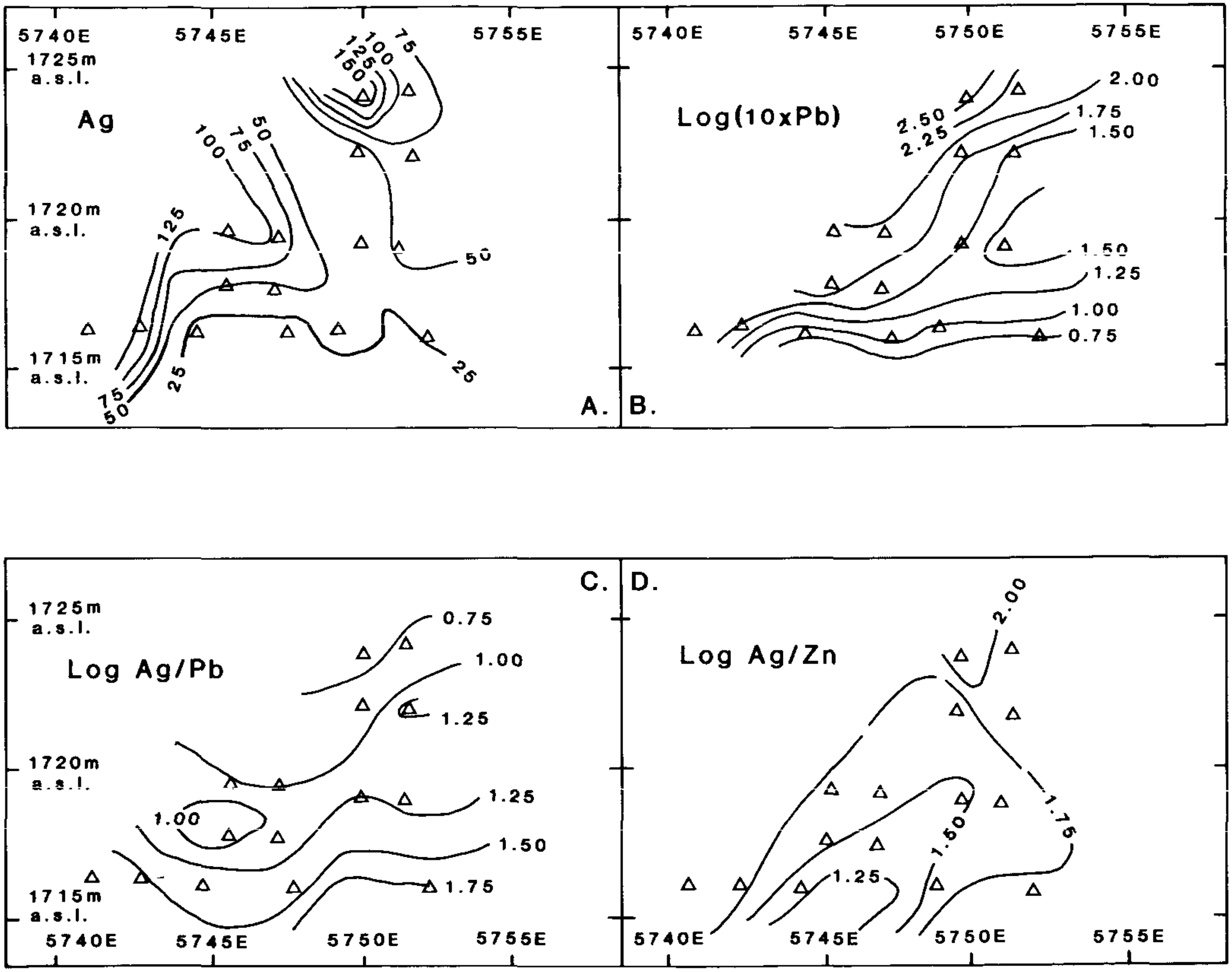

Figure 45-11. Contoured assay values for subdrift 1715 W. Triangles give data points. A: silver in ounces per ton; B: log (10 x Pb) in per cent; C: log Ag/Pb ratios, silver in ounces per ton and lead in per cent, D. log Ag/Zn ratio with silver in ounces per ton and zinc in per cent.

discussed lateral continuity within lode structures and suggested a concentric zoning pattern. Ideally, mineral deposition in a dilation structure should produce a concentric zoning pattern which reflects the paragenesis. The earliest minerals adjacent to vein walls and the latest in the centre or core. Missing zones would reflect intermittent closures of the structure that restricted fluid flow.

Triangular plots have been shown effective on a single deposit scale in defining separate groups of data. Such plots utilize proportions rather than absolute amounts of three elements. Thus, where strong correlation exists between the elements, little or no distinction is made between high-grade or low-grade samples. Discrimination between slightly mineralized wallrock and low-grade vein material or waste is possible on the basis of relative proportions, particularly silver, lead, and zinc. Using either relative proportions or selective metal ratios, 'discriminant areas' could be defined for triangular plots. These areas would correspond to specific zones within the ideal zonation pattern for Slocan ore shoots and provide a more predictive alternative for locating ore shoots. Historically silver values alone have directed underground exploration.

Contouring assay data allows recognition of generalized metal associations and spatial distributions within the Hallmac deposit. Analysis of Hallmac metal distribution patterns, following Sinclair and Tessari's method (1980), indicates a generalized zonation pattern compatible with the established paragenesis. The method involves arranging samples in order of decreasing values of a key metal; in this study both silver and zinc were tested. Other element distributions are examined relative to this idealized ordering of one element. Upper population (A) values correspnding to high-grade ore shoots reflect a simple zonation model of high zinc values peripheral to or enveloping a high silver and lead core. This zonal pattern does not extend beyond the scale of ore shoots for either footwall or hangingwall data.

Contoured ratios of metal pairs for both hangingwall and footwall structures show a distinctive zonation pattern for subdrift 1715 W. This departure from the generalized 'wet-ore' zonation pattern suggests either a separate silver mineralizing event of enrichment or nonsymmetric overlap of zonation patterns. Contouring the data indicates that high ratios in which log (silver/lead) exceeds 1 are localized at the fringes of ore shoots where average ratios are 1. Comparing absolute values of silver and lead indicates only lower average lead rather than higher silver for subdrift 1715 W. Silver values extend outward from this silver-lead core, likely in the form of late-stage silver-bearing minerals. The lower than average abundance of galena is evident in polished aggregate sections from 1715 W subdrift, where half of the samples contained few visible sulphides of any type. Pyrargyrite and acanthite have replaced both galena and locally calcite, suggesting a late stage of predominantly silver mineralization. An equally plausible explanation for apparent enrichment of silver and copper with respect to lead is supergene enrichment.

CONCLUSIONS

Hallmac deposit contains the mineralogy typical of Cairnes' 'wet-ore' classification. Mineralogical and paragenetic studies have established the presence of pyrite-sphalerite-galena and a complex assemblage of silver minerals. Early and late stages of silver mineralization are characterized by distinctive mineralogies and are separable by their respective metal zoning patterns. Observed textures and distribution patterns of early freibergite and silver sulphosalts indicate an exsolution origin in galena. Late-stage silver minerals, pyrargyrite, andorite, and acanthite, postdate the bulk of galena deposition; thus, replacement of galena and overprinting of earlier developed zoning patterns typify this younger stage of silver mineralization.

Early-stage silver-sulphosalt textures indicate exsolution following an initial precipitation as some $PbS\text{-}Ag_2S\text{-}Sb_2S_3$ solid solution. Exsolution laths of freieslebenite in galena suggest a temperature of deposition of about 350 degrees Celsius (Hoda, *et al.*, 1975).

Sulphide microstructures within the lode indicate redistribution of minerals on both a macro and microscopic scale related to ductile deformation and annealing processes. Exsolution minerals in galena are most affected.

Statistically defined contour values (thresholds) clearly identify a zonal distribution of sulphides in ore shoots. These patterns illustrate the 'classic' camp zoning pattern, developed for single ore shoots. Ratios of metal pairs isolate subdrift 1715 W as different from the generalized zonal pattern.

Triangular plots of metal abundances are also effective in distinguishing vein material in subdrift 1715 W from the rest of Hallmac deposit. The 1715 W data cluster close to the silver vertex on the silver-zinc-lead plot indicating relatively higher silver and lower lead than the remainder of the data. With the exception of lead, absolute metal values for subdrift 1715 W are comparable in range and proportion (A:B:C populations) with the rest of the footwall data. Lead values are an order of magnitude lower, but do not account solely for the relative increase in silver. Polished sections indicate less galena and related sulphosalts and a greater proportion of pyrargyrite and argentite. This suggests that late-stage silver mineralization took place in the 1715 W drift area of the mine.

ACKNOWLEDGMENTS

This study has been supported by research funds from Arctex Engineering Ltd. and the Natural Science and Engineering Research Council of Canada to A. J. Sinclair. The cooperation of Hallmac Mines Ltd. and their consultant, Guy Salazar, is appreciated.

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A RE-EVALUATION OF PRODUCTION DATA BRIDGE RIVER-BRALORNE CAMP (92J)

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INTRODUCTION

Production data can be used to develop quantitative models for exploration and evaluation of polymetallic vein deposits in mining camps (Sinclair, 1979, 1982; Goldsmith and Sinclair, 1985). Many of the polymetallic deposits in the Bridge River-Bralorne camp have produced gold and silver and a few contained substantial tonnages of ore. This investigation of available production data from the Bridge River-Bralorne camp was undertaken due to the resurgence of gold exploration in the area.

The Bridge River area has been known as a gold-bearing area since the last century and originally was developed extensively by placer miners before lode mining became important. The rugged valleys and peaks of the Bralorne area have hindered development, most of which has been confined to the valleys of Cadwallader Creek and Carpenter Lake. In its early days the area was referred to as the Bridge River camp but since dams on the Bridge River have led to the formation of Carpenter and Downton Lakes the name Bralorne camp has been adopted, after the largest mine in the area.

TABLE 46-1. PRODUCERS

Map No.	Name	Tonnes	UTM Coord. E-ing	UTM Coord. N-ing	Latitude	Longitude	Grade[2]	Au/Ag	Country Rock	Reference[1] Author	Reference[1] Year
39	Ample[3]	2 789	5652	56097	50°39′00″	122°02′40″	Au 8.11		brgp	BCMM	1946
2	Blackbird[4]	145	5143	56241	50°46′20″	122°47′45″	Au 17.8 Ag 2.1	8.3	brin pion pres		
1	Bralorne	4 981 419[5]	5129	56259	50°46′40″	122°49′00″	Au 17.6 Ag 4.4	5.4	brin pion pres		
41	Brett Group[3]	9 177	5348	56078	50°38′00″	122°28′20″	Au 2.4		brin		
29	Congress	943[6]	5155	56378	50°53′30″	122°46′40″	Au 2.7 Ag 1.4	2	brgp dyke	McCann AR9355	1922 1981
7	Coronation .	11 155	5148	56234	50°45′45″	122°47′30″	Au 19.7 Ag 2.8	7.0	brin pion		
22	Gloria Kitty .	4 343	5123	56308	50°49′45″	122°49′30″	Au 0.11 Ag 0.07	1.5	brin pion		
49	Jewel	51	5043	56395	50°54′30″	122°56′20″	Au 73.2 Ag 8.1	0.24[8]	pres dyke hurl		
42	Lucky Strike	29[9]	5097	56478	50°59′00″	122°51′40″	Au 53.3 Ag 1.8	0.45[8]	hurl brgp brin	BCMM	1936
46	Minto ..	80 650	5176	56386	50°54′00″	122°45′00″	Au 6.8 Ag 19.5	0.35	brgp dyke		
4	Pioneer	2 313 552	5156	56228	50°45′30″	122°46′40″	Au 17.9 Ag 3.3	4	brin pion		
30	Wayside	39 094	5121	56362	50°52′40″	122°49′40″	Au 4.2 Ag 0.67	6.4	brin		

[1] Only given where the source was not MINFILE. The abbreviations are BCMM for British Columbia Minister of Mines Annual Report and AR . . . for Assessment Report files with the provincial government. For names see bibliography.
[2] Grams per tonne.
[3] Not in map-area, included for study purposes.
[4] Part of the greater Bralorne mine, figures kept separate for study.
[5] Not including reserve estimates of 211 000 tonnes (cut-off 0.033 ounces per ton) to 544 000 tonnes (cut-off 0.0275 ounces per ton).
[6] Not including reserve estimates of from 50 000 to 100 000 tons. Production was done on a test scale only.
[7] Part of the greater Bralorne mine, figures kept separate for study.
[8] Au-Ag ratio taken from various assay results.
[9] Test sample only, no further work.

British Columbia Ministry of Energy, Mines and Petroleum Resources, Geological Fieldwork, 1985, Paper 1986-1.

TABLE 46-2. DEVELOPED PROPERTIES

Map No.	Name	UTM Coord. E-ing	UTM Coord. N-ing	Latitude	Longitude	Grade[1]	Au/Ag	Country Rock	Reference[1] Author	Reference[1] Year
3	Alma	5255	56119	50°46′55″	122°49′45″	Au 0.61		brgp pion brin	McCann	1922
24	Arizona	5115	563200	50°50′30″	122°50′15″	Au 2.1		brin	McCann	1922
28	B & F	5095	56401	50°54′45″	122°51′45″	Au 3.77		brgp pres dyke	BCMM Cairnes	1933 1937
13	Bramoose	5238	56190	50°43′30″	122°39′45″	Au		brgp bend pres	McCann BCMM	1922 1933
11	Butte	5242	56173	50°42′30″	122°39′30″	Au 6.1		noel pion brin	Cairnes BCMM BCMM	1937 1932 1933
20	California	5126	56298	50°49′20″	122°49′15″	Au 23.0 Ag		noel brin	Cairnes	1937
12	Dan Tucker	5222	56187	50°43′20″	122°41′10″	Au		pion brin		
45	Dauntless	5180	56392	50°54′20″	122°44′40″	Au 5.1 Ag 3.0	1.2	brgp	Cairnes	1943
36	Empire	5300	56159	50°51′40″	122°34′30″	Au 0.6 Ag		brgp dyke	McCann	1922
23	Forty Thieves	5118	56309	50°49′50″	122°50′00″	Au		brin	McCann Cairnes BCMM BCMM BCMM BCMM	1922 1937 1938 1931 1932 1933
47	Golden	5167	56385	50°54′00″	122°45′40″	Au 14.4 Ag 46.2	0.31	brgp	Cairnes	1943
25	Golden Gate	5114	56324	50°50′40″	122°50′15″	Au	4.2	brin	Cairnes	1937
44	Little Gem	5034	56383	50°53′45″	122°57′15″	Ag Au	2.5	coas		
48	Northern Light	5092	56467	50°59′30″	122°52′15″	Au 53.3 Ag 1.8	0.45	brgp dyke pres shul	BCMM Cairnes AR6002	1936 1943 1976
50	Olympic	5175	56374	50°53′30″	122°44′20″	Au 3.1 Ag 15.3	0.20	brgp dyke	Cairnes	1943
52	Peerless	5148	56414	50°55′30″	122°47′20″	Au Ag	0.11	brgp	AR8457	1980
27	Pilot	5078	56357	50°52′30″	122°53′20″	Au Ag	0.06	coas	McCann	1922
9	Pioneer Extension	5173	56223	50°45′15″	122°45′15″	Au Ag		brgp		
38	Ranger	5179	56314	50°50′15″	122°44′40″	Au Ag	0.53	brgp brin	BCMM	1946
33	Reliance	5163	56363	50°52′45″	122°46′10″	Au Ag	1.5	brgp	BCMM	1936
34	Spokane	5417	56373	50°53′20″	122°24′20″	Au Ag	0.95	rxmt brgp	McCann	1922
35	Summit	5176	56266	50°47′30″	122°45′00″	Au Ag	1.0	brgp dyke		
32	White & Bell	5075	56487	50°59′30″	122°53′30″	Au Ag	2.0	brin	McCann BCMM	1922 1914
21	Whynot	5124	56301	50°49′30″	122°49′30″	Au 15.3		brin	McCann Cairnes	1922 1937

[1] Grams per tonne.

TABLE 46-3. PROSPECTS

Map No.	Name	UTM Coord. E-ing	UTM Coord. N-ing	Latitude	Longitude	Grade[1]	Au/Ag	Country Rock	Reference[1] Author	Reference[1] Year
40	Benboe	5321	56281	50°48′20″	122°32′40″	Au 6.0 Ag 15.3	0.5	brgp	BCMM	1937
69	Canadian Gold	5088	56462	50°58′10″	122°52′30″	Au		brgp pres	AR6002	1976
56	Chalco	5257	56186	50°43′15″	122°38′10″	Au 61.2 Au 0.31	0.01	brgp bend	BCMM	1948
57	Conbra	5219	56184	50°43′10″	122°41′30″	Au		brgp brin pres		
51	Gray Rock	5213	56274	50°48′00″	122°42′00″	Ag Au		brgp		
17	Grull	5118	56268	50°47′40″	122°49′45″	Au		brgp		
64	Gun Creek	5062	56396	50°54′30″	122°54′40″	Au		brgp	AR8911 AR9927	1980 1981
26	Haylmore	5112	56327	50°50′45″	122°50′30″	Au		brin pres		
8	Holland	5172	56228	50°45′30″	122°45′30″	Au		brgp		
65	Jean	5116	56397	50°54′30″	122°50′00″	Au		unkn	AR8875	1980
71	Kangaroo	5088	56343	50°51′45″	122°52′30″	Au		noel brin	AR8488	1980
63	Kelvin	5175	56374	50°53′20″	122°45′00″	Au Ag		brgp dyke		
66	Lynn	5133	56402	50°55′00″	122°48′30″	Au		unkn	AR9080	1980
53	Marconi	5128	56357	50°52′30″	122°49′00″	Au		brgp	McCann	1922
43	Mary Mac	5220	56342	50°51′30″	122°41′15″	Au		brgp brin		
5	Mix	5188	56218	50°44′50″	122°44′00″	Au		brgp		
58	Native Son	4970	56456	50°57′50″	123°02′20″	Au Ag		hurl		
6	Native Son	5133	56238	50°46′00″	122°48′40″	Au		noel dyke	Cairnes	1937
60	North Star—University	5146	56387	50°54′10″	122°47′30″	Au 0.61 Ag 18.4	0.03	brgp dyke	BCMM	1910
70	Oro	5088	56256	50°47′00″	122°52′20″	Au		hurl	AR8234	1980
10	Paymaster	5183	56204	50°44′20″	122°44′40″	Au		hurl pion brin		
37	Primrose	5296	56417	50°55′40″	122°34′45″	Au		king		
61	Red Hawk	5227	56186	50°43′15″	122°40′40″	Au		brin pres noel		
14	Royal	5251	56167	50°42′15″	122°48′45″	Au		brin brgp		
16	Short o'Bacon	5113	56246	50°46′30″	122°50′20″	Au Ag		brin pres brgp	Cairnes	1937
15	Standard	5282	56155	50°41′30″	122°36′15″	Au		brgp pres		
18	Success	5127	56269	50°47′40″	122°49′15″	Au		brgp noel	Cairnes	1937
59	Summit	5336	56354	50°52′15″	122°31′20″	Au Ag	0.18	brgp	BCMM	1910
68	Thule		located over very large area			Au		brgp	AR9526	1981
67	Ural		located over very large area			Au		brgp dyke pres	AR9062	1981
31	Veritas	5063	56318	50°50′30″	122°54′40″	Au		brin	McCann	1922
62	Vine	5137	56288	50°48′45″	122°48′20″	Au		brgp	AR8292	1980
19	Waterloo	5166	56269	50°47′40″	122°45′50″	Au		brgp		
55	Wide West	5103	56485	50°49′20″	122°51′15″	Au		brin brgp		
54	24th of May	5094	56485	50°59′20″	122°52′00″	Au Ag	0.22	brgp hurl dyke	BCMM	1913

[1] Grams per tonne.

AVAILABLE DATA

To initiate this study a geological map of the camp (Harrop and Sinclair, 1985) was compiled using information from government publications and from company assessment files. A total of 71 mineral occurrences were identified (Tables 46-1, 46-2, and 46-3). All contain gold and silver, although a few, such as Minto are enriched in silver. Most production and exploration in the camp took place during the 1930's and 40's, but during recent decades considerable information about some properties has been lost. The individual property names given during the most productive period are used in this study. Data for all occurrences are summarized in Tables 46-1, 46-2, and 46-3 and the occurrences are separated into the three following groups:

(1) **Producers**: Those with a recorded tonnage milled and from which gold and generally silver were recovered.
(2) **Developed Properties**: Those having considerable work done over a long period but no recorded production.
(3) **Prospects**: Those about which little is known either due to little activity or lack of records.

These locations are known accurately, their geology is known to some extent and a gold-silver ratio could be established with confidence for the ore recovered. Generally there is a good record of the geology and in almost every case an average gold-silver ratio could be established.

Sources for this compilation include reports of the B.C. Ministry of Energy, Mines and Petroleum Resources, Geological Survey of Canada papers and memoirs, assessments reports, and an unpublished manuscript by Stevenson (1958). A computer test file of map-area 92J for development of MINDEP, a computer-based filing system developed at the University of British Columbia (Sinclair *et al.*, 1978), was a detailed file on 92J and this was used as a starting point for the study. Of the earlier workers Cairnes (1937, 1943) was found to be the most informative. The maps from Stevenson also would have added to the study, but unfortunately these unpublished maps were not available. Other workers whose mapping has been studied in the compilation are Drysdale (1916), McCann (1922), Roddick and Hutchison (1973), Geological Association of Canada Guidebook #4 (1983), and various British Columbia Ministry of Energy, Mines and Petroleum Resources yearly reports and assessment reports.

GENERAL GEOLOGY

Harrop and Sinclair (1985) recently compiled a regional geological map of the Bralorne area. A brief description of the principal units follows:

(1) **Bridge River Group (Fergusson Series) (Middle Triassic and older)**: basalt; andesite; tuff; breccia; minor crystalline limestone; thinly bedded chert and argillite; massive chert; greenstone and biotite schist.
(2) **Noel Formation (Upper Triassic)**: argillaceous and tuffaceous sedimentary rocks; conglomerate; some chert and greenstone.
(3) **Pioneer Formation (Upper Triassic)**: greenstone derived from andesitic flows and pyroclastic rocks; andesite breccia, tuff, and flows; minor rhyolite, slate, argillite, limestone, and conglomerate.
(4) **Hurley Formation (Upper Triassic)**: thinly bedded limy argillite, phyllite, limestone, tuff, conglomerate, andesite, and minor chert.
(5) **Shulaps Ultramafics (Upper Triassic)**: peridotite; dunite.
(6) **Lower Jurassic (Lower Jurassic)**: argillite and shale; minor sandstone, limestone, and conglomerate.
(7) **Taylor Creek Group (Lower Cretaceous)**: conglomerate; shale; tuff; volcanic breccia; andesite and basalt.
(8) **Kingsvale Group (Upper Cretaceous)**: arkose; greywacke; shale and minor conglomerate.
(9) **Coast Plutonic Rocks (Upper Cretaceous)**: granite; granodiorite.
(10) **Bralorne Intrusives (Upper Cretaceous to Lower Tertiary)**: augite diorite; gabbro; trondhjemite; minor quartz diorite and soda granite.
(11) **Bendor Pluton (Lower Tertiary)**: granodiorite.
(12) **Rexmount Porphyry (Miocene ?)**: rhyolite porphyry.
(13) **President Intrusives (Age Unknown)**: serpentine; peridotite; dunite; pyroxenite.
(13a) **Sumner Gabbros (Age Unknown)**: peridotite; dunite; pyroxenite.
(14) **Dykes (Ages Various and Unknown)**: porphyry diorite; feldspar porphyry; hornblende porphyry; aplite.

Radiometric dating (Pearson, 1977, Table IV) of the various intrusive units has provided a recent understanding of the overall geology. Earlier workers assumed the Bralorne intrusives were older than the Coast Plutonic Complex to the west and the Bendor pluton to the east but current age data indicate that Bendor pluton is the younger, eastern edge of the Coast Plutonic Complex. The Bralorne intrusives north of Gold Bridge and near the Wayside mine give K/Ar age of 62.5 ± 1.8 Ma which is intermediate in age between the Coast Plutonic Complex and the Bendor pluton (Table 46-4). This is supported by another date for a dyke in the Minto mine, which indicates igneous activity at 67.7 ± 2.4 Ma. Overall a general easterly younging trend occurs across the map-area. However, the ultramafic President intrusives are an exception; they are found along both fault or shear zones and in larger masses. Cairnes (1943) relates the Sumner gabbro to these larger masses and implicitly associates the ultramafics in the Bralorne mine and surrounding area to the same President intrusives. Stevenson (1958) notes that the serpentinite in the ultramafic unit contains chromite

TABLE 46-4. K/Ar AGE DATES

Coast Plutonic Complex (West of study area)	Bi	77.8 ± 2.9 Ma (GSC 76-49)[1]
	Hb	72.9 ± 3.6 Ma (GSC 76-50)[1]
Bralorne Intrusives (trondhjemite)	Phen	62.5 ± 1.8 Ma (UBC)[2]
Minto Mine:		
(a) dyke; microdiorite porphyry	WR	67.7 ± 2.4 Ma (UBC)[2]
(b) mariposite in vein		45.4 ± 1.1 Ma (UBC)[2]
Bendor Pluton	Bi	57.4 ± 2.3 Ma (GSC 76-54)[1]
Dyke near Congress mine	WR	67.1 ± 2.2 Ma (UBC)[3]

[1] Wanless, *et al.*, 1977.
[2] Pearson, 1977.
[3] Cooke, B., personal communication.

TABLE 46-5. HOST LITHOLOGIES

	Producers (12)	Developed (24)	Prospects (35)
Bralorne intrusives	8	10	10
Coast plutonic and Bendor	0	3	1
President intrusives	3	3	7
Miscellaneous dykes	3	5	5
Bridge River Group	4	14	24
Pioneer Formation	5	3	1
Hurley Formation	1	0	4
Noel Formation	0	2	4
Others	0	2	1

Total properties, all groups: 71

NOTE: apparent discrepancies in numbers reflect multiple lithologies at some properties.

and magnetite. The President intrusives are of interest because some economic gold-bearing veins lie adjacent to, and terminate against, the serpentinite bodies.

MINERAL DEPOSIT CHARACTERISTICS

Stevenson (1958) summarizes both the controls and indicators of potential mineralization in the area, but some of the conclusions are difficult to verify due to incomplete records for many occurrences. The common proximity of the President intrusives to mineralization and the hosting of veins in the Bralorne intrusives and Pioneer greenstone is stressed by all workers. The incompetent sedimentary rocks lack open-spaced fracturing, consequently veins pinch out when entering the sedimentary units. Veins in the Bralorne area also bear a constant angular relationship of 30 degrees to the trend of their host diorite-granite. Most dip north or northeast but a few significant veins are oriented across this attitude. Some productive veins comprise 1 to 5-centimetre-thick quartz ribbons separated by thin layers of sericite and chert. These schist layers may contain fine-grained sulphides, as well as native gold which is locally slickensided. Gold is also found in quartz-cemented breccias and in massive quartz. Gangue minerals include widespread quartz with local calcite; sericite, chlorite, and dolomitic and ankeritic carbonates also occur in minor amounts, while mariposite, talc, and scheelite are sporadically present. These minerals have only a limited use for exploration because they are also found in gold-poor areas. The main sulphides associated with gold are pyrite and arsenopyrite, with traces of sphalerite, galena, chalcopyrite, and tetrahedrite. A high stibnite content is generally associated with enhanced silver values.

Harrop and Sinclair (1985) noted the presence of two linear trends defined by faults, the Bralorne intrusives, and mineral occurrences. Two fault zones closely follow these trends; these are steeply dipping and may join at depth. The northwesterly and northerly striking fault zones intersect in the Bralorne mine area, which is the largest producer in the area.

A tabulation of rocks hosting the gold occurrences is shown in Table 46-5. The Bralorne intrusives predominate as host rocks to economic veins.

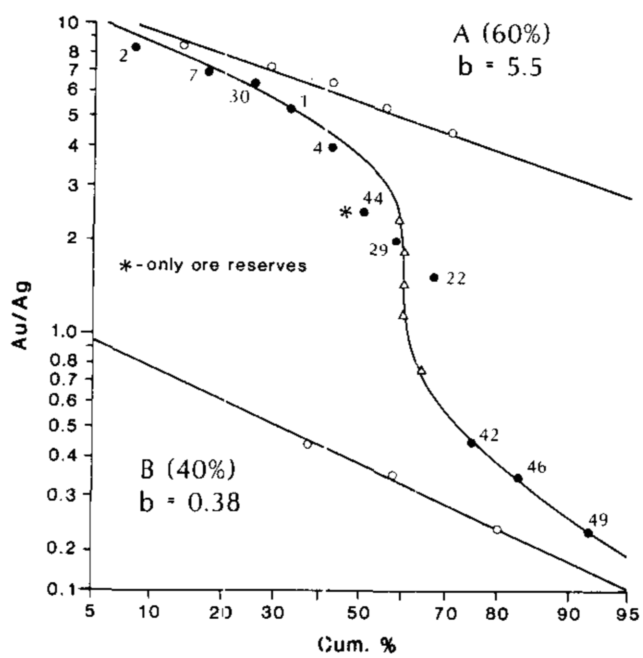

Figure 46-1. Probability graph of Au/Ag ratios for past producers from Bralorne Mining Camp, cumulated individually from high to low volumes. Black dots are original data with associated deposit numbers relating to Table 46-1. Straight lines (A and B) are two ideal partitioned populations described in text with geometric means given by b.

PRODUCTION DATA

The only quantitative data available for producers and developed properties are gold and silver production and assay results. Production figures are not always easy to relate to assay figures, so to reduce bias, gold/silver ratios are an important consideration in this study. Average gold/silver values for 29 deposits were established as

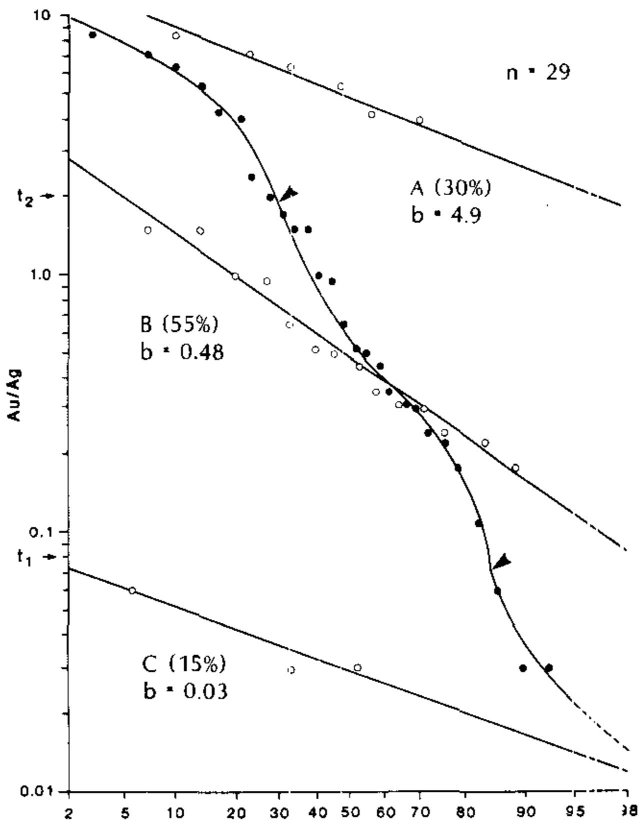

Figure 46-2. Probability graph of Au/Ag ratios for all producers and developed properties in Bralorne Mining Camp, cumulated individually from high to low volumes. Symbols as on Figure 46-1.

representative of developed and productive properties. Only limited information is available for tungsten, copper, and antimony. Two log-probability plots were drawn using the gold/silver data, one from the producers' data and one from all the data. The producers' data plot has only 11 points, but shows the presence of two populations (Fig. 46-1) at a ratio of 60:40 (A:B) with A being the population with higher gold/silver values. In the plot of all available gold/silver points (Fig. 46-2) there is a distinct three population curve, the upper two populations being comparable to those of Figure 46-1. The range of gold/silver values found in occurrences within the primarily sedimentary sequences such as the Bridge River Group correspond very well with the B population of Figure 46-2. Also, the occurrences within the Bralorne intrusives correlate with the A population of Figure 46-2. A threshold value of gold/silver = 1.5 to 2.0 separates these two populations. Note that of the 11 values of gold/silver = >1.5, nine are from producers. Veins within the Bralorne intrusives seem to have a higher potential to be ore bearing and are distinguishable by high gold/silver ratios. Higher gold/silver ratios are generally present in the more economically successful properties; this suggests that gold/silver ratios of vein samples probably represent a sound exploration parameter. The Blackbird mine has the highest gold/silver ratio in the area (8.3) and is closest to the intersection of the two regional trends mentioned earlier.

Unlike the Bralorne-type deposits of population B on the probability plot, which are called 'Congress-type' deposits, are not characterized by high gold/silver ratios and are not in close proximity to Bralorne intrusives.

A further examination of gold/silver ratios was undertaken on the Bralorne and Pioneer mines production results. Average annual gold/silver ratios are plotted versus year of production; this assumes that the mines deepened with time at a constant rate and extant records suggest that this assumption is correct. The only other mine that recorded its change in depth with time is the Congress mine (Cairnes, 1937; Stevenson, 1958) where gold and arsenopyrite

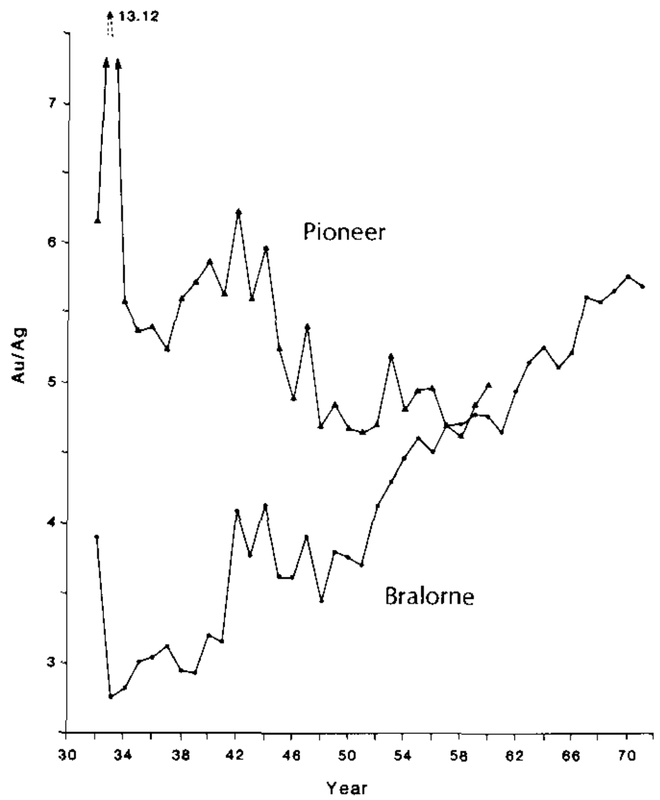

Figure 46-3. Plots of average annual Au/Ag ratios for Bralorne and Pioneer production, 1930 to 1971 inclusive.

apparently increase with depth; by contrast stibnite predominates at surface and decreases with depth. Extraction methods can affect the recovery of gold and silver differently causing a bias to gold/silver ratios. The recovery methods at Bralorne changed as follows:

1898 — two arrastras
1900 — 5-ton stamp mill
1932 — jig and blanket with amalgamation
1960 — cyanidation plant

From 1933 to the close of the Bralorne-Pioneer mine in 1971 a steady increase in the gold/silver ratio (Fig. 46-3) occurred which is not due to changes in the extraction process.

At Pioneer mine (Fig. 46-3) there is an overall decrease in the gold/silver ratio corresponding to the following recovery history:

1900 — hand-operated stamp mill
1905 — arrastra
1916 — Bryan (Chilean) type mill
1924 — Bryan mill and cyanidation
1928 — all cyanidation
1932 — new cyanidation plant

It is noteworthy that these two connected mineralized systems have dramatic differences in their gold/silver ratio distributions. The Pioneer system is generally considered to be worked out, whereas the Bralorne system apparently contains substantial reserves. While gold/silver ratios show district-scale use in predicting ore-bearing gold occurrences, they can also be used in a single mine to reveal zonal patterns.

Several other graphs dealing with the 11 production figures were studied. In Figure 46-4 a strong linear relationship between log gold production (grams) and log silver production (grams) is demonstrated. Figure 46-5 is a plot of log (grams metal) versus log (tonnes mined) showing that gold is slightly in excess of silver in this camp. Figure 46-6 demonstrates that grade is not a function of tonnage. Figure 46-7 shows a log-probability plot of the deposit size; this shows the deposits form two populations with the two largest mines, Bralorne and Pioneer, being the upper population.

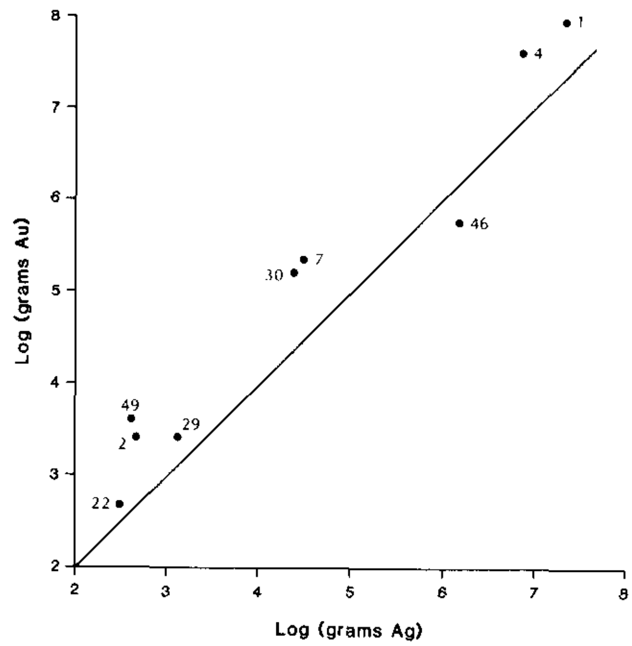

Figure 46-4. Log — log plot of total Au production versus total Ag production for Bralorne Camp. Numbers correspond to deposit numbers in Table 46-1.

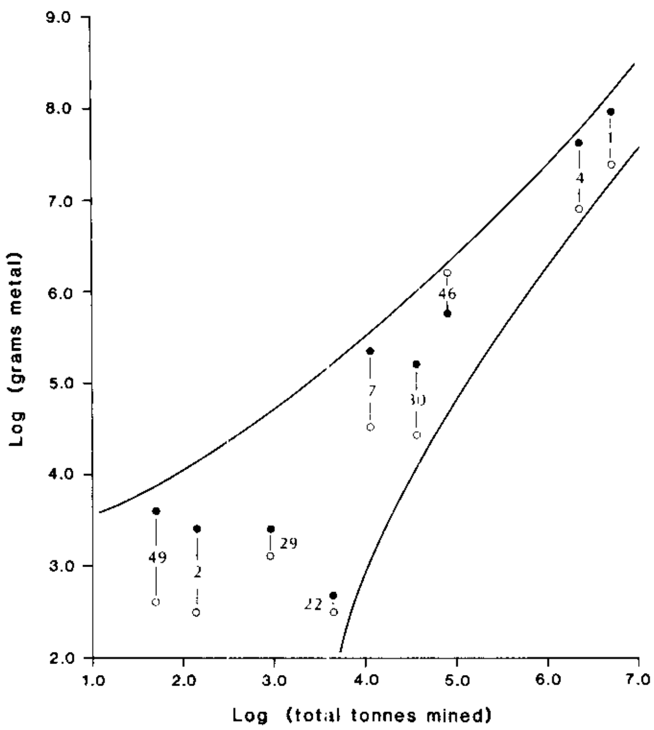

Figure 46-5. Log (grams combined metal) versus log (production tonnes) for Bralorne Camp. Solid circles are deposit numbers in Table 46-1.

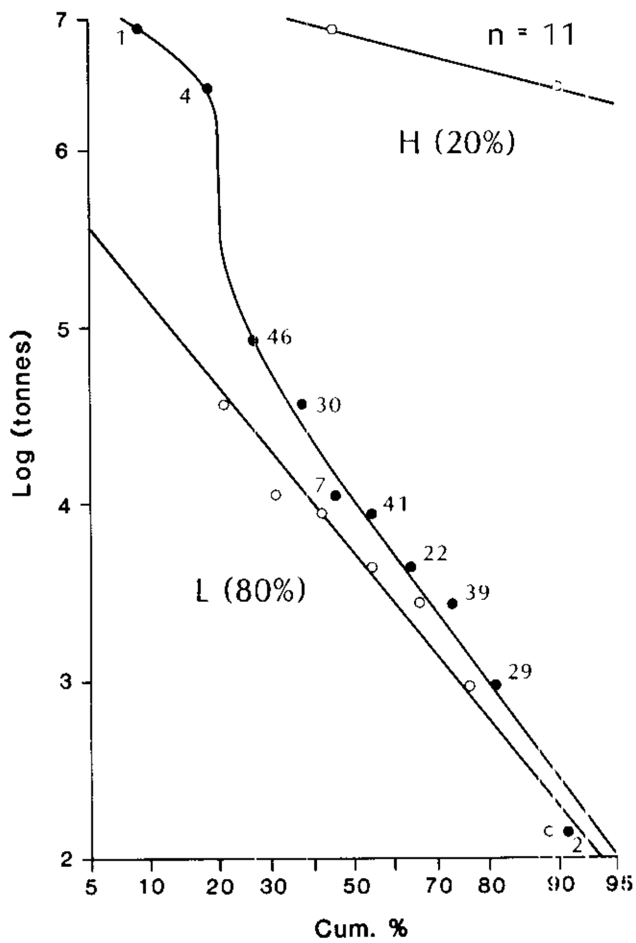

Figure 46-7. Probability plot of production tonnages, Bralorne Camp, cumulated from high tonnages to low. Symbols as on Figure 46-1.

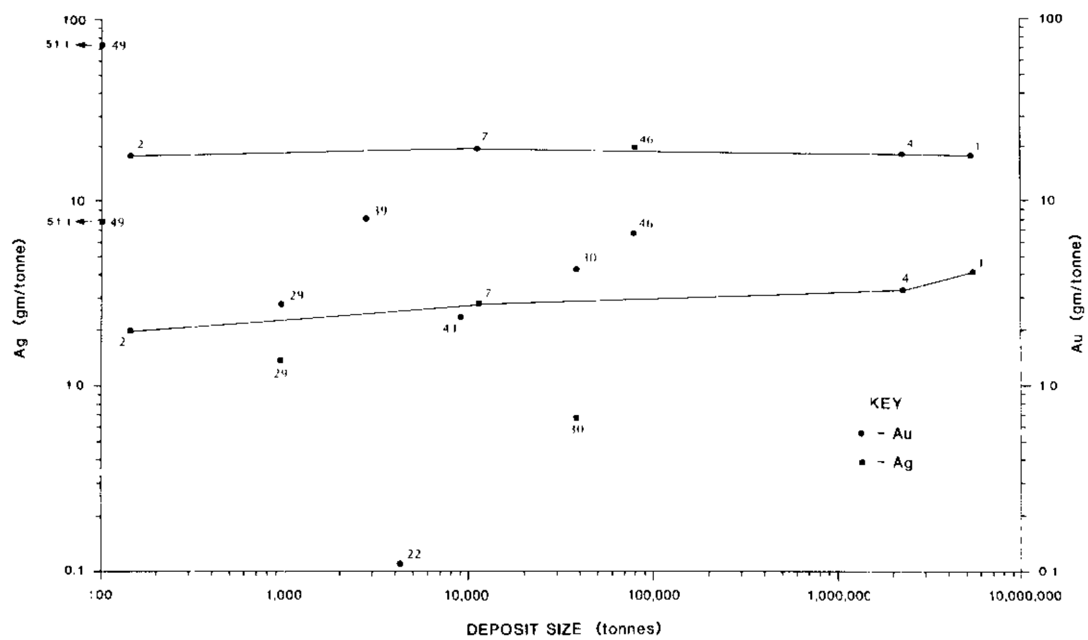

Figure 46-6. Plot of metal content versus production tonnages for past producers, Bralorne Camp. Numbers correspond to deposit numbers in Table 46-1.

CONCLUSIONS

This study outlines two types of precious-metal-bearing mineralization in the district, namely the Bralorne and Congress types; several guidelines for selecting Bralorne-type exploration targets are recognized; the most productive location for these deposits is at the intersection of two regional structural trends in the vicinity of the Bralorne and Pioneer deposits. Other comparable intersections make interesting targets for further detailed examination. Investigations of the Bralorne intrusives, especially near their contact with serpentinite bodies, could be useful in locating either deposits or structural intersections. Gold/silver ratios can also be used to recognize occurrences with economic potential and in individual deposits the gold/silver ratios have systematic (zonal) distribution patterns.

The Congress-type occurrences differ from Bralorne type in having less obvious geologic controls related to lithological variations in the Bridge River Group and associated crosscutting dykes.

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British Columbia Geological Survey
Geological Fieldwork 1985

GEOLOGY OF THE BRALORNE-PIONEER GOLD CAMP (92J/15)

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INTRODUCTION

The Bralorne-Pioneer gold camp produced more gold than any other camp in British Columbia (7 million tonnes of 18 grams per tonne gold or 4 million ounces of gold; Barr, 1980). It is the only vein camp in the Canadian Cordillera whose production approaches the major vein camps in the Canadian Shield, such as the Hollinger or MacIntyre mines which both produced more than 10 million ounces of gold (Bertoni, 1983). Hodgson (1982) notes similarities between the Bralorne camp and those of the Canadian Shield.

Remapping of both surface and the eighth level underground — from available outcrops, accessible workings, and intact drill core — was carried out in August and September 1985 by the senior author. Preliminary results, presented in Figures 47-1 and 47-2, include a synthesis of much old data combined with a re-interpretation of certain key lithologies.

REGIONAL GEOLOGY

The Bralorne-Pioneer gold camp lies within a fault-bounded slice of oceanic rocks called the Bridge River terrane by Tipper (1981). This "suspect" terrane is sutured between the larger accreted terranes of Wrangellia on the west and Stikinia on the east. The Bridge River terrane could represent ocean floor obducted onto and/or transported with the larger terranes.

Units within the Bridge River terrane (identified by Woodsworth, 1977) are Triassic, Permo-Pennsylvanian, and possibly Jurassic in age (Table 47-1). The base of the succession consists of a thick sequence of oceanic basalts, ribboned cherts, and argillites of the (?) Permo-Triassic Fergusson or Bridge River Group. This is overlain by the (?) Triassic-Jurassic Cadwallader Group, which from oldest to youngest is divided into the Hurley Formation of calcareous argillite, the Pioneer andesite, and the Noel argillite (Table 47-1). No fossils have been identified from these rocks.

Stratified rocks within the Bridge River terrane are intruded by the Bralorne intrusives and the Coast Range plutonics. All K/Ar data from the area yield Jurassic to Cretaceous dates and presumably represent only the Coast Range plutonic event. Hybrid contact relationships indicate that the Bralorne intrusives might be as old as the Triassic or Permian Pioneer andesites. Stevenson (1958), who mapped the Bridge River area surrounding the Bralorne-Pioneer camp at a scale of 1:7200, followed Cairnes' (1937) division of the Bralorne intrusives; this is, from oldest to youngest, the largely serpentinized President ultramafic, the Bralorne diorite, the soda granite, and albitite (quartz-plagioclase porphyry) dykes.

PROPERTY GEOLOGY

Detailed mapping was at 1:1200 on the surface and on the main adit level (eighth level, approximately 400 metres underground). Preliminary results, presented on Figures 47-1 and 47-2 show large areas with extensive glacial drift and little outcrop. Nevertheless, there is close correspondence between trends of dykes and contacts deduced at surface with those found underground. The geology of the eighth level is complex, but most data were derived from logging underground drill core (both the old Bralorne-Pioneer core and the recent core drilled by Mascot Gold Mines Ltd.) rather than from the underground workings. In some currently inaccessible areas, particularly in the old King mine workings, the map is drawn largely from old data.

TABLE 47-1
FORMATIONS IN THE BRALORNE-PIONEER CAMP SOUTHWESTERN BRITISH COLUMBIA
(Figures 47-1 and 47-2 show distribution of units.)

UNIT NO.	MAP SYMBOL	DESCRIPTION
JURASSIC (?)		
10		Lamprophyre dykes
9		Green hornblende porphyry dykes
		Quartz veins (major, named)
8		Albitite (plagioclase porphyry) dykes
JURASSIC (?) BRALORNE INTRUSIVES		
7		Soda granite
6a		Hornblendite
6		Diorite
5		President ultramafics (serpentinite)
TRIASSIC-JURASSIC (?) CADWALLADER GROUP		
4		Hurley-Noel sediments (volcaniclastic)
3		Pioneer andesites
PERMO-TRIASSIC (?) FERGUSSON (BRIDGE RIVER) GROUP		
2		Sediments (ribbon chert, argillite)
1		Volcanics (basalt)

Principal lithologic units on Figures 47-1 and 47-2 match those mentioned in the section on regional geology and in Table 47-1. They are described following, from oldest to younger.

FERGUSSON (BRIDGE RIVER) GROUP

Unit 1, Basalts: Dark green, brown-weathering basalts outcrop along the northern edge of the mapped area (Fig. 47-1A and 1B). In outcrop, they are massive and fine grained; no pillows were observed in this area although elsewhere abundant pillows are present. The basalts are not seen in either the underground workings or in drill core.

Unit 2, Cherty Argillite: Black to grey, laminated to thin-bedded chert and cherty argillite are common in the Fergusson Group and make up thicknesses of several hundred metres. Due to its shattered nature, the argillites are generally poorly exposed close to the Fergusson thrust (Fig. 47-1) but form larger outcrops further northeast. These rocks were not seen in the underground workings.

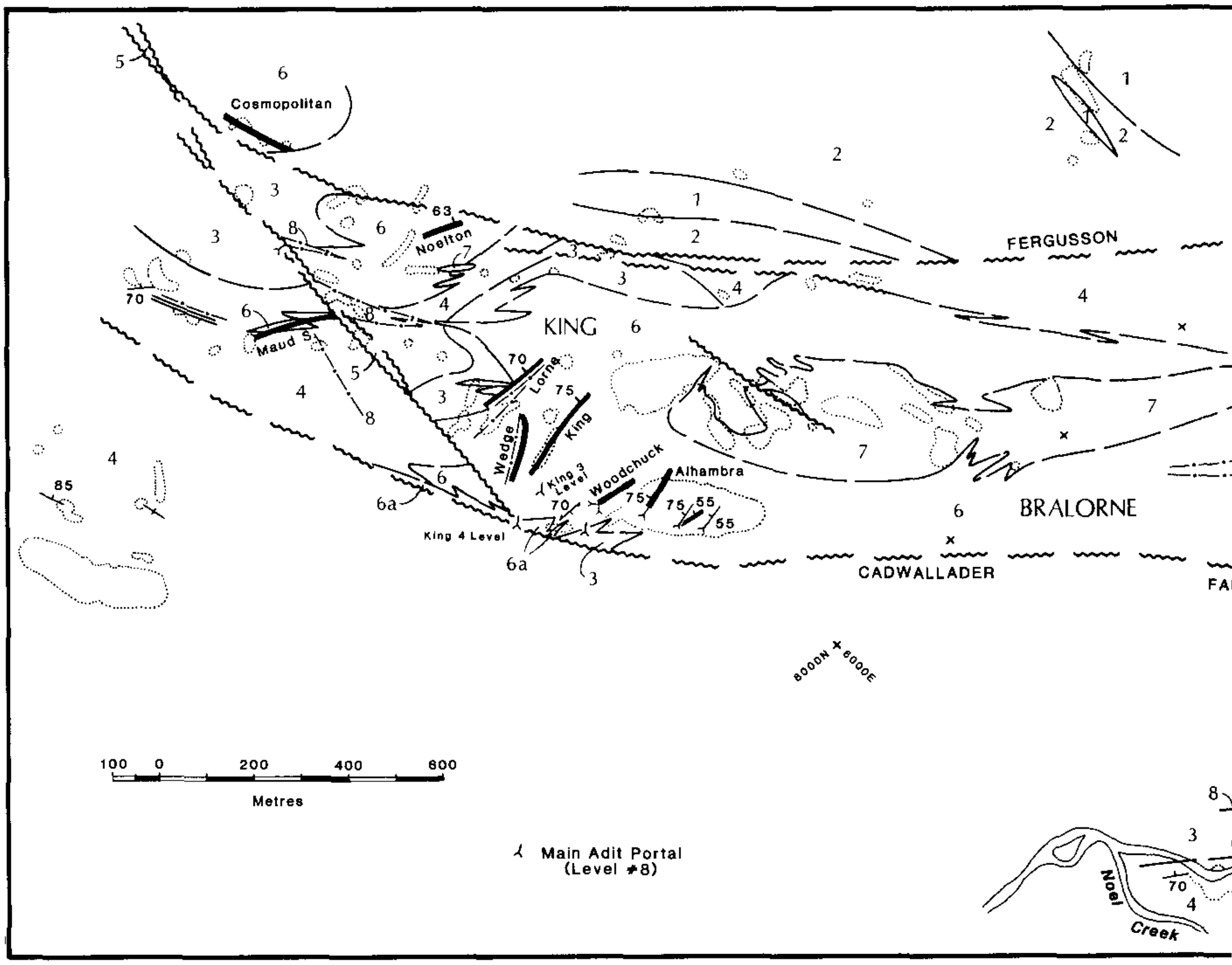

Figure 47-1. Surface geology of the Bralorne-Pioneer gold-quartz vein camp, Bridge River district, southwestern British Columbia. Units are defined in Table 47-1. *See* Figure 47-2 for eighth level underground plan.

CADWALLADER GROUP

Unit 3, Pioneer Andesites: Although commonly called "greenstones" in mine usage, the Pioneer Formation consists mainly of andesitic volcanic and volcaniclastic rocks. In drill core the andesites vary from fine-grained, massive, amygdaloidal flows and medium-grained dykes, to coarse lapilli tuffs and breccias. The constant colour index suggests little compositional variation. A paler, possibly dacitic phase is rarely seen and quartz-eye porphyry fragments were observed in the Pioneer No. 2 shaft dump. This unit grades stratigraphically upward into the Hurley-Noel sediments.

Unit 4, Hurley-Noel Sediments: The Hurley Formation comprises green volcanic wacke and dark argillite, while the Noel Formation consists of black argillite. Interlaminations of the green wacke and argillite are common as is characteristic in much of the Jurassic Hazelton Group near Stewart (Tipper and Richards, 1976). The Hurley and Noel Formations were not separated in this study; the Hurley-Noel rock sequence lacks ribbon chert, which distinguishes it from the Fergusson Group. Volcanic wackes grade stratigraphically into volcaniclastic rocks of the Pioneer Formation (Table 47-1).

BRALORNE INTRUSIVES

Unit 5, President Ultramafic: The President ultramafic largely comprises serpentinite; it lies along the Cadwallader fault zone (Figs. 47-1 and 47-2) that bounds the south side of the rocks hosting the gold veins. Some serpentinite was also mapped on surface by previous workers near the north end of the Fergusson fault. Where unserpentinized (for example, near the King workings), this unit includes distinct, network-textured hornblendite cut by dykes of the Bralorne diorite. However, it is sometimes difficult to distinguish this hornblendite from amphibolitized diorite (unit 6a) and greenstone. A repeated interlayering of hornblendite, diorite, and ultramafic(?) is seen in drill core as the serpentinite contact is approached. Further work is needed to understand this unit.

Unit 6, Bralorne Diorite: Bralorne diorite underlies much of the area and interfingers in a complex manner with the Pioneer andesite on the south side of the Bralorne intrusives. The diorite is typically dark grey-green, medium to coarse grained, and contains equal amounts of plagioclase and amphibole; it is commonly foliated parallel to its northwest-striking margin, and is commonly cut by a stockwork of late deuteric pale green quartz-epidote veinlets which may contain prehnite (Stevenson, 1958). Similar but sparser quartz-epidote veinlets also cut the soda granite which is described follow-

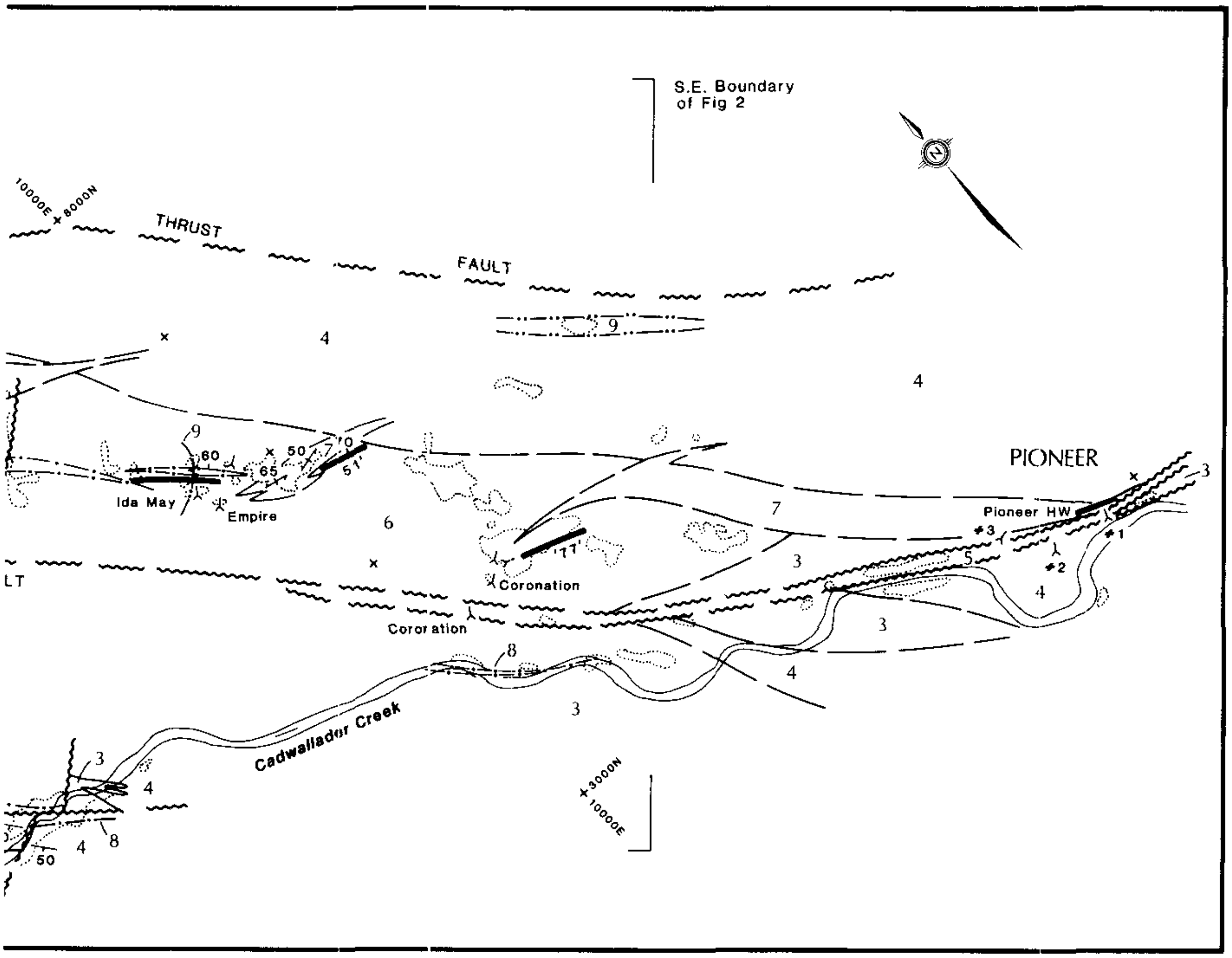

Figure 47-1. Surface geology of the Bralorne-Pioneer gold-quartz vein camp, Bridge River district, southwestern British Columbia. Units are defined in Table 47-1. *See* Figure 47-2 for eighth level underground plan.

ing. Near the large quartz vein systems the diorite is altered to either a dark green, chloritic facies or a buff-coloured carbonate-rich facies; these facies may alternate over a few metres.

Unit 6a, Hornblendite: Hornblendite commonly exhibits an apparent gradational contact with the Bralorne diorite.

Unit 7, Soda Granite: The major mass of soda granite lies along the north side of the Bralorne intrusives (Figs. 47-1 and 47-2); its northern contact with the Pioneer andesite and Hurley-Noel sediments is relatively sharp. In contrast, its contact with the diorite is generally gradational over a 200-metre distance; this is partly due to numerous, small, irregular masses of soda granite within diorite giving the rock a migmatitic appearance. However, dykes of soda granite with sharp contacts against diorite are also common. Soda granite is pale, medium grained, and distinguishable from the diorite by the presence of quartz and its lighter colour due to a lower percentage of chloritized mafics. Nevertheless, altered, bleached diorite can look very similar. Stevenson (1958) notes that the plagioclase is albite in the soda granite and andesine in the diorite. The origin of the complex relationship between the diorite and the soda granite is not understood; it could result from either anatectic partial melting of the diorite with subsequent remobilization (favoured by Godwin), or differentiation and intrusion of soda granite following formation of still plastic diorite (favoured by Leitch).

Unit 8, Albitite Dykes (Intra-mineral): Most albitite dykes are 1 to 10 metres in thickness, except near the centre of the Bralorne intrusive where they reach 30 metres thick (Figs. 47-1 and 47-2). Contacts against diorite or soda granite can be sharp, chilled, and flow banded, but usually are sheared and/or veined. These pale buff to greenish intra-mineral dykes cut the Bralorne intrusives but rarely extend into surrounding rocks. They are very fine grained, have quartz and/or plagioclase phenocrysts, and are compositionally similar to the soda granite. A few albitite dykes contain relict hornblende, commonly marked by pyrite blobs. Altered diorite and soda granite resemble albitite, but the two are distinguishable by the aphanitic texture of the dykes; this caused early workers on the property to erroneously map highly altered quartz-carbonate rock as albitite. Albitite dykes commonly have gold-bearing veins parallel to their margins, but are rarely cut by these veins.

Unit 9, Green Hornblende Porphyry Dykes (Post-mineral): These dykes cross the easterly striking contacts of the earlier intrusives, and commonly intrude and taper into the post-mineral faults. They are relatively fresh, lack veining, and have sharp, flow-banded and chilled contacts. The relationship between the green dykes and the albitite dykes is generally unclear due to shearing near the margins of the former; however one large outcrop of green dyke includes blocks of apparent albitite dykes, confirming the older age

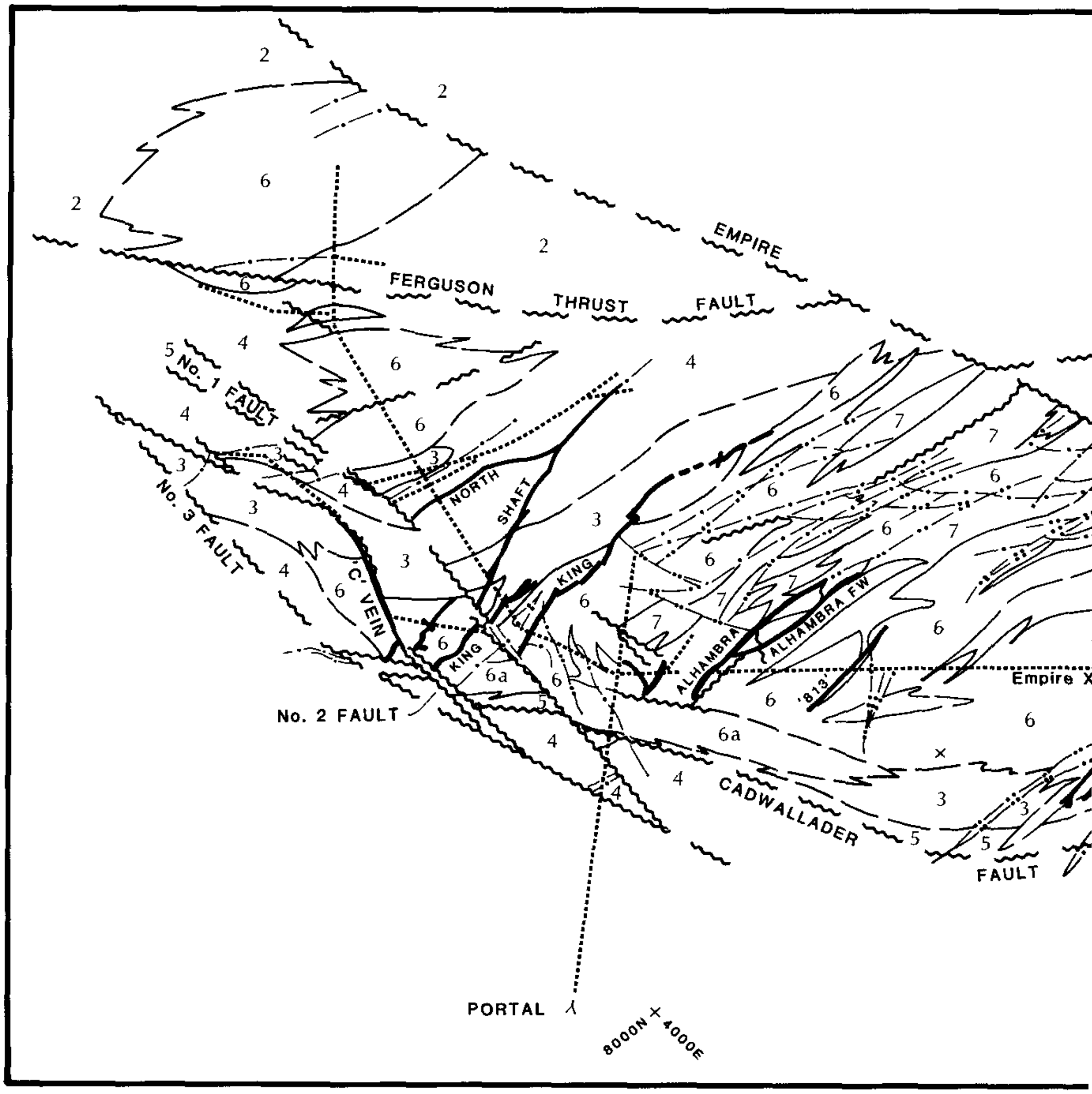

Figure 47-2. Eighth level underground plan (about 400 metres below the surface) of the Bralorne-Pioneer gold-quartz vein camp, Bridge River district, southwestern British Columbia. Units are defined in Table 47-1. Surface geology is on Figure 47-1.

of the albitite. Common hornblende and lesser plagioclase (never quartz) phenocrysts in an aphanitic groundmass characterize this unit.

Unit 10, Lamprophyre Dykes: Pieces of late stage black, mafic, biotite-bearing lamprophyre dykes are seen both in core and on the dump at the Bralorne portal; however, these late-stage intrusive dykes have not been seen underground. Their location on Figure 47-2 is from old Bralorne-Pioneer maps.

STRUCTURE

Outstanding features of the Bralorne-Pioneer veins are their great length (6 kilometres) and depth (1.5 kilometres), and also their parallelism to the Cadwallader and Fergusson faults, the long axes and contacts of the intrusives, the dykes, foliation, bedding, and shearing directions. Veins are ribboned, with quartz layers separated by thin, black septa of crushed and sheared auriferous sulphide. Repeated episodes of vein filling by a crack and seal mechanism may account for the alternating layers of quartz and gold-bearing sulphide. Striations along the sheared sulphide-rich surfaces plunge about 45 degrees east and indicate reverse fault movement along the veins which strike about 110 degrees and dip north at 70 degrees. Joubin (1948) considered the veins to follow planes of shear failure.

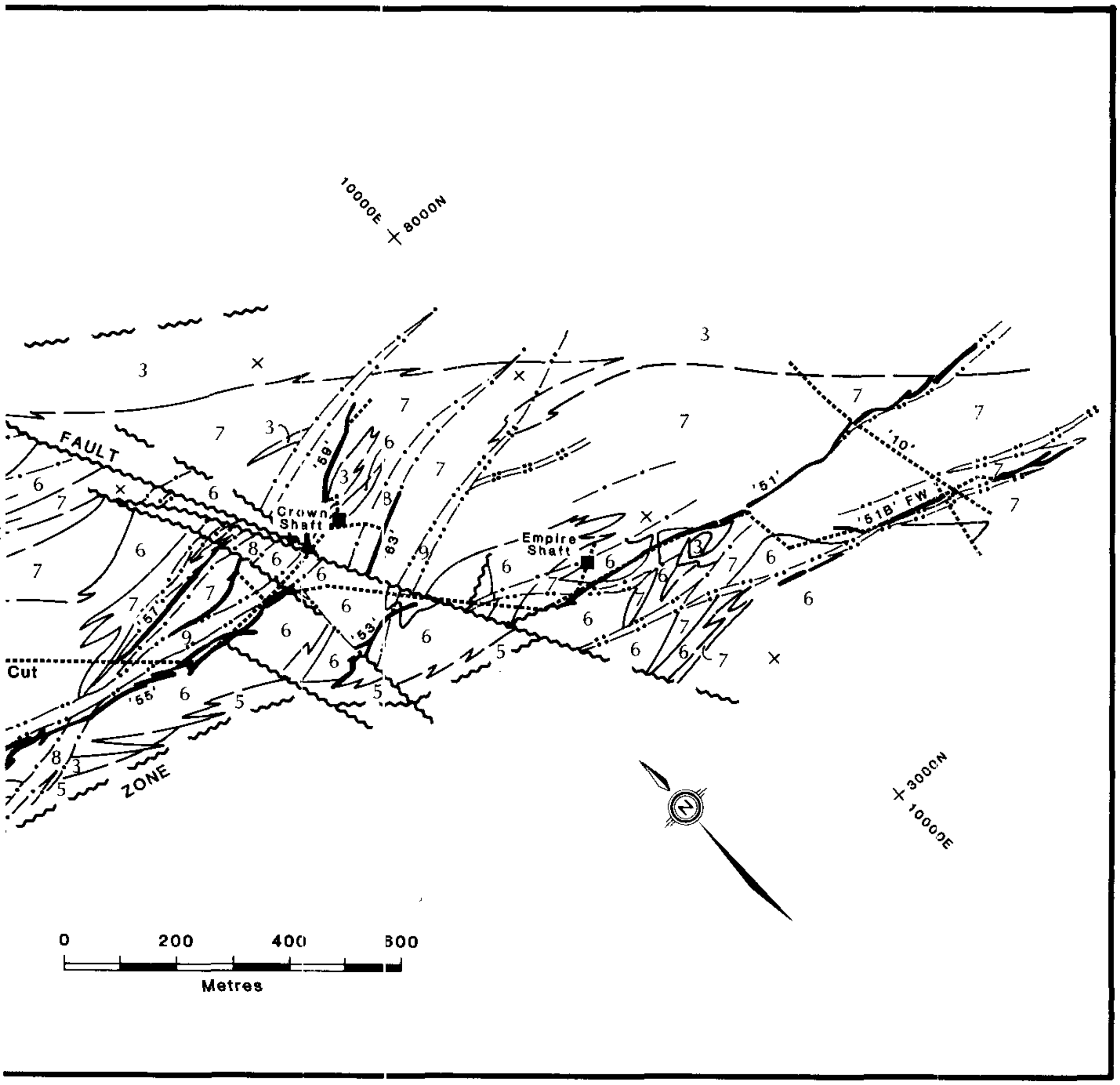

Figure 47-2. Eighth level underground plan (about 400 metres below the surface) of the Bralorne-Pioneer gold-quartz vein camp, Bridge River district, southwestern British Columbia. Units are defined in Table 47-1. Surface geology is on Figure 47-1.

ALTERATION

Hydrothermal alteration is developed as wide envelopes around the veins; these may coalesce to form pervasive alteration envelopes extending tens of metres away from major veins. Pyrite may also extend for several metres from the larger veins. A characteristic zonation toward the veins hosted in diorite are: (1) green chloritization of the hornblende, (2) buff carbonatization of the hornblende with intact granitic texture, (3) intense brown quartz-carbonate alteration, which destroys the granitic texture and is commonly foliated from shearing, and (4) cream-coloured, paper-like, intensely sheared quartz-carbonate schist, with local fuchsite and common disseminated pyrite, adjacent to major veins.

MINERALIZATION

Gold is concentrated in the sulphide septa of the ribboned quartz veins. Most of the sulphide is pyrite, but arsenopyrite laths up to 1 millimetre long are common. Where sheared the sulphides are powdered, but visible native gold is locally present on striated smears. Sphalerite and galena are reported by Cairnes (1937) but only noted on the King 4 level adit dump and in core from the Pacific Eastern Gold property southeast of the Pioneer mine.

CONCLUSIONS

The Bralorne-Pioneer gold camp has an igneous and hydrothermal system that exceeds 6 kilometres in strike length. The virtual restriction of the gold-bearing quartz veins to the Bralorne intrusives is similar to some of the deeper level "plutonic" porphyry copper-molybdenum systems in British Columbia (Sutherland Brown, 1969). These porphyry systems have elongate rather than circular intrusives; mineralization is sometimes in ribbon veining, but contains molybdenite and chalcopyrite rather than pyrite-arsenopyrite and gold; and intra and post-mineral dykes are common to both.

The petrogenesis, age, and relationship of a number of units remain obscure, particularly the andesite, ultramafic, hornblendite, diorite, soda granite, and albitite dykes. Understanding the relationships between gold veining and the various intrusive events could enhance our understanding of this major gold camp. Age dating of intrusive and altertion events, possibly by U/Pb of $^{39}Ar/^{40}Ar$ methods could also clarify the geological history of the area.

ACKNOWLEDGMENTS

We thank the management and staff, particularly John Bellamy, of Mascot Gold Mines Ltd., Vancouver, for permission to visit and sample the underground workings, to examine the voluminous drill core from current and past programs, and to view data from their development of the property. Brad Cooke of Cooke Geological Consultants Ltd., Vancouver, helped orient our study. The open assistance and discussions with Gary Nordin and Rick Barclay of Amir Mines Ltd., Vancouver, are gratefully acknowledged. Core from their 3 500-metre drill program on the Pacific Eastern Gold property, adjoining the old Pioneer mine to the southeast, was made available.

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WOLF EPITHERMAL PRECIOUS METAL VEIN PROSPECT CENTRAL BRITISH COLUMBIA (93F/3W)

By Kathryn P. E. Andrew and C. I. Godwin
Department of Geological Sciences
The University of British Columbia
and
Robert M. Cann
Rio Algom Exploration Inc.

INTRODUCTION

The Wolf epithermal precious metal vein prospect (Fig. 48-1) is near latitude 53 degrees 12 minutes north and longitude 125 degrees 26 minutes west in central British Columbia, about 6 kilometres southeast of Entiako Lake approximately 185 kilometres southwest of Prince George. Access is by helicopter or floatplane to one of several nearby lakes. The Wolf claims were located in 1983 by Rio Algom Exploration Inc., Vancouver, as a result of anomalous silver values in lake sediments. Preliminary mapping and sampling of soil and rock in 1983 and 1984 indicated epithermal mineralization within Tertiary Ootsa Lake Group rhyolites (Cann, 1984). A silicified zone was trenched in 1984. Drilling and additional trenching were undertaken in 1985; the main area of drilling is shown on Figure 48-1. Mapping and ongoing studies of the Wolf area by Andrew form the basis for an M Sc. thesis.

REGIONAL GEOLOGY

Duffell (1959) named the Ootsa Lake group and noted that it unconformably overlies Hazelton Group rocks above a basal conglomerate near Whitesail Lake, about 100 kilometres northwest of the Wolf property. In the vicinity of the Wolf prospect, Geological Survey of Canada Map 1424A shows the Eocene (?) Ootsa Lake group to unconformably overlie the Jurassic Hazelton Group. Tipper (1963) postulated that much of the Ootsa Lake Group occupies depressions in pre-Tertiary valleys. He also subdivided the Ootsa Lake volcanics into two units: rhyolite and andesite. The Wolf prospect lies within the rhyolite unit that is composed of rhyolite, trachyte, dacite, with minor andesite and basalt, and related breccias and tuffs. Sedimentary rocks of Ootsa Lake Group are not abundant and generally occur as poorly consolidated, soft, friable stream gravels and sands along major valleys. In the Wolf area outcrops of sedimentary rock are rare. The recessive weathering sedimentary rocks were only encountered in drill core.

LOCAL GEOLOGY

Field relations on the property and petrographic observations define 12 map units within the Ootsa Lake major rhyolite unit. They are shown on Figure 48-1 and described in detail following. The map units can be divided into four assemblages: a basal package (units 1, 2, and possibly 3), a pyroclastic package (units 4 to 7), a dome and vent breccia package (units 8 and 9), and a late-stage and intrusive package (units 10 to 12). Sedimentary rocks underlying unit 8, the rhyolite, do not outcrop and were only intersected in drill holes. The rocks are not described here; they might occur in the valleys — note that outcrop, as shown on Figure 48-1, is sparse. Figure 48-2 schematically illustrates the stratigraphic relationships.

BASAL PACKAGE (1)

Unit 1, volcanic conglomerate, crops out in a creek on the northwest side of the property (Fig. 48-1). It is matrix supported with 30 per cent well-rounded granodiorite clasts (5 to 50 centimetres in diameter), 10 per cent angular andesite clasts (up to 15 centimetres in diameter), and 5 per cent subrounded aplite clasts (20 to 30 centimetres in diameter). The tuffaceous matrix has up to 60 per cent quartz. The quartzose matrix, granodiorite, and aplite clasts indicate a predominantly granitic, as well as a volcanic, provenance.

Unit 2, felsic lapilli tuff, has a pale grey to green aphanitic groundmass which supports various amounts of clasts, 1 to 10 millimetres in size. The unit crops out in the same creek as unit 1 on the northwest side of the property (Fig. 48-1). In two outcrops clay-altered clasts show alignment with an indicated strike of 175 degrees and a steep dip.

Unit 3, porphyritic andesite and andesite breccia, is restricted to the eastern edge of the property (Fig. 48-1). It is dark green to black, has plagioclase phenocrysts, and is locally propylitically altered. The andesite breccia contains up to 5 per cent calcite-rich clasts. This unit might be part of the Hazelton Group because of the porphyritic nature of the andesite, its association with calcite-bearing breccias, and its proximity to known Hazelton Group rocks.

PYROCLASTIC PACKAGE (2)

Unit 4, grey-green lithic crystal tuff, has an aphanitic groundmass that supports 10 per cent quartz and orthoclase crystals and 25 per cent lithic fragments ranging in texture from flow-banded to agglomeratic. The tuff crops out in the southwestern part of the property forming the basal unit of a shallowly westward-dipping pyroclastic sequence (Fig. 48-1). Quartz veinlets, 1 to 2 centimetres in width are common.

Unit 5, cream aphanitic ash tuff, is generally massive but locally contains up to 2 per cent smoky quartz crystals, 1 millimetre in size. The unit appears to lie conformably above unit 4 in the southwestern part of the property (Fig. 48-1). Spherulites are seen in thin section. Shallow, southwestwardly dipping quartz veinlets 2 centimetres in width are characteristic in this unit.

Unit 6, maroon K-feldspar-quartz porphyry, is a locally columnar-jointed flow extending over much of the southwestern portion of the property (Fig. 48-1). Quartz and orthoclase phenocrysts, each up to 5 per cent by volume, are suspended in a cryptocrystalline groundmass. No hydrothermal alteration is evident in this unit.

Unit 7, grey-maroon crystal tuff, marks the top of the pyroclastic package and crops out over much of the west-central part of the property (Fig. 48-1). This unit is near map units 9 and 11

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Unit 6, maroon K-feldspar-quartz porphyry, is a locally columnar-jointed flow extending over much of the southwestern portion of the property (Fig. 48-1). Quartz and orthoclase phenocrysts, each up to 5 per cent by volume, are suspended in a cryptocrystalline groundmass. No hydrothermal alteration is evident in this unit.

Unit 7, grey-maroon crystal tuff, marks the top of the pyroclastic package and crops out over much of the west-central part of the property (Fig. 48-1). This unit is near map units 9 and 11

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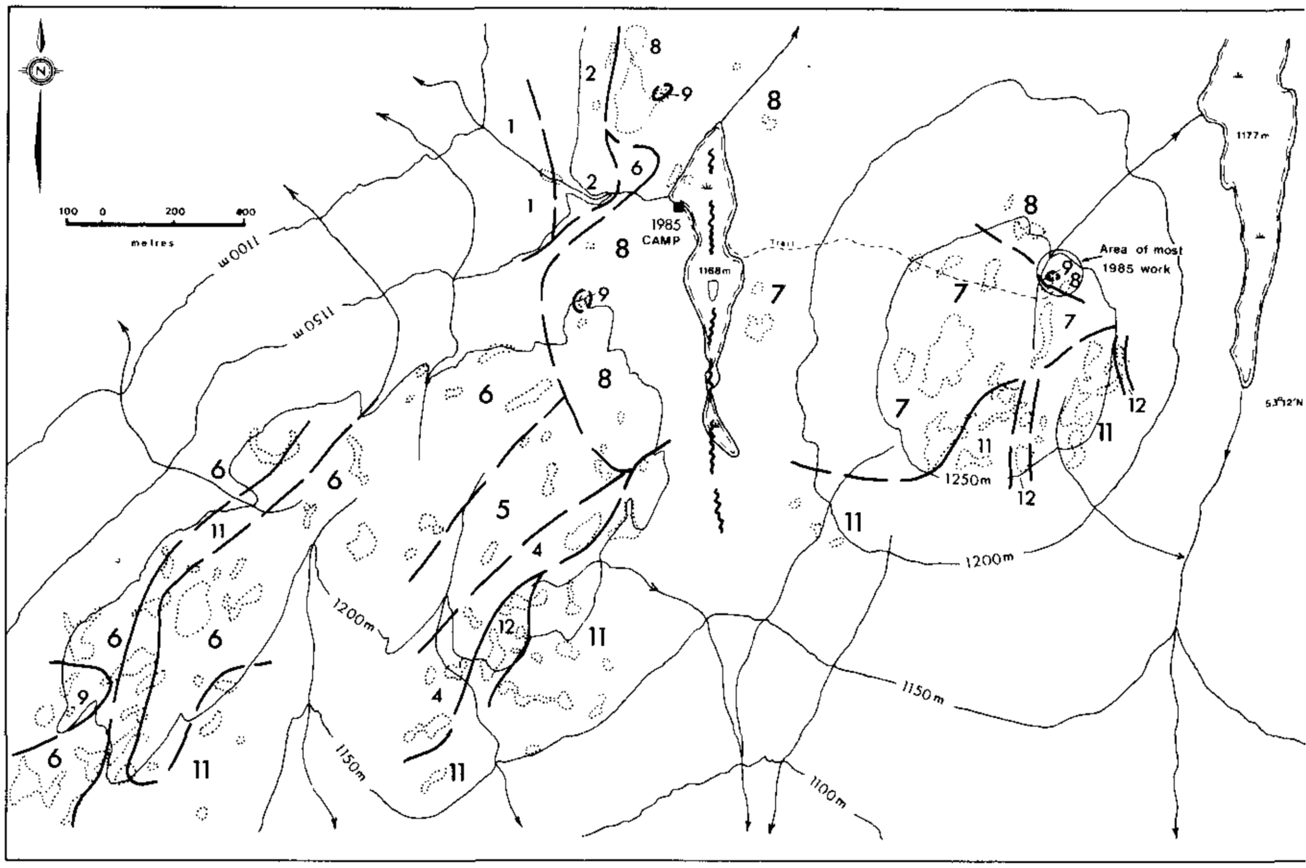


Figure 48-1. Geology of the Wolf epithermal, precious metal prospect, central British Columbia. *Basal package*: 1 = volcanic conglomerate, 2 = felsic lapilli tuff, 3 = porphyritic andesite and andesite breccia; *pyroclastic package*: 4 = grey-green lithic crystal tuff, 5 = cream aphanitic ash tuff, 6 = maroon K-feldspar-quartz porphyry, 7 = grey-maroon crystal tuff; *dome and vent package*: 8 = rhyolite, 9 = volcanic breccia; and *late-stage and intrusive package*: 10 = dark green porphyritic andesite, 11 = rhyolite porphyry, 12 = quartz-eye porphyry.

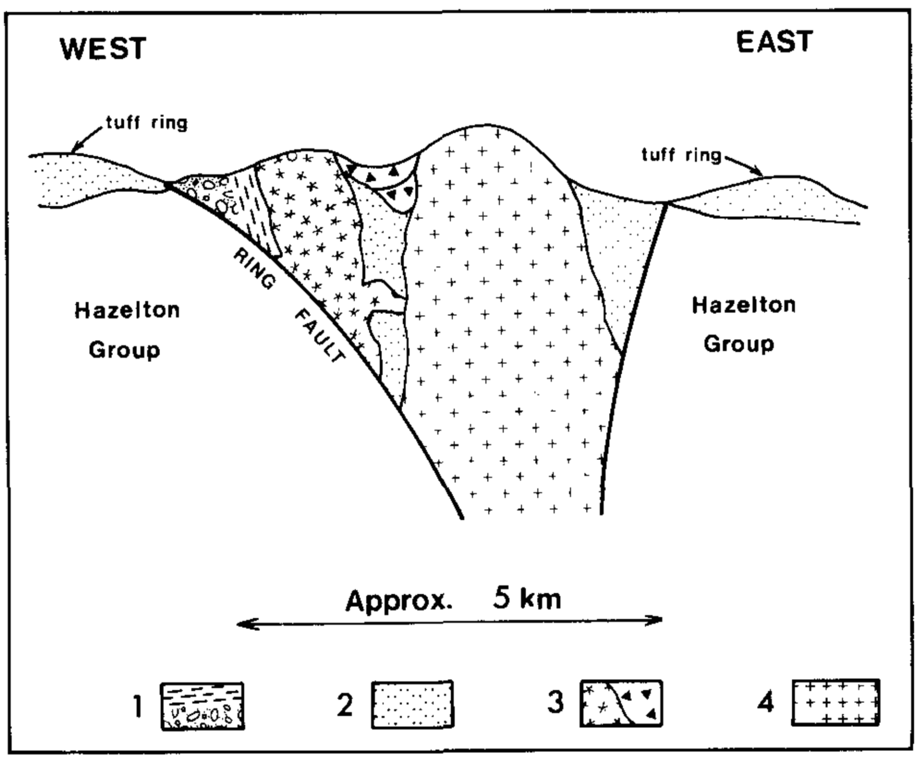
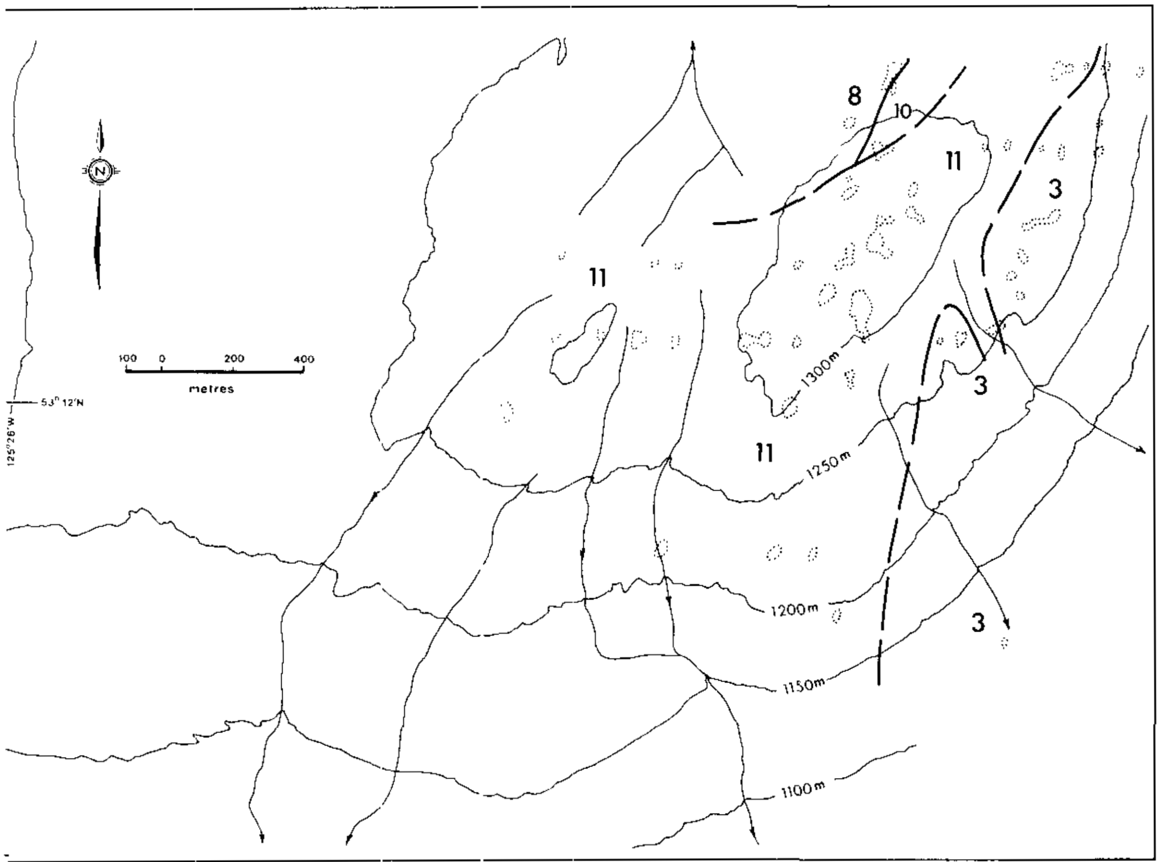


Figure 48-2. Schematic diagram illustrating maar characteristics of the Ootsa Lake Group volcanics near the Wolf prospect area, central British Columbia. 1 = basal package, 2 = pyroclastic package, 3 = dome and vent package, and 4 = late-stage and intrusive package.



which host the most significant mineralization found to date. The unit is a "crowded" porphyry with 30 per cent euhedral orthoclase phenocrysts (1 to 3 millimetres in diameter), and 10 per cent irregular quartz phenocrysts (1 millimetre in diameter). Many of the crystals are broken. Locally argillic alteration is evident. Massive quartz and bladed quartz-carbonate veins occur; they range up to 1 metre in width.

DOME AND VENT PACKAGE (3)

Unit 8, rhyolite, is commonly flow banded and spherulitic. The map unit crops out along both the west and east in the northern part of the map-area (Fig. 48-1). The unit appears to unconformably overlie units 1 to 7. The rock generally contains 10 per cent euhedral orthoclase phenocrysts (1 to 2 millimetres in diameter) and 5 per cent irregular quartz crystals (1 millimetre in diameter). Field relations suggest that the rhyolite may have been emplaced as a dome. Areas of silicification as well as 5-centimetre-wide, steeply dipping chalcedonic veinlets are common. Trenched areas expose highly brecciated and silicified zones within this map unit in which some of the highest gold values found on the property occur.

Unit 9, volcanic breccia, occurs as small, irregular and pod-shaped bodies within units 7 and 8. The breccia consists of 35 per cent lithic fragments (generally felsic but of varying compositions and sizes) and 5 per cent subhedral orthoclase crystals, in an aphanitic black groundmass. The pod-like occurrence of the breccia and variable sizes of the fragments, combined with the proximity of the unit to silicified zones, indicate that it might be a hydrothermal breccia.

LATE-STAGE AND INTRUSIVE PACKAGE (4)

Unit 10, dark green porphyritic andesite, occurs on the eastern part of the property (Fig. 48-1). An aphanitic matrix hosts phenocrysts of grey plagioclase or dark green to black augite. Hornfels in this unit is apparent within 20 metres of the contact with unit 11.

Intrusive Package

Unit 11, rhyolite porphyry, is coarse grained and porphyritic; it crops out over most of the southern part of the property (Fig. 48-1). It contains up to 60 per cent euhedral orthoclase crystals and 10 per cent quartz crystals. Field relations indicate that the unit is intrusive. Zones of silicification with vuggy and bladed quartz veins up to 50 centimetres in width host mineralization.

Unit 12, quartz-eye rhyolite, occurs within unit 11, but is distinguished from it by the presence of up to 10 per cent stubby commonly embayed, smoky quartz phenocrysts, and several per cent of euhedral orthoclase crystals. The unit is locally flow banded. This map unit may represent a late dyke-like stage of the magma which formed unit 11. The unit is locally silicified and has slight argillic alteration.

DISCUSSION

Limited outcrop and drill information make interpretations of the geology of the Wolf prospect difficult. Preliminary evidence indicates that the Wolf epithermal, precious metal mineralization might be genetically related to a maar (Williams and McBirney, 1979

Best, 1982; Sillitoe and Bonham, 1984; and Sillitoe, *et al.*, 1984) within volcanics of the Tertiary Ootsa Lake Group. Figure 48-2 illustrates some preliminary interpretations. In the figure, package 1, steeply dipping conglomeratic and tuffaceous units, might reflect proximity to a major, ring fault that could define the boundary of the maar with Hazelton and Takla volcanics. Package 2, mainly flat-lying pyroclastic units, represents a tuff ring and deposits within a crater. Package 3, consisting of domes, hydrothermal breccias and associated precious metal mineralization, might represent resurgent domes and associated hydrothermal products related to volcanic activity within a caldera. Package 4, which consists of late-stage intrusive phases, appears to have welled up within or through the maar and is locally mineralized. Detailed analysis of the drill core and a better understanding of sedimentary rocks encountered in drilling are expected to modify Figure 48-2.

ACKNOWLEDGMENTS

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PALYNOLOGICAL ZONATION AND CORRELATION OF THE PEACE RIVER COALFIELD NORTHEASTERN BRITISH COLUMBIA

By Jane Broatch

INTRODUCTION

Strata of the Peace River Coalfield formed along the southwestern edge of the Jurassic/Cretaceous Clearwater sea. The rocks were deposited during a series of major and minor transgressive-regressive cycles and reflect a complex depositional setting. Mapping and correlation of economic coal deposits are difficult, but the task is made more so by numerous thrusts and folds which occurred when the region underwent compression. A diverse body of geological information from a variety of disciplines is required to unravel the structure and stratigraphy.

PREVIOUS WORK

Stratigraphic work in the area (Fig. 49-1) was carried out by Stott (1968, 1973, 1974, 1981) and Hughes (1964, 1967). Extensive drilling by coal companies has provided core samples and geophysical data for a number of more recent studies aimed at locating, identifying, and interpreting environmental indicators, rock-stratigraphic and time-stratigraphic horizons, and subtle distinctions between similar lithologies contained within and between formations (Duff and Gilchrist, 1981; Leckie, 1981; Leckie and Walker, 1982; McLean, 1977, 1982; Carmichael, 1983). Paleontological work has been attempted by Bell (1956) with leaves, McLean and Wall (1981) with foraminifera, Chamney (report in Stott, 1968) also with foraminifera, and Duff and Gilchrist (1981) with marine macrofossils; but the usefulness of these studies has been limited by a paucity of specimens and generally poor preservation. Regular symposiums sponsored by the British Columbia Ministry of Energy, Mines and Petroleum Resources have encouraged a cooperative attitude amongst the companies holding coal licences, and the many workers conducting research in the area. The resultant exchange of information has led to a better understanding of the complex structure, stratigraphy, and depositional setting.

The present palynological study was undertaken with the support of the Ministry in the hope of providing another tool for accurately identifying rock units, particularly where faulting has displaced or thickened them; for correlating units or horizons within units and ultimately the coal seams themselves; and for identifying minor marine incursions and tracing their extent. In addition, the palynomorphs will provide information for dating the rock units and for locating the Jurassic/Cretaceous boundary in the undifferentiated Minnes Formation.

STRATIGRAPHY

The stratigraphy of the Peace River Coalfield is summarized on Figure 49-2. The following brief description of the rock units sampled for this study is intended to provide insight into problems specific to the region and into the interpretation of results.

Minnes Formation: The Minnes Formation south of Burnt River is a sequence of interfingering marine and non-marine rocks composed of thin to thick-bedded mudstone, siltstone, conglomeratic sandstone, and coal beds, that range from thin partings in the southern extremes to medium thick beds in the northwest; the sequence cannot be differentiated into mappable units. North of Burnt River, however, the character of the formation changes enough to allow four distinct members to be identified and for the Minnes Formation to become a target for coal exploration.

Cadomin Formation: The Cadomin conglomerate lies unconformably on the Minnes Formation. Although quite variable in thickness (3 to 200 metres), a general trend of thinning eastward and northward is evident (Stott, 1968). Within the study area the Cadomin Formation is predominantly conglomerate, but to the northwest it becomes a pebbly sandstone containing silty, shaly, and coaly lenses. Where this occurs it is mapped as the Dresser Formation, after the nomenclature of Hughes.

Gething Formation: The Gething Formation is a dominantly terrestrial sequence of interbedded conglomerate, sandstone, siltstone, and mudstone. Coal occurs in the upper half of the formation but is only of economic importance in the central regions of the coalfield. The conglomerates, which occur toward the base of the formation, are thickest in the southeast and are commonly confused with the Cadomin Formation. Although it has been noted that the Cadomin conglomerate exhibits a clean matrix sand response on geophysical logs (Duff and Gilchrist, 1981) and that the pebble content is more quartzitic, the conglomerates are rarely drilled to allow comparison. Furthermore, the differences are not consistent or easily recognizable in surface outcrop. In many places the Gething Formation resembles both the Minnes and Gates Formations, but its overall texture is somewhat coarser and average bedding is thicker.

Moosebar Formation: The Gething Formation passes abruptly into black marine shales of the Moosebar Formation. At its base the formation is similar in appearance to the marine Hulcross shales that overlie the Gates Formation, however, the upper third of the unit is a transitional sequence of interbedded siltstones, mudstones, and thin sandstones. This sequence, although not recognized everywhere in the field, is identifiable on geophysical logs and is now mapped by most workers as a separate member of the Moosebar Formation. Southeast of the study area this transitional unit has been proposed as a formal member of the Gates Formation (McLean, 1982). Unfortunately the gradational nature of this unit and the uncertainty in locating the sandstone bed which marks the base of the Gates Formation in the coalfield increase the confusion regarding the actual location of the Moosebar-Gates contact.

Gates Formation: The Gates Formation consists of both marine and non-marine sandstones, siltstones, and mudstones; thin conglomerates are present. Coal occurs throughout, but mineable seams are more common in the southeast where the marine influence is less pronounced. Recognition of the marine component of the formation has been the focus of several recent studies (Leckie, 1981; Carmichael, 1983), particularly since it is thought to play a major role in truncating the coal in many areas.

Although familiarity with the rock units locally allows fairly accurate mapping of the formations, structural complexity often confuses interpretation. The region is dominated by imbricate thrusting and associated folding which have greatly shortened the section in a west to east direction. Identification of formations and thrust faults at surface does not guarantee what will be encountered

British Columbia Ministry of Energy, Mines and Petroleum Resources, Geological Fieldwork, 1985, Paper 1986-1.

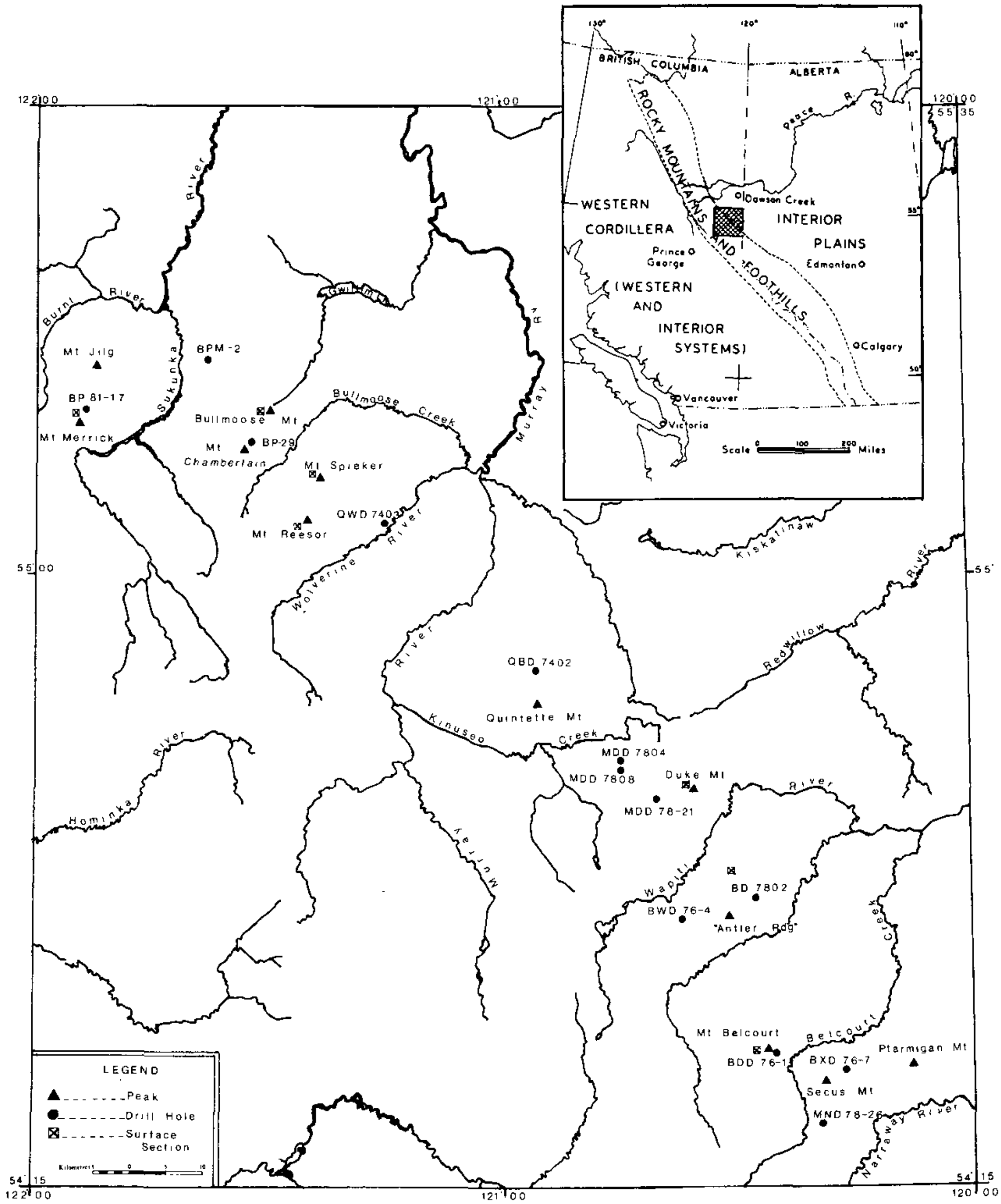

Figure 49-1. Peace River Coalfield study area and section locations.

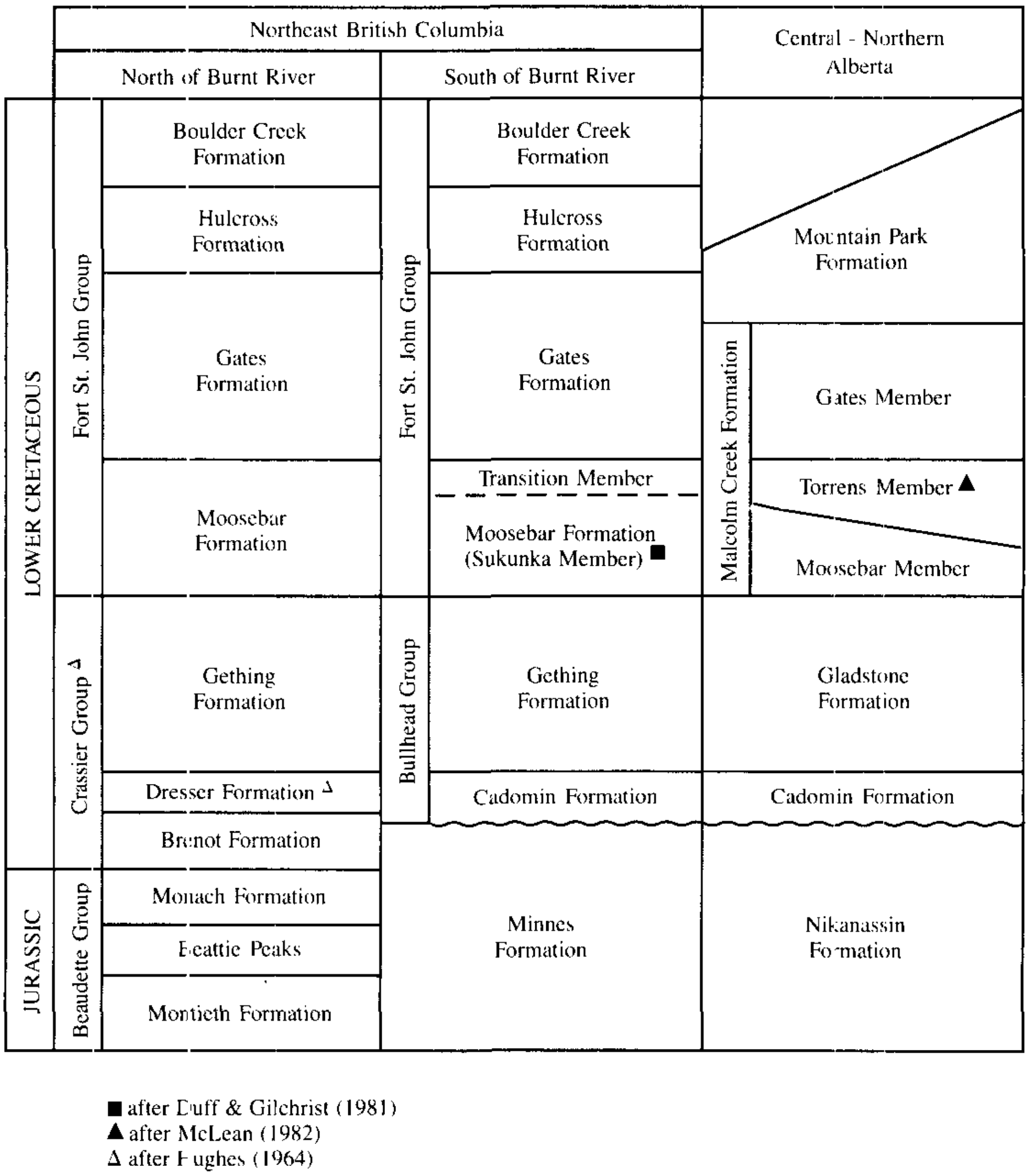

Figure 49-2. General stratigraphy (modified after Stott, 1968, 1974).

in drill holes. Units often appear unusually thick or are faulted off to be replaced by unexpected, and occasionally unidentifiable, units. Complex structures and rapidly changing facies present a need for highly specific information where correlation from one drill hole to another is required, particularly if the decision to mine a coal seam rests on the accuracy of that correlation.

CURRENT STUDY

In an attempt to identify and correlate horizons in the coal measures, a study of fossil spores and marine dinocysts was undertaken. Two hundred thirty-eight core samples were collected from 13 drill-hole locations between Burnt River in the northwest and Narraway River in the southeast (Fig. 49-1). The cores represent approximately 3 600 metres of section, from the upper Minnes through Gates Formations, sampled at 15-metre intervals on average. The drill holes have been pieced together to obtain composite sections from the regions shown on Figure 49-3. An additional 89 samples were collected from surface sections adjacent to the drill-hole locations (Fig. 49-1) to determine the usefulness of surface 'grab' samples compared to the unweathered, relatively fresh core samples.

Processing and examination of the core samples are near completion. A preliminary zonation scheme has been worked out (Fig. 49-4); identification and correlation of marine facies are in progress, but still subject to revision. Eleven of the 89 surface samples were selected for processing, based on results obtained from approximately equivalent drill-hole samples. Slides from the surface samples have not yet been examined.

RESULTS

Of the 204 samples examined to date 80 per cent have yielded palynomorphs. A species list containing approximately 370 spores and 115 dinocysts was compiled. Although some of the species identifications are subject to review, it is expected that this list will be slightly larger on completion because half the slides have not yet been examined and these represent a section of the Minnes Formation which is expected to yield exclusively Jurassic palynomorphs.

The generalized zonation shown on Figure 49-4 includes 25 of the 43 dinocyst species and 30 of the 85 pollen and spore species which are restricted to specific formations. The original plot of species was done on a formation basis, which does not allow for easy recognition of zones within the formations. The exception is the Minnes Formation where distinct zonation is apparent at the Jurassic/Cretaceous boundary (dotted line). The division occurs between 280 and 294 metres from the top of the Minnes Formation in the Belcourt section.

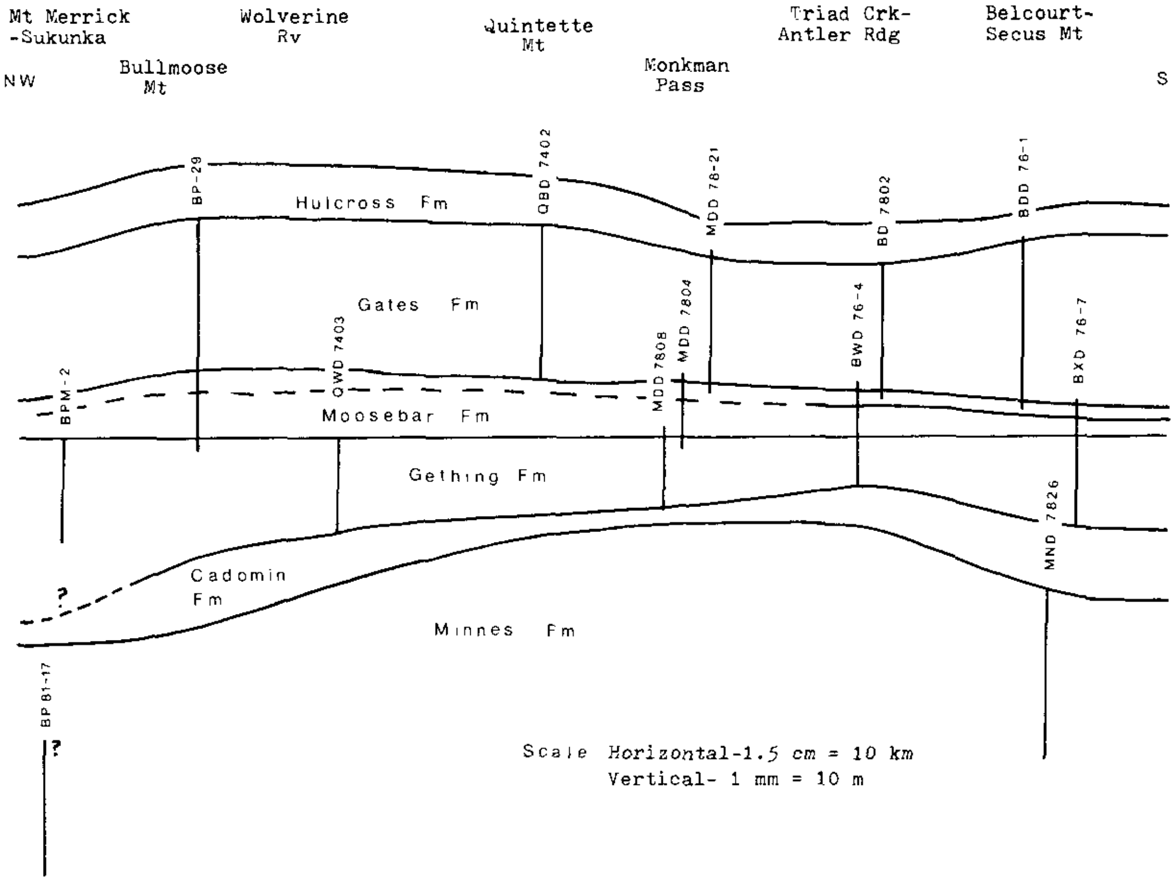

Figure 49-3. Generalized section from Burnt River to Narraway River showing diamond-drill hole sample distribution.

A plot of the age range of species has been completed for the Gething assemblage only. Initial data suggest a Middle Albian age for this formation. Plots of the species ranges for the remaining formations, coupled with information from other paleontological studies, will establish the accuracy of this dating. If a Middle Albian age is confirmed for the Gething Formation, and only the upper 300 metres of the Minnes Formation is Early Cretaceous in age, a considerable time gap (? Middle Berriasian through Early Albian) can be inferred at the Minnes/Cadomin unconformity.

Despite this age difference of approximately 30 million years, examination of slides and TAI mounts indicates a degree of preservation in reverse of what might be expected. The Minnes Formation exhibits good preservation of palynomorphs and a TAI value in the pale yellow through amber yellow (1.5-2.25) range. Preservation in the overlying units is highly variable from one section to the next and, commonly, from one formation to the next within a single section. TAI values also vary considerably and suggest that, at least on the scale of this study, TAI is related more to depositional environment than to depth of burial (*see* Manum, *et al.*, 1976). This relationship may be unique to coal measures where humic acids increase the oxidation rate of organic matter, but at the time of writing no attempt has been made to establish this through a literature search.

Interpretation of depositional environments is currently in progress. The original mudstone samples can, after processing and examination, be grouped by palynomorph content into four categories: marine, marine influenced, terrestrial, and barren. It is hoped that the marine-influenced samples, containing both terrestrial spores and marine dinocysts, will provide a time-stratigraphic link between the marine and non-marine facies.

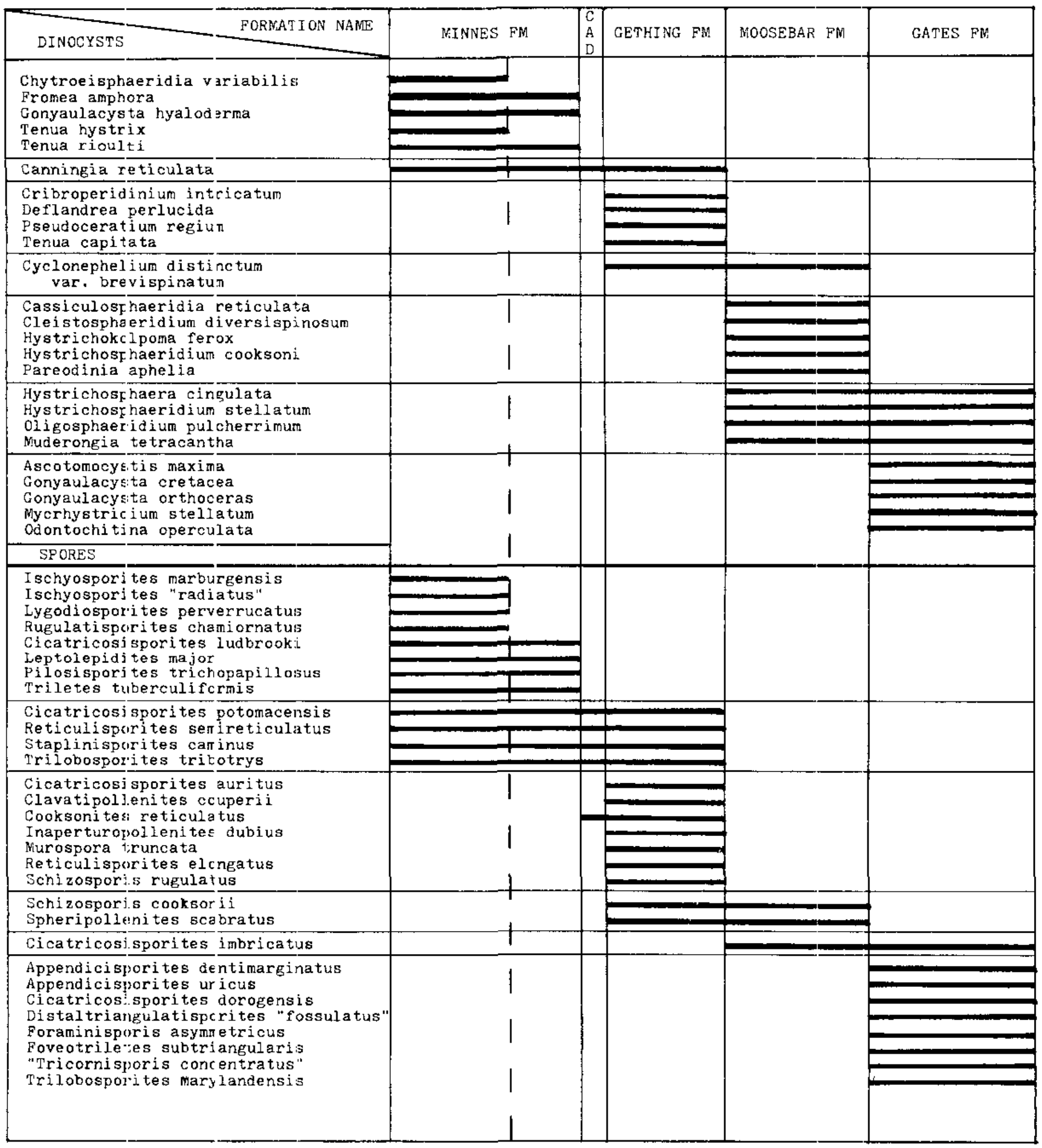

Figure 49-4. Palynological zonation of the Peace River Coalfield, northeastern British Columbia.

COMMENTS

The results to date from this study have been encouraging. The detail of information indicates that the formations present in the Peace River Coalfield can be identified and dated by their palynomorph assemblages. Further plots of the spore and dinocyst species by location (that is, as continuous sections) may reveal further zonation and the specific relationship of the transition member occurring between the Moosebar shales and the coal-bearing Gates Formation. Correlation of the marine and non-marine facies may reveal time-stratigraphic horizons, in addition to those provided by tonstein and bentonite layers already recognized.

In the future it is hoped that coal companies will use the palynological results of this study for the more refined task of drill-hole correlation of coal seams using the palynomorph assemblages found in roof shales. The groundwork has also been laid for further studies of the rocks to the northwest and southeast of the study area where the application of a different nomenclature reflects the uncertainty of stratigraphic relationships.

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GEOLOGY OF THE DOLLY VARDEN CAMP ALICE ARM AREA (103P/11, 12)

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INTRODUCTION

The Dolly Varden property straddles the Kitsault River 27 kilometres upstream from Alice Arm in the Portland Canal area, approximately 185 kilometres north of Prince Rupert. Geological mapping, initiated by Lytton Minerals Ltd., Toronto, in the area developed the base map and cross-section of Figures 50-1 and 50-2. Previous workers considered all mineralization to be in epithermal veins (Hanson, 1921; Black, 1951; Campbell, 1959). Mapping, however, shows that the main mineral occurrences can be reconstructed to form one continuous ore horizon that conforms to stratigraphy. This type of mineralization is called, here, 'Dolly Varden type' (DVT); it is stratiform, volcanogenic massive sulphide.

Fieldwork during June and July 1985 by a two-man crew included 1:5000-scale regional geological mapping and 1:2000-scale mapping of the Torbrit, Moose-Lamb, Dolly Varden, Northstar, and Wolf deposit areas. This mapping forms the basis of a M.Sc. thesis study for the senior author.

PROPERTY GEOLOGY

LITHOLOGY

The Dolly Varden property is underlain by sedimentary and volcanic rocks of the Lower Jurassic Hazelton Group. These rocks have been intruded by basaltic, andesitic, and lamprophyric dykes of probable Tertiary age (not shown on Figs. 50-1 and 50-2). Black (1951) subdivided rocks of the Hazelton Group in the area into two sedimentary formations and two volcanic formations. Mapping this past summer, however, showed that the Dolly Varden property is underlain by only one major volcanic and one major sedimentary formation; these could be subdivided into units based on lithologic characteristics and on consistent stratigraphic relationships.

Sedimentary rocks exposed in the southeast and northeast parts of the map-area, and in the Kitsault River valley to the northwest, appear to be the oldest rocks on the property. These sedimentary rocks consist of thinly bedded shale and argillite (Figs. 50-1 and 50-2; unit 1a) overlain by massive fossiliferous greywacke and sandstone (unit 1b), which in places is capped by a locally well-bedded, maroon-coloured siltstone (unit 1c).

Volcanic rocks, primarily pyroclastics, conformably overlie the sedimentary formation. These volcanic rocks, the most abundant rock type in the map-area, host the most significant silver-lead-zinc prospects. The volcanic formation has also been subdivided. Unit 2b is a light green, dacitic ash tuff that rests conformably upon the rocks of the sedimentary formation; it grades upward into a thick sequence of darker green andesitic tuff (unit 3). Lenses or individual flows of andesite are observed locally in unit 3. Unit 3 grades into an overlying maroon-coloured rock (unit 4) which consists of locally well-bedded, lapilli and crystal-lithic tuff. Unit 4 is relatively siliceous, possibly indicating a more dacitic composition. Unit 5a overlies the maroon-coloured unit and consists of pale green tuff of either an andesitic or dacitic composition; it has very distinct, angular, shard-like fragments. Unit 5a is also siliceous and possibly albitic; it is invariably interbedded with DVT mineralization (unit 5b). Unit 5a is well defined in the hangingwall of the Dolly Varden and Northstar deposits, as seen in drill core and underground workings. Unit 6 overlies either unit 5a or unit 5b; it is another maroon lapilli tuff and tuff breccia of either andesitic or dacitic composition. Unit 7, a green andesitic tuff, overlies unit 6. This green tuff unit appears to be the youngest unit within the volcanic formation identified within the map-area.

Hazelton Group rocks in the northwest and east-central parts of Figure 50-1 are intruded by either stocks or sills (unit 2) of the 'Copper Belt' intrusives. When fresh, unit 2 intrusions are porphyritic with plagioclase and minor hornblende phenocrysts, and either a dioritic or andesitic appearance. West of the Kitsault River and north of Evindsen Creek, Copper Belt intrusives are closely associated with a zone of silicification annd pyritization (unit 2a), which characteristically is strongly altered feldspar porphyry. The Copper Belt porphyries are probably cogenetic, based on preliminary galena-lead isotope data, with the Hazelton Group volcanic rocks, in particular the dacitic ash tuff (unit 2b). Other intrusive rocks in the map-area include numerous fine-grained basalt, andesite and lamprophyre dykes, which intrude all rocks of the Hazelton Group and the Copper Belt intrusives. These dykes are probably Tertiary in age.

STRUCTURE

Reliable bedding plane measurements were obtained both from compositional layering within the sedimentary units and alignment of tuff and lapilli fragments in the tuffaceous units. This, along with other structural data, shows a series of anticlines and synclines with gentle, northwest plunges. Thus, sedimentary rocks exposed east of the Torbrit mine area lie in the core of an anticline, which, when projected to the northwest, crops out in the Kitsault River valley. Mineralized zones of the Dolly Varden, Northstar, Torbrit, and Moose-Lamb prospects (Figs. 50-1 and 50-2) are conformable to the enclosing host rocks and occur on the steeply north-dipping, western limb of a syncline which is adjacent to, and west of, this anticline.

Numerous nearly vertical block faults striking in two directions, occur in the map-area. Timing of the faulting events is defined by relative displacements of units — especially the stratiform horizons — and earlier faults by younger faults. The earliest set of faults trends northwest and downdrops blocks to the west. Examples of this set include the Dolly Varden and Moose-Lamb faults (Figs. 50-1 and 50-2). The later set of faults trends north-northeast, with displacement either up or down. These faults include the Campbell, Mitchell, and Hanson faults (Figs. 50-1 and 50-2).

MINERALIZATION

Mineral occurrences on the Dolly Varden property have been described by most workers as quartz-barite-jasper-sulphide-native silver veins in Hazelton Group rocks (Hanson, 1921; Black, 1951; Campbell, 1959) or chalcopyrite-gold-silver veins associated with the Copper Belt zone of silicification and pyritization (Hanson,

British Columbia Ministry of Energy, Mines and Petroleum Resources, Geological Fieldwork, 1985, Paper 1986-1.

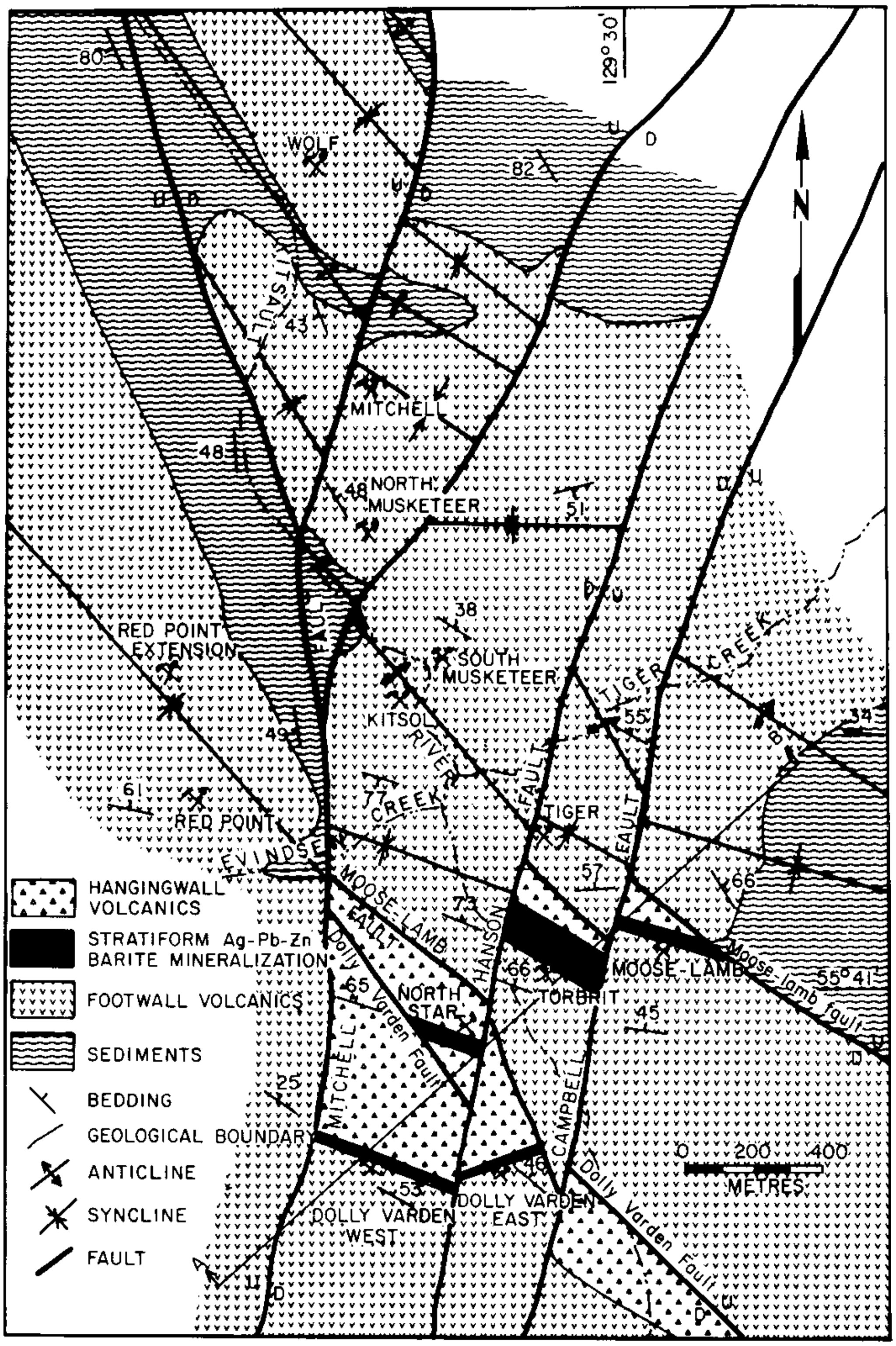

Figure 50-1. Geology of the Dolly Varden property, Alice Arm area, northwestern British Columbia. Cross-section A-B is on Figure 50-2. All units are within the Jurassic Hazelton Group (Tertiary dykes are not shown). Sediments: unit 1a = black argillite and shale; unit 1b = greywacke; unit 1c = maroon siltstone. Footwall volcanics: unit 2 = feldspar porphyry; unit 2a = silicified and pyritized zone; unit 2b = dacite ash tuff; unit 3 = green andesite tuff and flows; unit 4 = maroon andesite lapilli and crystal-lithic tuff. DVT horizons: unit 5a = siliceous tuff and pale green shard tuff; unit 5b = stratiform silver-lead-zinc-barite mineralization. Hangingwall volcanics: unit 6 = maroon andesite lapilli tuff and tuff breccia; unit 7 = green andesite tuff.

1921; Black, 1951; Carter, 1970) In this study, the two types of mineralization are recognized but the quartz-barite-jasper-sulphide-native silver veins are interpreted to be stratiform volcanogenic silver-lead-zinc-barite deposits (DVT).

DVT mineral occurrences typically contain significant silver and base-metal values; barite is strontium rich (up to 1 per cent) (Campbell, 1959). Examples on Figure 50-1 include the Dolly Varden, Northstar, Torbrit, and Moose-Lamb deposits as well as two small, isolated occurrences north of Tiger Creek on the east side of the Kitsault River. Mineralization of this type is commonly layered and conformable with enclosing wallrocks. Another characteristic feature is property-scale mineral zoning from the Dolly Varden (quartz-sulphide), through the Northstar (carbonate-barite-sulphide), to the Torbrit and Moose-Lamb (barite-oxide-sulphide). Vertical mineral zonation with a pyrite-rich footwall and a sphalerite-galena-rich hangingwall has also been recognized in drill core from the Northstar deposit (W. Pearson, personal communication, 1984).

On the Dolly Varden property silver-lead-zinc mineralization also occurs as structurally controlled replacement deposits and veins. Examples of this type include the Wolf deposit and North and South Musketeer, Kitsol, Tiger, and Mitchell prospects (Fig. 50-1). Generally, this type of mineralization is not restricted to any specific rock unit, but volcanic rocks, especially the dacitic ash tuffs of unit 2b, are favoured. These occurrences are usually discontinuous and develop along a northeast direction, subparallel to the youngest set of faults in the area. The zones are predominantly quartz and pyrite with minor calcite, barite, and other sulphides. Wallrock alteration and limonite staining are common. Metal values are generally erratic as indicated by drilling at the Wolf deposit (W. Pearson, personal communication, 1984).

Showings within the Copper Belt are mainly vein deposits. Examples include the Red Point and the Red Point Extension showings (Fig. 50-1) which are characterized by chalcopyrite, with locally significant gold and silver values, within an extensive zone of silicification and pyritization related to feldspar porphyry. These veins are generally small, discontinuous, and randomly oriented; gold, silver, and copper values are erratic.

CONCLUSIONS

The oldest rocks on the property were formed during the Lower Jurassic Hazelton period by submarine deposition of sedimentary strata; this was followed by intrusion of the Copper Belt porphyritic rocks, then submarine eruption of predominantly tuffaceous rocks. Submarine volcanism was accompanied by deposition of stratiform volcanogenic Dolly Varden-type (DVT) mineralization. The area was then regionally folded into upright folds with axes plunging gently northwest. The area was subsequently cut by steeply dipping, northwest-trending faults which downdropped rocks to the west and displaced the stratiform DVT horizon. Numerous north-northeast-trending, steeply dipping faults cut these earlier structures. Epithermal silver-lead-zinc occurrences, such as the Wolf deposit, and later dykes of probable Tertiary age, are subparallel to these later north-northeast faults. Gold-silver-copper vein mineralization occurring in a zone of silicification and pyritization in the western part of the property, is believed to be related to intrusion of the Copper Belt porphyritic rocks.

Two major sets of faults bound structural blocks that host DVT mineralization, such as the Moose-Lamb, Torbrit, Northstar, Dolly Varden East, and Dolly Varden West deposits. Within these individual blocks, orebodies on the southwest sides of northwest-trending faults have been downdropped. An example of this relationship is shown for the structural block bounded by the Hanson and Campbell faults containing the Dolly Varden East deposit (Fig. 50-1). This orebody has been downdropped by the Dolly Varden fault and is laterally equivalent to the Torbrit deposit. Similar conclusions for the Dolly Varden West deposit indicate that it is the downdropped equivalent of the Northstar deposit. It is also possible that DVT mineralization reported in the southern part of the map-area might represent the extension of the Moose-Lamb deposit.

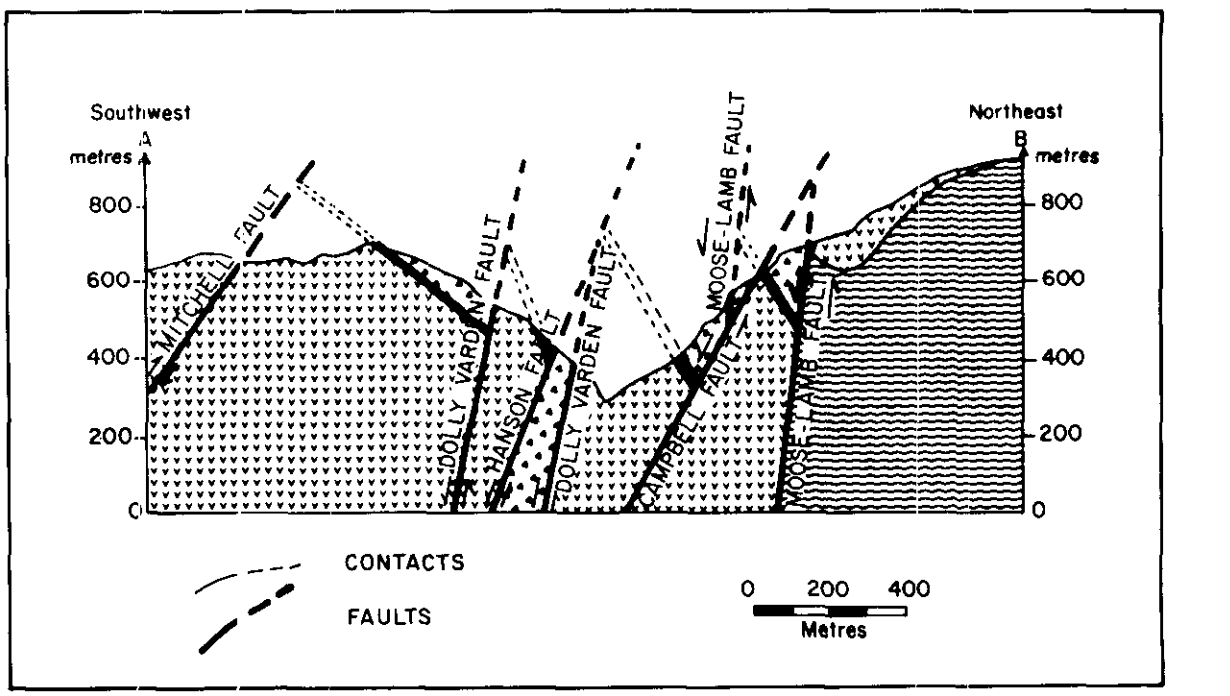

Figure 50-2. Cross-section A-B (for location *see* Fig. 50-1), looking northwest, of the Dolly Varden, Northstar, Torbrit, and Moose-Lamb areas. Units are described in the caption for Figure 50-1.

The genesis of DVT mineralization is of special importance because of its exploration implications. DVT mineralization probably formed as submarine exhalative deposits associated with andesitic and dacitic volcanism. Conformity with stratigraphy is key support for this hypothesis. Another line of evidence for a volcanogenic origin is the typical mineral zonation from quartz-pyrite lodes in the vent or source area of mineralization located in the vicinity of the Dolly Varden East deposit, through the quartz-carbonate-barite-sulphide Northstar lode, to the well-layered, barite-oxide-sulphide mineralization of the Torbrit and Moose-Lamb deposits; the latter represents distal, shallower deposition. Vertical mineral zonation in the Northstar deposit from a pyritic footwall to a galena-sphalerite-rich hangingwall is also typical of volcanogenic deposits. Other key features supporting this model include a consistent stratigraphic position between the maroon hangingwall (unit 6) and the grey-green footwall (unit 5a), conformability of the layered mineralization (unit 5b) to enclosing host rocks, and fragments of stratiform ore within the tuffaceous hangingwall rocks (either unit 5a or unit 6).

ACKNOWLEDGMENTS

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Late Submissions

REFERENDUM MINE
(82F/6)

By G. G. Addie

INTRODUCTION

For the last several years Tom Cherry of Nelson has been surface sampling the Referendum mine (MI 82F/SW-177); this year he was successful in finding a new vein. The grade from a bulk sample of 181.4 tonnes obtained from the Referendum vein was 6.2 grams gold per tonne. The silica credit from Cominco pays for the smelting.

GENERAL GEOLOGY (Fig. 51-1)

The host rocks for the veins are roof pendants in the Nelson batholith and include andesites of the Lower Jurassic Rossland Group. Recently this unit has come under intensive examination by exploration companies searching for massive sulphides. In the Referendum mine area (Fig. 51-1) zones of alternating sedimentary rocks, metamorphic rocks, and volcanic rocks are present. The rocks include agglomerates, conglomerates with boudinage texture, tuffs, and crystal tuffs. The metamorphic rocks (included with the sediments for mapping purposes) include quartz augen sericite schist (bird's eye sericite schist) and chlorite schist. The volcanic rocks are basalts and andesites. The mine area (Fig. 51-2) is in andesite which has been intruded by lamprophyre dykes. Throughout the area there are small tension veins with tourmaline and ilmenite. Some are quartz carbonate filled and some have quartz only. Zoning within the veins is suspected, but not proven. Only rarely is visible gold seen, yet production from the main vein and new vein has given consistent grades. To the southeast of the mine area there is a small Eocene Coryell plug which is believed to have a shonkinite rim (Fig. 51-1).

REFERENDUM MINE (Fig. 51-2)

The Annual Report of the Department of Mines for 1907 indicates that total production to that date was 2 268 tonnes grading 12.4 grams gold per tonne. The mining was apparently at the 61-metre level. The grade was approximately double that being obtained at present from the surface. In the vicinity of the shaft, which has not been trenched, the main vein has considerable amounts of massive, fine-grained tourmaline. Tension veins join the main vein in this area and also have tourmaline. In prospecting for the extension of the main vein it was noted that on the footwall side of the vein the andesites are sheared, while the hangingwall has blocky jointing. On this basis, a small vein was found on the east side of the biotite lamprophyre dyke with a horizontal displacement by the dyke of approximately 10 metres to the northwest.

NEW VEIN SHOWING

The 'new vein' (Fig. 51-2) was found by trenching. It is on strike with an unnamed vein on the next claim to the west (Fig. 51-1). The west segment of the 'new vein' may be a separate vein; its vuggy nature and high tourmaline content appear quite different from the shear vein. Based on the displacement of the main vein on the east side of the biotite lamprophyre dyke, it is likely that the 'new vein' will be found displaced to the northwest by a similar amount (10 metres). A bulk sample was taken at the visible gold location; it returned a grade of 3.1 grams gold per tonne.

OTHER VEINS AND MINERALIZATION

On the logging road south of Referendum mine, a small gold-bearing tension vein striking 125 degrees and dipping 77 degrees south has been discovered by Tom Cherry. It is a quartz calcite vein with visible gold in bornite. Unfortunately the vein is only a few metres long.

On the same road, but further west, there is a 5-metre-wide chlorite schist band with a small amount of pyrite which is reported to assay 1.5 grams gold per tonne. This type of exploration target has not been explored and warrants further investigation.

ACKNOWLEDGMENT

We appreciate having the property brought to our attention by Tom Cherry, and his donation of vein samples for study.

British Columbia Ministry of Energy, Mines and Petroleum Resources, Geological Fieldwork, 1985, Paper 1986-1.

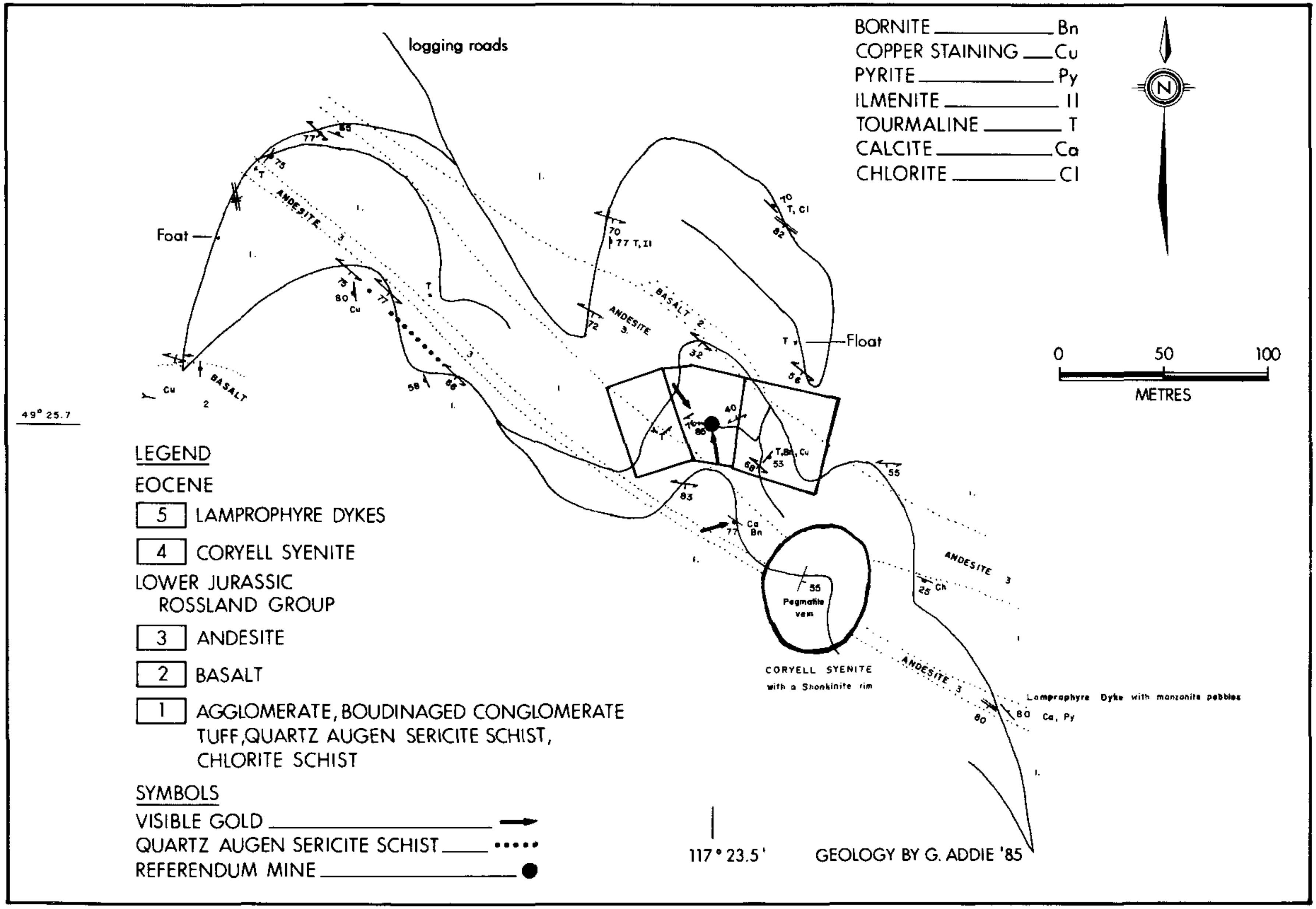

Figure 51-1. Geology of the Referendum mine area.

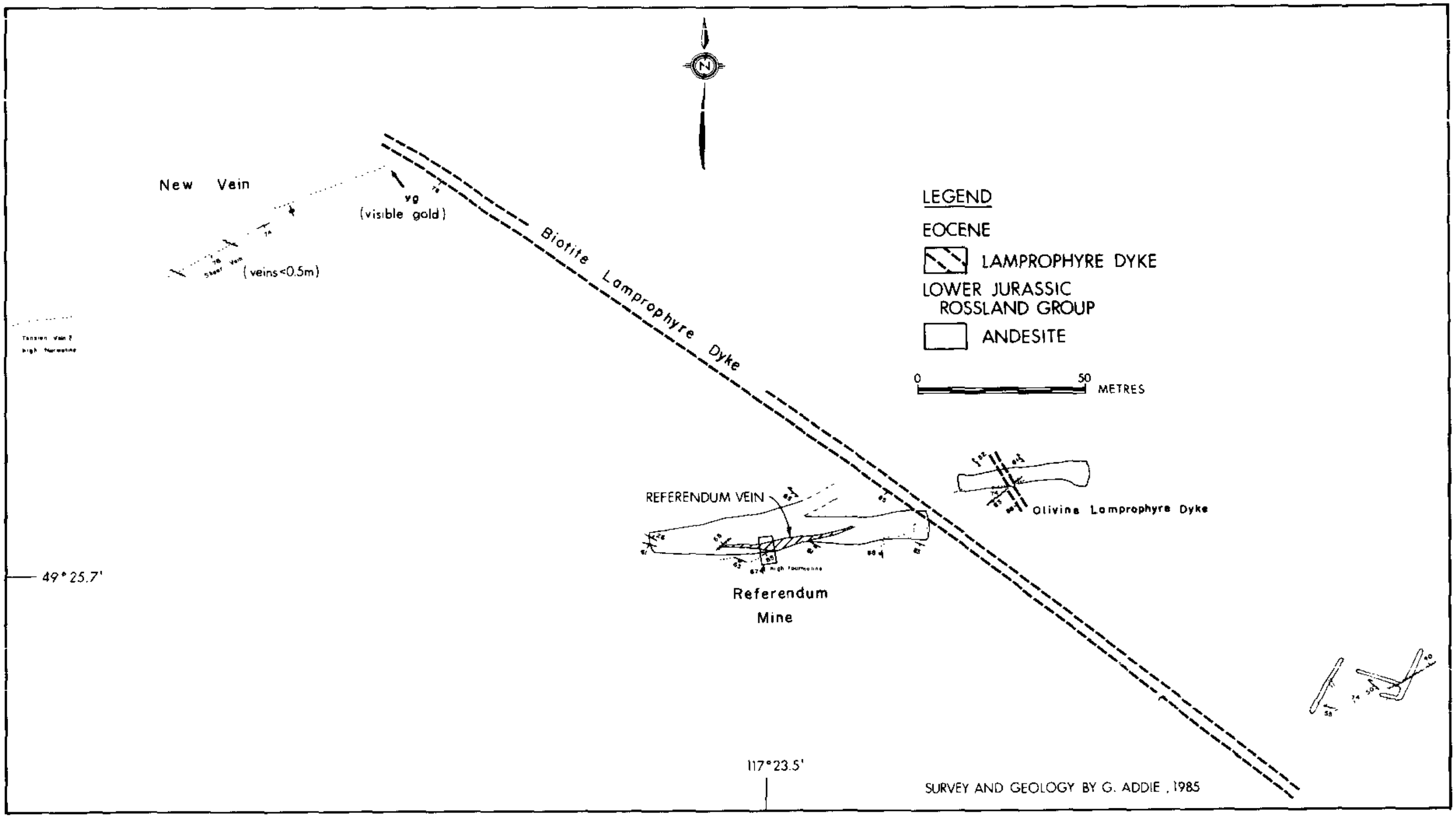

Figure 51-2. Geology of the Referendum mine, 82F/6.

HAILSTORM MOUNTAIN GOLD PROSPECT RECONNAISSANCE GEOLOGY AND SELF-POTENTIAL SURVEY (82F/13)

By G. G. Addie

INTRODUCTION

Bonanza-type gold has been discovered by Alex Strebchuck on his Caribou claims located at the headwaters of the west branch of Caribou Creek located on Hailstorm Mountain. This location is 3.2 kilometres east of Tillicum Mountain peak.

The target area was initially indicated by a soil geochemical survey conducted by T. R. Stokes in 1983 under the direction of F. M. Smith. Since then Mr. Strebchuck has put in a caterpillar road to his discovery pit (Fig. 52-1) In this area free gold occurs as individual crystals and small nuggets in the soil, as similar material in a black sandy fault gouge, and as 'splashy' gold disseminated in a marble contained in a skarn zone adjacent to the fault. The discovery zone responds particularly well to geophysical surveys such as self potential (Fig. 52-2) and VLF-EM 16, possibly because of the graphite content of the fault.

GEOLOGY

The rocks containing gold in the Hailstorm Mountain area are similar to those in the Tillicum Mountain area to the west (Ray, 1985). The metasedimentary rocks are believed to be in the Pennsylvanian to Triassic Milford Group. The sedimentary units are repetitive making correlations across the switchback roads questionable. The sediments have not received further study, and no volcanic rocks were recognized. Unit 8 was seen in only one location but is important because of its very high gold content. In hand specimen the gold mineralization is associated with black argillaceous (?) layers which also contain pyrite, arsenopyrite, pyrrhotite, and sphalerite.

All the igneous rocks in this area are believed to be intrusive. They range from light-coloured feldspar porphyries to black lamprophyre dykes. One of the lamprophyre dykes is cut by a quartz vein suggesting the possibility of relatively young mineralization (50 Ma). However, no assays are available to confirm the hypothesis.

STRUCTURAL GEOLOGY

Twenty-one bedding plane observations plotted on a Schmitt stereographic projection indicate folding with an axis plunging 40 degrees toward 276 degrees (Fig 52-3). A syncline observed on the west side of the gold-bearing fault (Fig. 52-1) plunges 35 degrees toward 279 degrees. Using Figure 52-3 it is possible to estimate an axial plane that strikes northwest and dips steeply west. The 'ac' or tension direction would therefore strike north-northeast. This is the direction of two of the faults in the discovery area, one of which is known to contain gold. The outcome of this preliminary study is that it is not possible to project the geology of the discovery area to the Hailstorm Mountain baseline.

OBSERVATIONS RELATING STRUCTURAL GEOLOGY AND GOLD GEOCHEMISTRY (Stokes, 1983)

The highest geochemical values for gold form a zone that is elongated in a north-northeast direction, approximately parallel to the 'ac' joint direction. The discovery zone on the initial survey had 170 ppb gold. At 525 metres due north of this location, another anomaly is 550 ppb gold; 1 300 metres north of the discovery pit on a bearing of north 5 degrees east there is another anomaly of 175 ppb gold. This line of projection is at the south end of the Hailstorm Mountain baseline.

SELF-POTENTIAL SURVEY (SP)

The long wire method (Thornton, 1980) was used to carry out the 1985 survey. Previous data using the short wire (20-metre) method was converted by accumulating the data. The SP anomalies observed are coincident with faults, one of which, in the discovery zone, is gold bearing. Three fault target areas are indicated by the survey (Fig. 52-2):

(1) The main gold-bearing shear zone identified with the -700 megavolt reading is interpreted to extend to the -230 megavolt location.

(2) The fault mapped at the -16 megavolt location may be offset to the -441-megavolt area.

(3) The -548-megavolt and -487-megavolt areas contain water seepages, however, the anomaly should be investigated.

WORKING HYPOTHESIS TO FIND MORE GOLD BASED ON STRUCTURAL GEOLOGY

There are probably a number of factors controlling the distribution of gold. At present it seems likely that there is a stratigraphic and a structural control. Relative to the other rock units the marble in the discovery area is highly anomalous in gold (G. Delane, personal communication). Because the sedimentary units are repetitive there should be other limestone or marble horizons. Where these units are intersected by gold-bearing faults it is likely that bonanza gold replacement deposits can be found.

Certainly the black, manganiferous, graphitic fault zones should be explored for their gold content. If they are in the 'ac' direction one would expect them to be short, but *en echelon*. This is the type of pattern indicated by the SP survey (Fig. 52-3).

Considering that the best geochemical values are to the north of the discovery zone, this is a favoured direction for further exploration. The potential strike length indicated to date from the reconnaissance geochemistry (Stokes, 1985) is 1 300 metres.

ACKNOWLEDGMENTS

The author wishes to thank Alex Strebchuck and his two sons, Stanley and Tim, for their many kindnesses. Able and cheerful field assistance was given by Paul Elkins. I also wish to thank Noranda (Robert Wilson) and Newmont (Gerry Delane) for sharing their observations.

British Columbia Ministry of Energy, Mines and Petroleum Resources, Geological Fieldwork, 1985, Paper 1986-1.

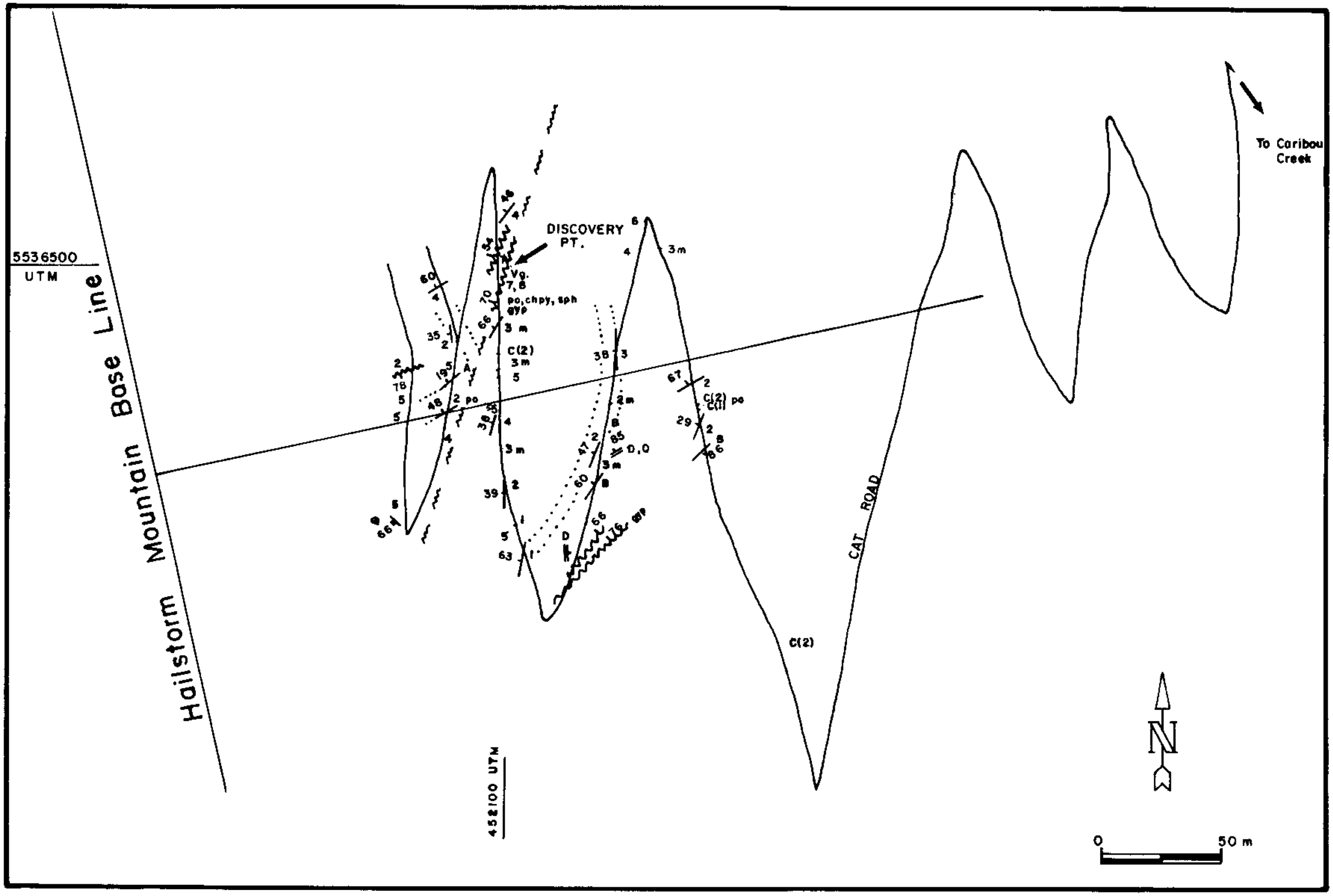

Figure 52-1. Reconnaissance geology of the Hailstorm Mountain gold prospect (82F/13).

LEGEND

IGNEOUS ROCKS

TERTIARY

- D — LAMPROPHYRE DYKES

CRETACEOUS AND/OR JURASSIC

- C — FELDSPAR PORPHYRY: (1) CROWDED FELDSPARS; (2) UNCROWDED FELDSPARS

AGE UNKNOWN (PROBABLY TERTIARY)

- B — ANDESITE DYKES
- A — APLITE DYKES

METAMORPHIC ROCKS

PRE-JURASSIC

MILFORD GROUP

- 8 — MARBLE
- 7 — SKARN
- 6 — BIOTITE SCHIST
- 5 — BIOTITE FELDSPAR GNEISS

BEDDED ROCKS

PRE-JURASSIC

MILFORD GROUP

- 4 — BLACK ARGILLITE
- 3 — SEDIMENTS, BLACK PELITES, SILTSTONES
- 2 — THIN-BEDDED SEDIMENTS, SILTSTONES WITH ARGILLACEOUS PARTINGS APPROXIMATELY 10 CENTIMETRES APART
- 1 — SANDSTONE AND/OR TUFF

MINERALS

Vg = VISIBLE GOLD
m = MELANTERITE
po = PYRRHOTITE

chpy = CHALCOPYRITE
sph = SPHALERITE
Q = QUARTZ VEIN
gyp = GYPSUM

Legend for Figure 52-1.

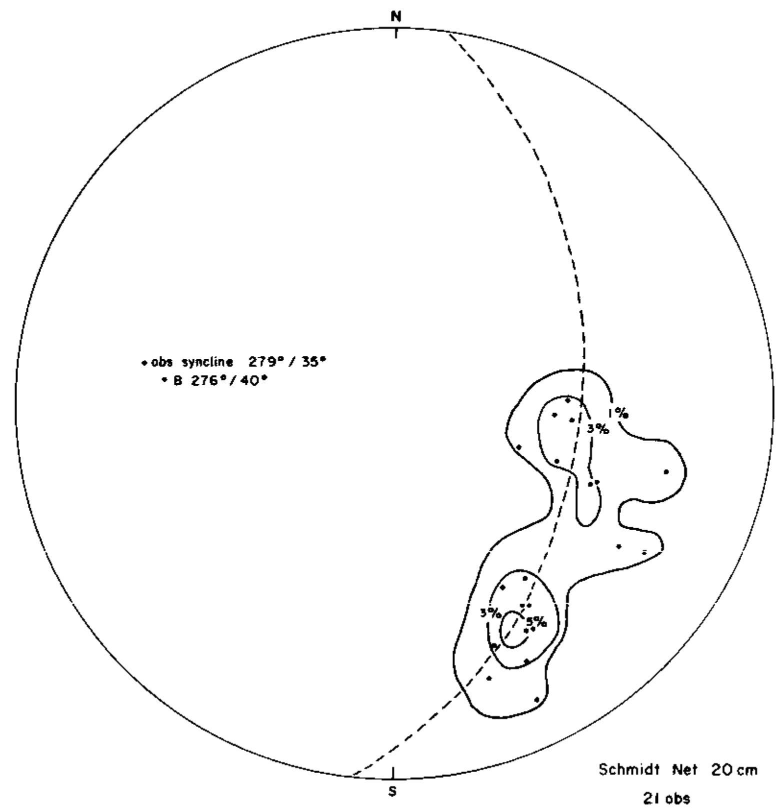

Figure 52-3. Bedding plane poles from the Hailstorm Mountain prospect.

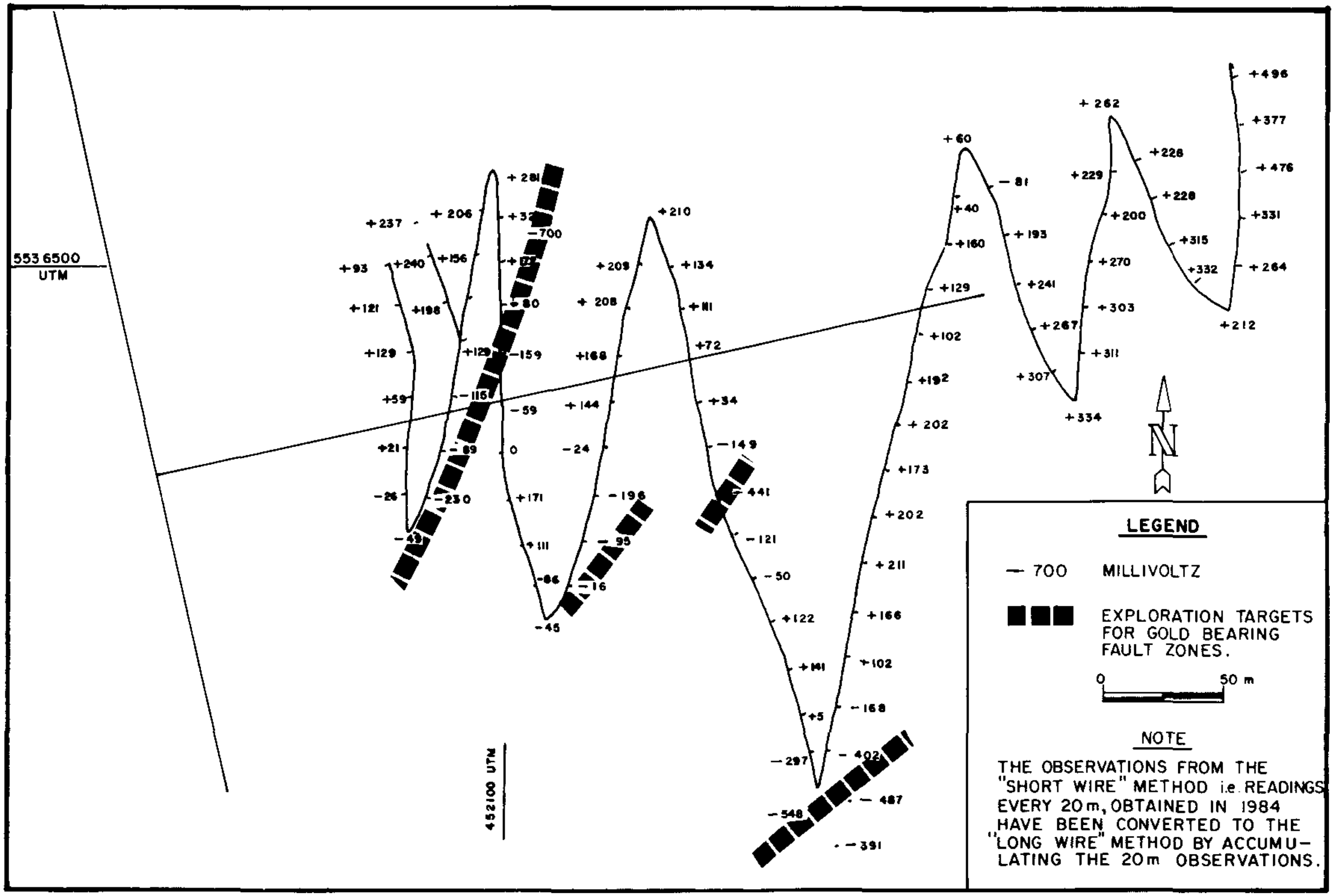

Figure 52-2. Reconnaissance self-potential survey of the Hailstorm Mountain gold prospect.

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STRUCTURE AND MINERALIZATION OF THE DRIFTPILE CREEK AREA NORTHEASTERN BRITISH COLUMBIA (94E/16, 94F/14, 94K/4, 94L/1)

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INTRODUCTION

This paper summarizes the preliminary results of a detailed study of the structure, mineralization, and sedimentology of the Driftpile Creek area (Fig. 53-1), carried out during the 1985 field season. The work represents the first stage of a three-year project on the sedimentation, tectonics, and mineralization of the Driftpile area Ba-Fe-Zn-Pb deposits and forms part of an ongoing research program on stratiform sediment-hosted Pb-Zn deposits in the Canadian Cordillera (McClay, 1983a, 1983b). The detailed study of the Driftpile Creek area will form part of a regional mapping program of the Gataga River district (NTS sheets (94E/16, 94F/14, 94K/4, and 94L/1).

The objectives of this project are: to determine the structure of the Driftpile Creek area; to establish a detailed stratigraphy of the area (incorporating a biostratigraphy based on conodonts); and to produce a model for the structural and sedimentological evolution of the Gataga district, and in particular for the distribution of stratiform Ba-Fe-Zn-Pb deposits. In the 1985 field season, detailed structural and stratigraphic mapping at 1:10 000 scale was carried out in the Driftpile Creek area and the results form the basis of this paper.

Previous work in the Driftpile Creek area of the Gataga district has been chiefly concerned with reconnaissance style mapping at 1:250 000 scale by Gabrielse (1962), Taylor and Stott (1973), and MacIntyre (1981, 1983). Work on the Driftpile deposit by Archer Cathro and Associates acting for the Gataga Joint Venture between 1977-1982 involved both detailed and regional mapping together with extensive diamond drilling. Through this exploratory work Carne and Cathro (1982) identified three main mineralized horizons in the Devonian siliciclastics. These strata occur within a 180-kilometre-long complex fold and thrust belt of Ordovician-Devonian sedimentary rocks — the Kechika Trough (Fig. 53-2) which is the southern extension of the Selwyn Basin.

LOCATION AND TOPOGRAPHY

The Driftpile Creek deposit is located at 58 degrees 04 minutes north and 125 degrees 55 minutes west (Fig. 53-1). It lies within the Muskwa Range of the northern Rocky Mountains, between the Kechika River (the northern extension of the Rocky Mountain Trench) to the southwest, and the Gataga River to the northeast. Elevations range from 1 000 metres to over 2 000 metres, and the area is characterized by long ridges and valleys parallel to the dominant northwest-trending structural grain. Tree line reaches up to 1 500 metres with abundant vegetation of mixed woodland in valley bottoms and poplar, pine, and grasses on higher ground. The best outcrop is found in river sections and on the more elevated terrane. Access to the area was via helicopter from Johanson Lake and float plane from Dease Lake. A 640-metre dirt airstrip, at an elevation of 1 340 metres, is suitable for small fixed wing aircraft; it is located approximately 2 kilometres from the camp on Driftpile Creek.

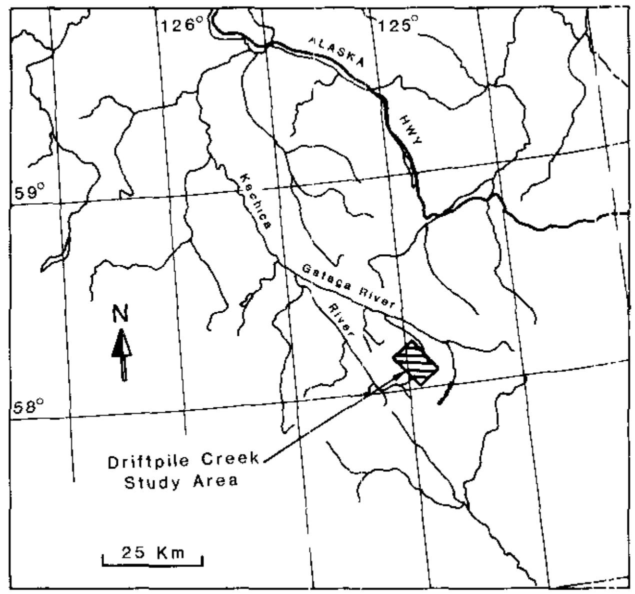

Figure 53-1. Location map of the Driftpile Creek area, northeastern British Columbia.

TECTONO-STRATIGRAPHIC SETTING

The Driftpile Ba-Fe-Zn-Pb deposit is located in the Rocky Mountain Fold and Thrust Belt. Host rocks are part of the long, narrow northwest-trending Kechika Trough — a southern extension of the Middle-Upper Paleozoic Selwyn Basin (Fig. 53-2). Sedimentation is dominated by black, fine-grained siliciclastic rocks reflecting a starved and restricted basin environment. The Kechika Trough also hosts the Cirque, Elf, and Fluke Pb-Zn-Ba deposits (MacIntyre, 1983) south of the Gataga area (Fig. 53-2). These stratiform barite-sulphide deposits are considered to have formed from metalliferous fluids discharged into local basins along contemporaneous faults during block faulting related to crustal extension during Middle to late Devonian time (Gordey, *et al.*, 1982; MacIntyre, 1983; Goodfellow and Jonasson, 1984).

STRATIGRAPHY

In the Driftpile Creek area, Ordovician through Upper Devonian strata are deformed into a northwest-trending fold and thrust belt (Fig. 53-3). These rocks represent the basinal facies of the Kechika Trough and are flanked to the east and west by Cambrian to Early Ordovician platformal carbonates (Fig. 53-2). To the east, the carbonate sequences constitute the western edge of the MacDonald Platform. The western margin of the basin is complicated by large right lateral strike-slip displacements along the Rocky Mountain

British Columbia Ministry of Energy, Mines and Petroleum Resources, Geological Fieldwork, 1985, Paper 1986-1.

Trench during Mesozoic and Cenozoic time (Tempelman-Kluit, 1979; Gabrielse, 1985). The stratigraphy of the Driftpile Creek area is shown on Figure 53-4. A basal sequence of Ordovician through Lower Devonian shales and siltstones has been assigned to the Road River Group; it is overlain with apparent conformability by fine-grained siliciclastics of the Lower Earn Group (Gordey, *et al.*, 1982).

ROAD RIVER GROUP (ORDOVICIAN-LOWER DEVONIAN)

The lowermost strata exposed in the Driftpile Creek area form a 30 to 40-metre-thick sequence of recessive carbonaceous black argillites, cherts, and minor thin limestones that often contain Ordovician graptolites. This is overlain by 130 metres of resistant, distinctly orange-weathering dolomitic micaceous siltstones; locally these contain Silurian graptolites. Two 3-metre-thick cryptalgal-laminated micritic limestone bands are present toward the top of this unit. The Silurian section forms a distinct marker in the Driftpile Creek area. A recessive, silver-grey-weathering package of black argillites, thin-bedded black chert, and locally developed crinoidal limestones with calciferous sandstones of probable Lower Devonian age, overlies the Silurian siltstone and represents the top of the Road River Group in the Driftpile Creek area.

LOWER EARN GROUP (MIDDLE-LATE DEVONIAN)

The Road River Group is conformably overlain by a sequence of black clastics of the Lower Earn Group (Gordey, *et al.*, 1982). In the Driftpile Creek area the base of the Lower Earn Group is characterized by a series of fining upward cycles of thin to medium-bedded laminated siltstones and silt-banded argillites. In the western part of the map-area (Fig. 53-3) these interdigitate with thick-bedded chert pebble conglomerates. This sequence is succeeded by a minimum of 450 metres of recessive, unlaminated to thinly laminated silver-

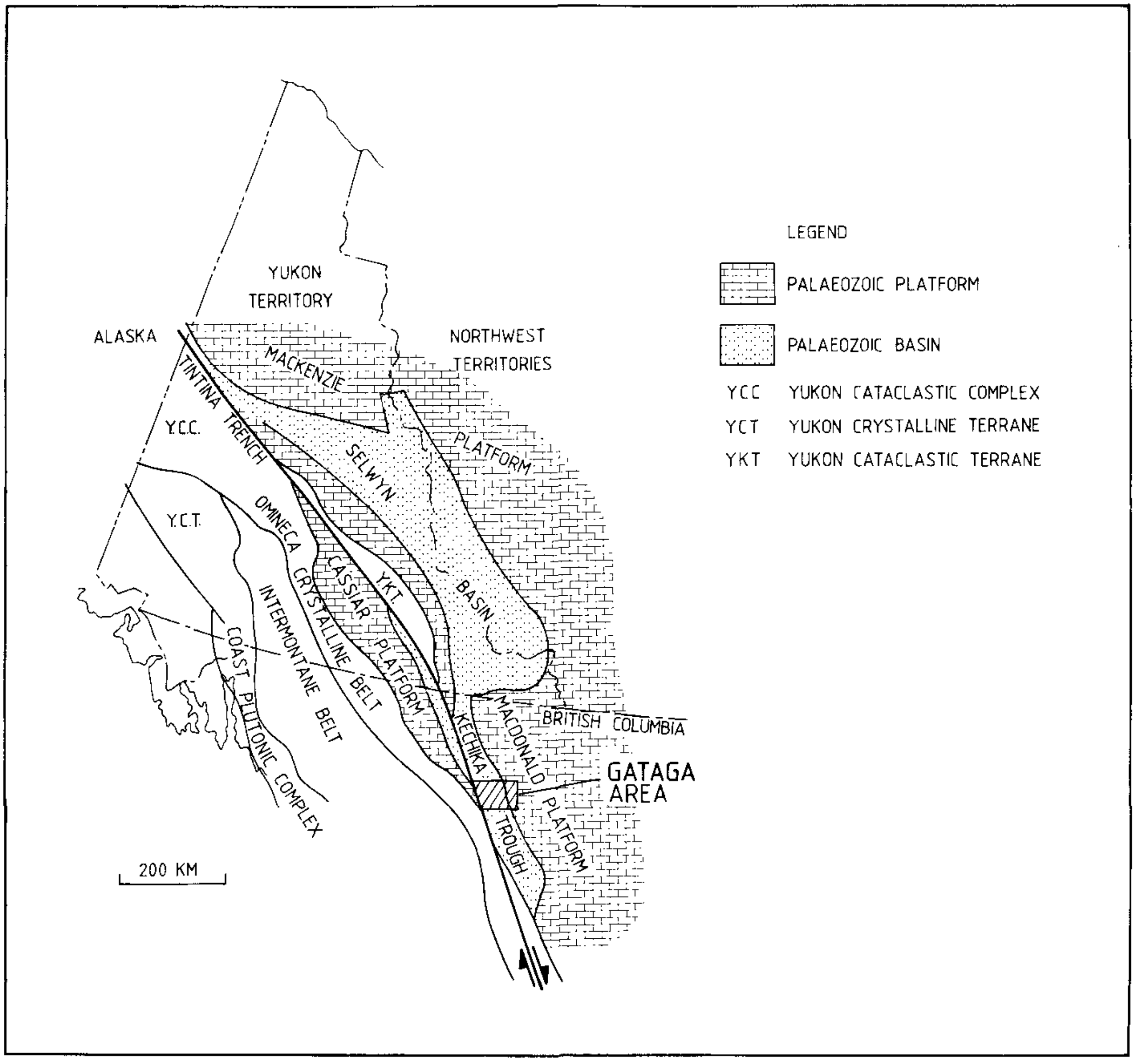

Figure 53-2. Lithotectonic map of the Kechika Trough and location of the Gataga area.

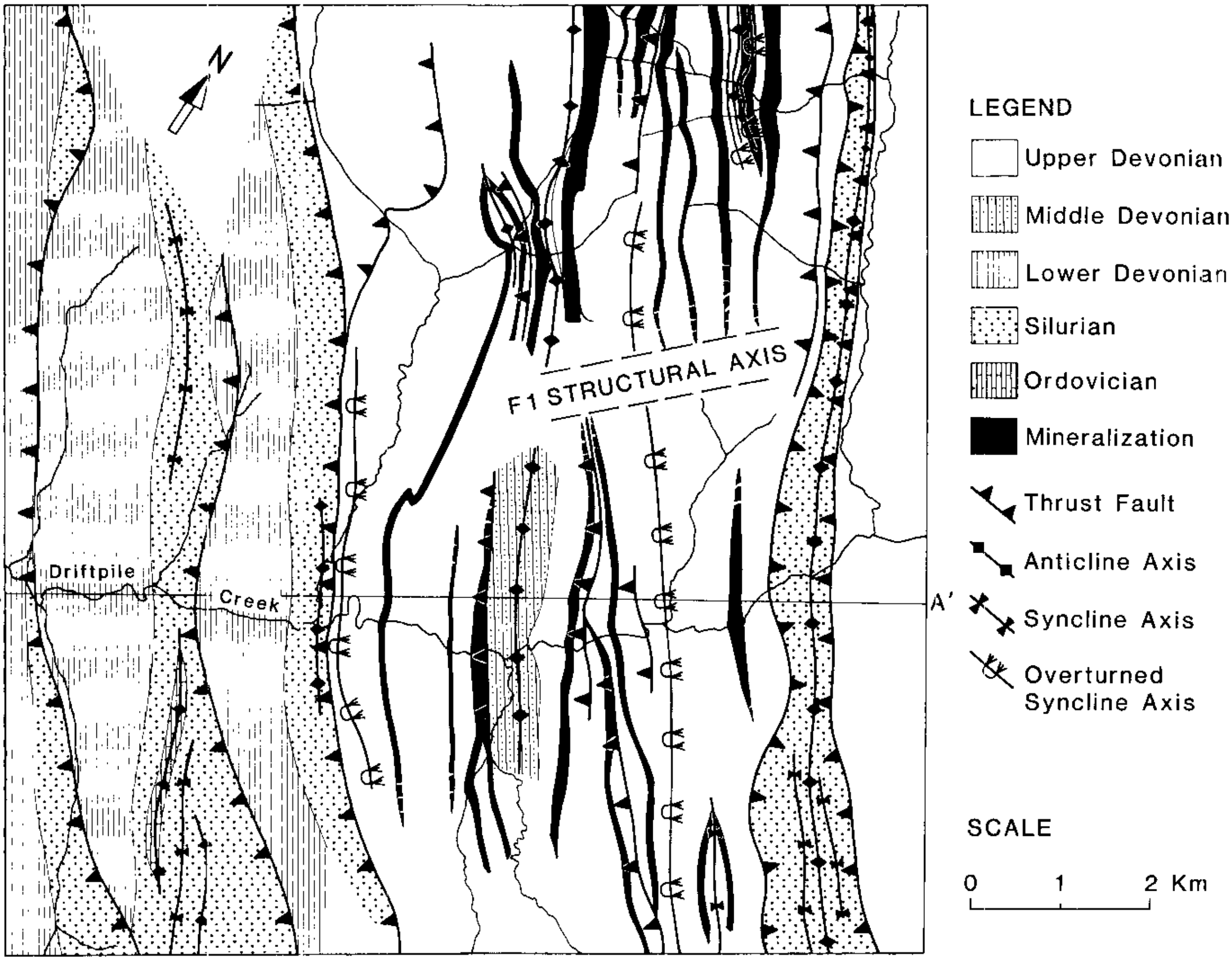

Figure 53-3. Preliminary geological map of the Driftpile Creek area.

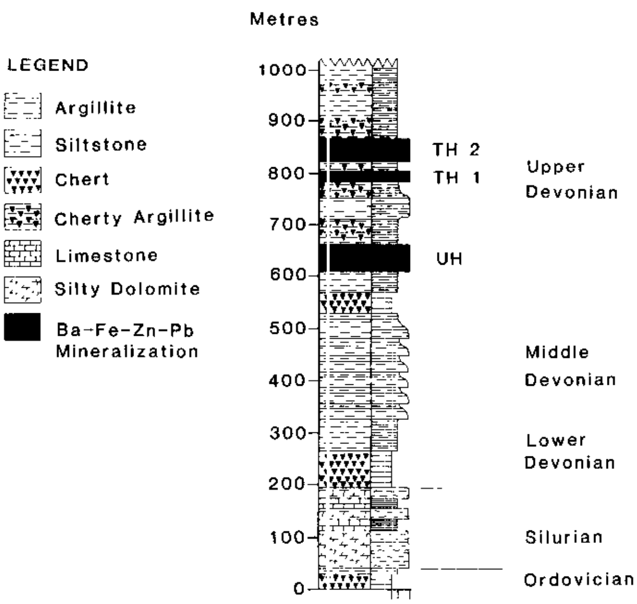

Figure 53-4. Stratigraphic column for the Driftpile Creek area.

grey-weathering black argillites, cherty argillites, and thin-bedded chert. These strata range in age from Frasnian to Famennian (M. Orchard, pers. comm., 1985). The Upper Devonian sequence contains at least three horizons of stratiform barite-pyrite-galena-sphalerite mineralization (Figs. 53-3 and 53-4).

STRUCTURE

The Driftpile Creek Ba-Fe-Zn-Pb deposit lies within a northwest-southeast-striking belt of tightly folded and thrust, recessive weathering Lower Earn Group strata (Fig. 53-3). At Driftpile Creek, packages of generally upright to steeply dipping chevron folds and strongly cleaved strata are bound by steep west-dipping thrust faults (Figs. 53-3 and 53-5). The western limit of this belt is marked by the Mount Waldemar Thrust (Fig. 53-3). West of this, the thrust faults root progressively in deeper and older strata. In the east of the map-area the position of a 'pop up' structure of Silurian siltstone (Figs. 53-3 and 53-4) indicates the first change in thrust vergence from northeasterly to southwesterly. This structure marks the eastern edge of the belt of dominantly Middle-Upper Devonian Lower Earn Group rocks.

Detailed structural studies have enabled three phases of deformation to be established:

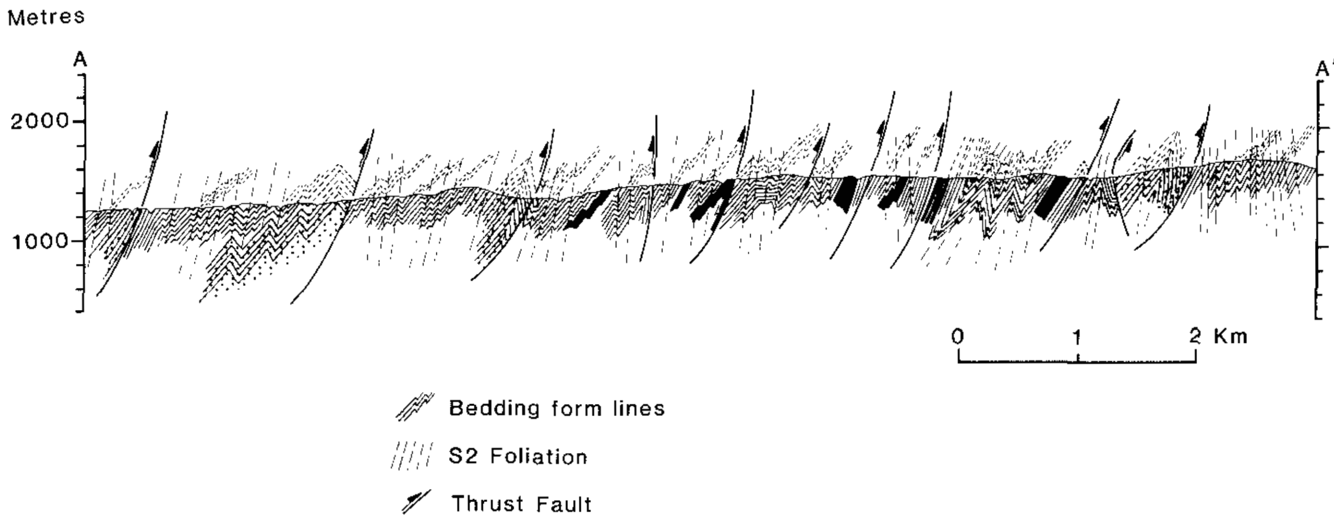

Figure 53-5. Structural section through the Driftpile Fold and Thrust Belt. Silurian siltstone is stippled.

Phase 1 deformation produced asymmetric folding on northeast-trending axes (Fig. 53-3). Phase 1 folds are associated with an early fanning axial planar cleavage that is only locally developed.

Phase 2 deformation is related to major Mesozoic compression resulting in a complex array of generally northeast-verging thrusts and folds. An intense penetrative cleavage (S2), is developed throughout the belt. This cleavage may accommodate 30 to 40 per cent shortening due to pressure solution along the cleavage planes. Fold axes and L2 lineations have generally horizontal to shallow plunges, although the presence of steep zones (where the S2 foliation has been superposed on earlier steeply orientated bedding surfaces) indicate positions of steep limbs of folds related to Phase 1 deformation.

Phase 3 deformation developed local steep to vertically plunging kink folds that are superposed on the general northwest Phase 2 structural trend. These folds are interpreted as dextral kinks probably related to late stage movement along the Kechika and Gataga strike-slip faults.

MINERALIZATION

In the Driftpile Creek area three intervals of stratiform Ba-Fe-Pb-Zn mineralization have been identified within the fine-grained black argillites, cherty argillites, and cherts of the Lower Earn Group (Carne and Cathro, 1982). These have been designated units UH, TH1 and TH2 (Archer Cathro and Associates, 1981). The mineralized intervals are located in poorly exposed panels of highly folded and sheared rocks (Figs. 53-3 and 53-4) which hampers correlation between different thrust bound packages. Data have been collected from detailed examination of surface exposures and by logging mineralized intervals in drill core. Preliminary conodont dating has shown that the UH horizon is Frasnian in age whereas TH1 and TH2 appear to be Famennian in age (M. Orchard, pers. comm., 1985).

The Ba-Fe-Zn-Pb mineralized intervals vary from 8 to 45 metres in thickness. They typically consist of beds of fine-grained massive to laminated barite and laminated fine-grained pyrite with subordinate sphalerite and galena interbedded with unmineralized black cherty argillite and chert. Beds vary from 10 to 100 centimetres thick. The sulphide content of the barite beds varies from almost zero to as much as 40 per cent by volume; the more sulphide-rich beds contain the higher Zn and Pb values. The sulphide-rich units are interpreted to be proximal style mineralization deposited in the vicinity of presumed feeder zones. Intense folding and shearing has locally produced strong transposition fabrics in the sulphides and barite.

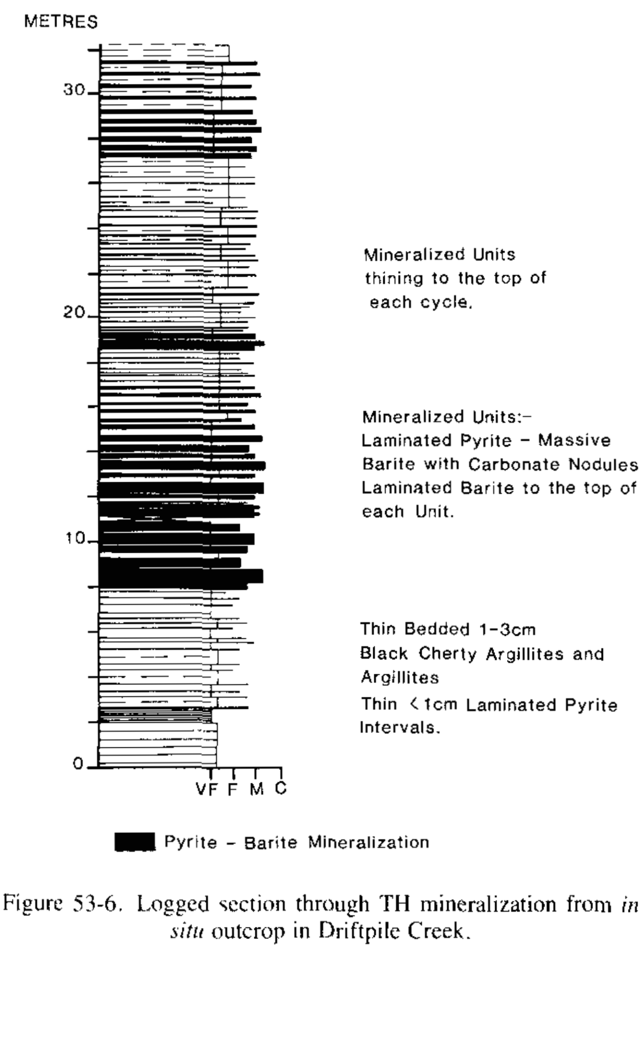

Figure 53-6. Logged section through TH mineralization from *in situ* outcrop in Driftpile Creek.

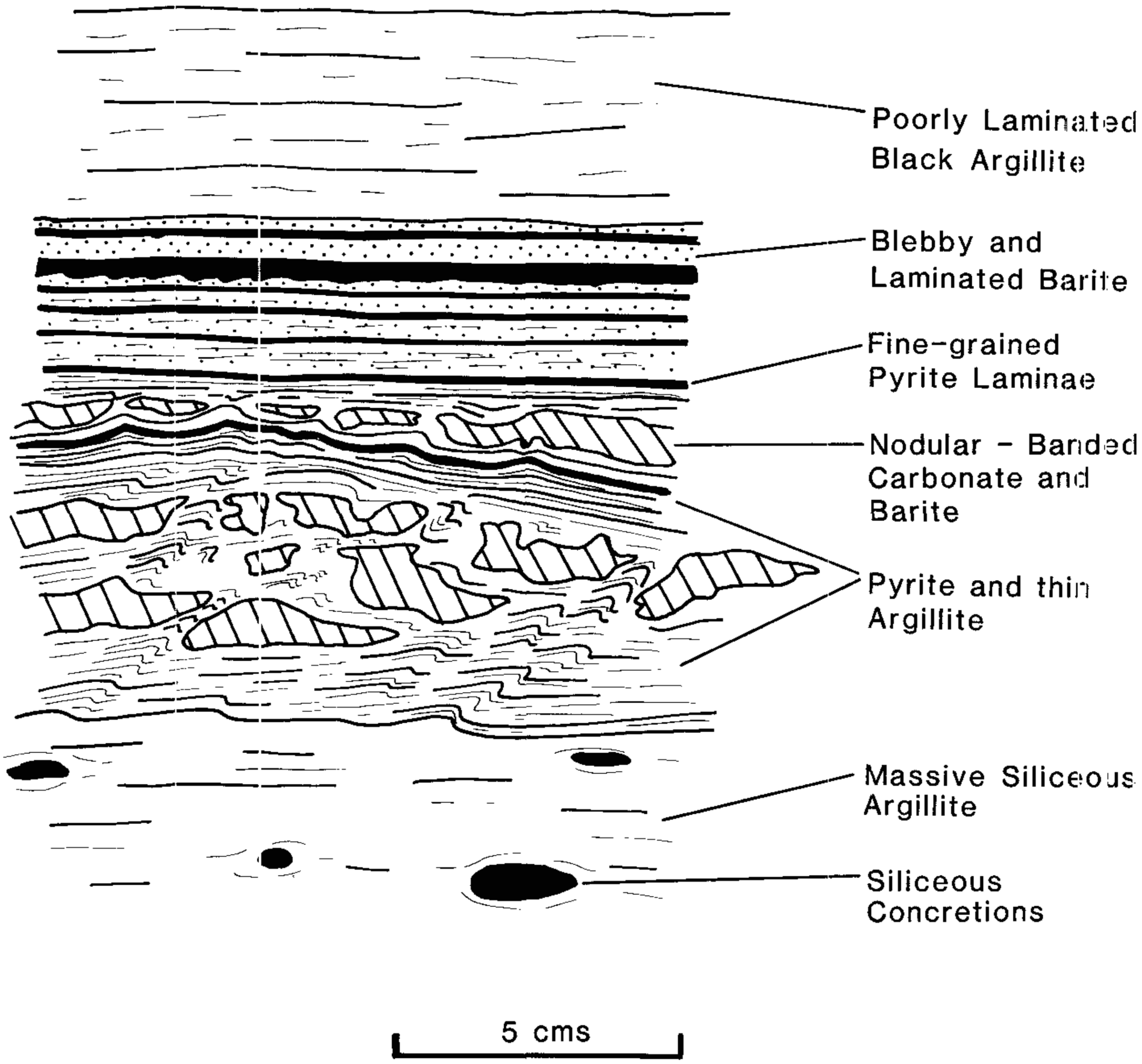

Figure 53-7. Detailed lithological section through a rhythmite cycle within TH, showing chemical differentiation with laminated sulphides at the base passing upward into massive barite and nodular carbonate. The top of the unit is characterized by sulphide-poor, laminated to blebby barite.

Detailed logging of drill core and of surface exposures revealed that the Ba-Fe-Zn-Pb mineralization exhibits a pronounced cyclic pattern of deposition with barite-sulphide beds alternating with chert and cherty argillite beds. This rhythmic pattern of sedimentation and mineralization is shown on Plate 53-1a and is found on all scales from millimetre-thick laminations to metre-thick thick alternating beds of barite-sulphide and interbedded argillite (Fig. 53-6). In general there is an inverse relationship between the thickness of the mineralized beds and the thickness of interbedded argillites (Figs. 53-6 to 53-8); the thicker mineralized units occur at the presumed stratigraphic base of the mineralized intervals. This style of interbedded barite-sulphide and unmineralized argillites is rhythmic in nature and similar to that predicted by Lydon (1983) for sulphide-barite deposition from a cooling brine pool.

In detail, many individual beds within the rhythmically mineralized intervals exhibit an internal chemical stratigraphy (Fig. 53-7) from pyrite-laminated siliceous-cherty argillite in the footwall, laminated sulphides (pyrite + sphalerite and galena) at the base of the mineralized bed, followed by massive barite with coarse-grained recrystallized carbonate nodules (Fig. 53-7) and overlain by laminated to blebby barite at the top of the bed. The carbonate nodules appear to overgrow primary bedding features and are interpreted to be diagenetic in origin. In any one bed not all the components described previously (Fig. 53-7) are developed. The concentration

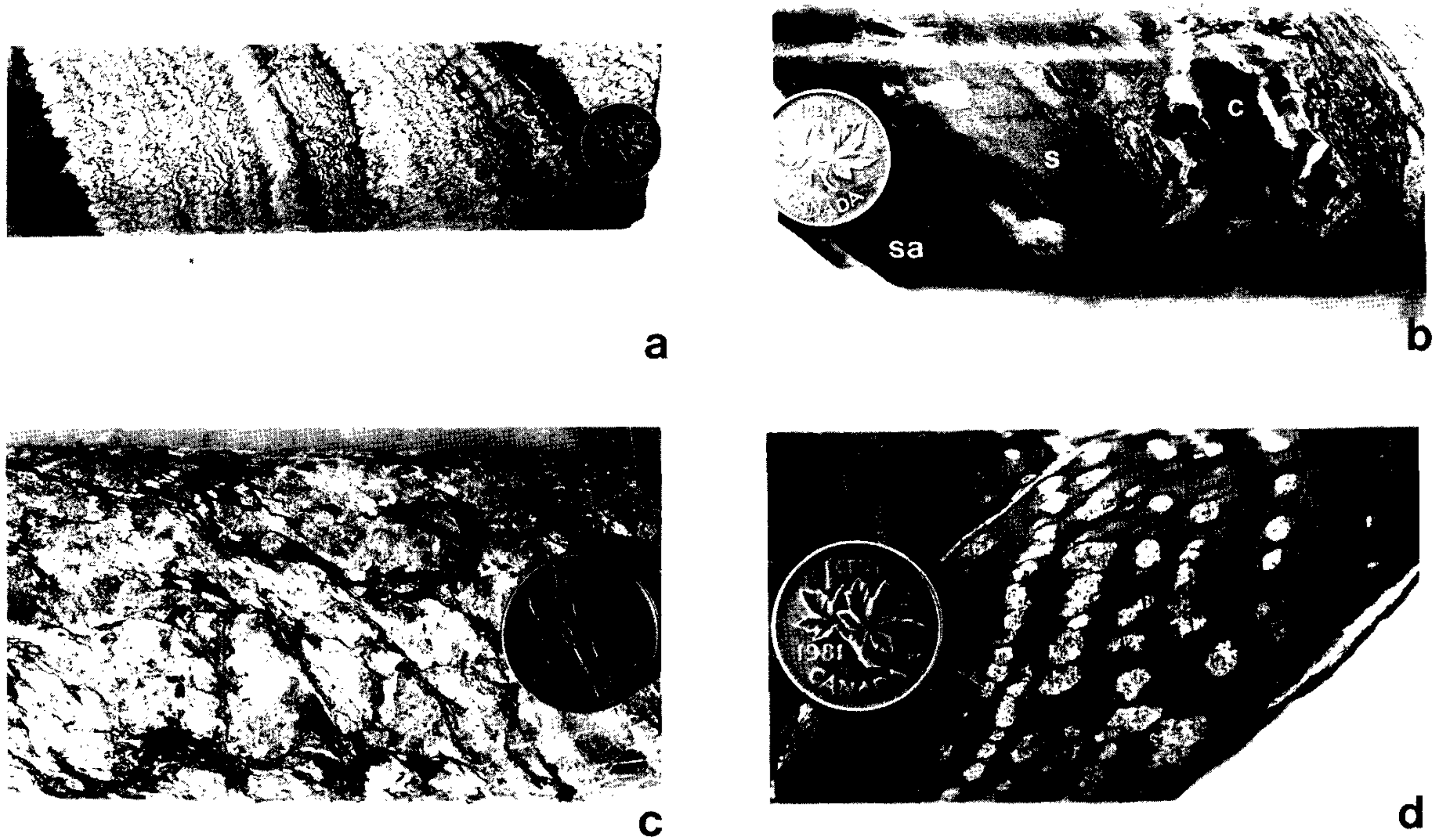

Plate 53-1. Photographs of drill core illustrating styles of mineralization in the Driftpile Ba-Fe-Pb-Zn deposit.

(a) Rhythmic bedding of laminated-blebby barite (white with thin black argillite interbeds. Grey laminated pyrite occurs at the base of the barite beds.

(b) Basal mineralization of a chemical rhythmite unit, TH interval. Base — black siliceous argillite (sa), fine-grained laminated sphalerite (s), coarse-grained carbonate nodules (c), and massive laminated barite (ba).

(c) Barite mineralization comprising dark bands of highly sheared and transposed pyrite that wrap around competent nodular carbonate and barite.

(d) Blebby barite mineralization consisting of barite nodules flattened by a pressure solution cleavage in siliceous argillites.

of pyrite laminations varies throughout the mineralized beds, in general they are more abundant at the base of a rhythmically bedded mineralized interval. Details of each of the types of mineralization are shown on Plate 53- .

In addition to the features described previously, detailed logging has revealed that distinct cycles of mineralization can be identified within any one mineralized interval (Fig. 53-8). These cycles are characterized by thick-bedded sulphide-barite units at the base that decrease in thickness toward the top of a cycle. Massive barite and laminated pyrite concentrations also decrease upward within a cycle and the proportion of laminated and blebby barite increases toward the top of the depositional cycle (Fig. 53-8). This pattern of mineralization is shown in the TH1 horizon on Figure 53-8 where at least three distinct chemical depositional cycles have been recognized.

DISCUSSION AND CONCLUSIONS

Preliminary fieldwork in the Driftpile Creek area has established a mappable lithostratigraphy and allowed determination of the tectonic evolution of the Gataga area. Three phases of deformation have been recognized. The identification of an early fold event with apparent northeast-southwest-trending axes, possibly associated with Devonian extensional faulting, warrants further study as this may have controlled the location of the barite-sulphide deposits and their feeder zones. Superposed upon this earlier deformation event is the main northeasterly directed folding and thrusting of presumed Mesozoic age. Later dextral kink folding is interpreted to be associated with regional dextral strike-slip faulting along the Rocky Mountain Trench (Gabrielse, 1985).

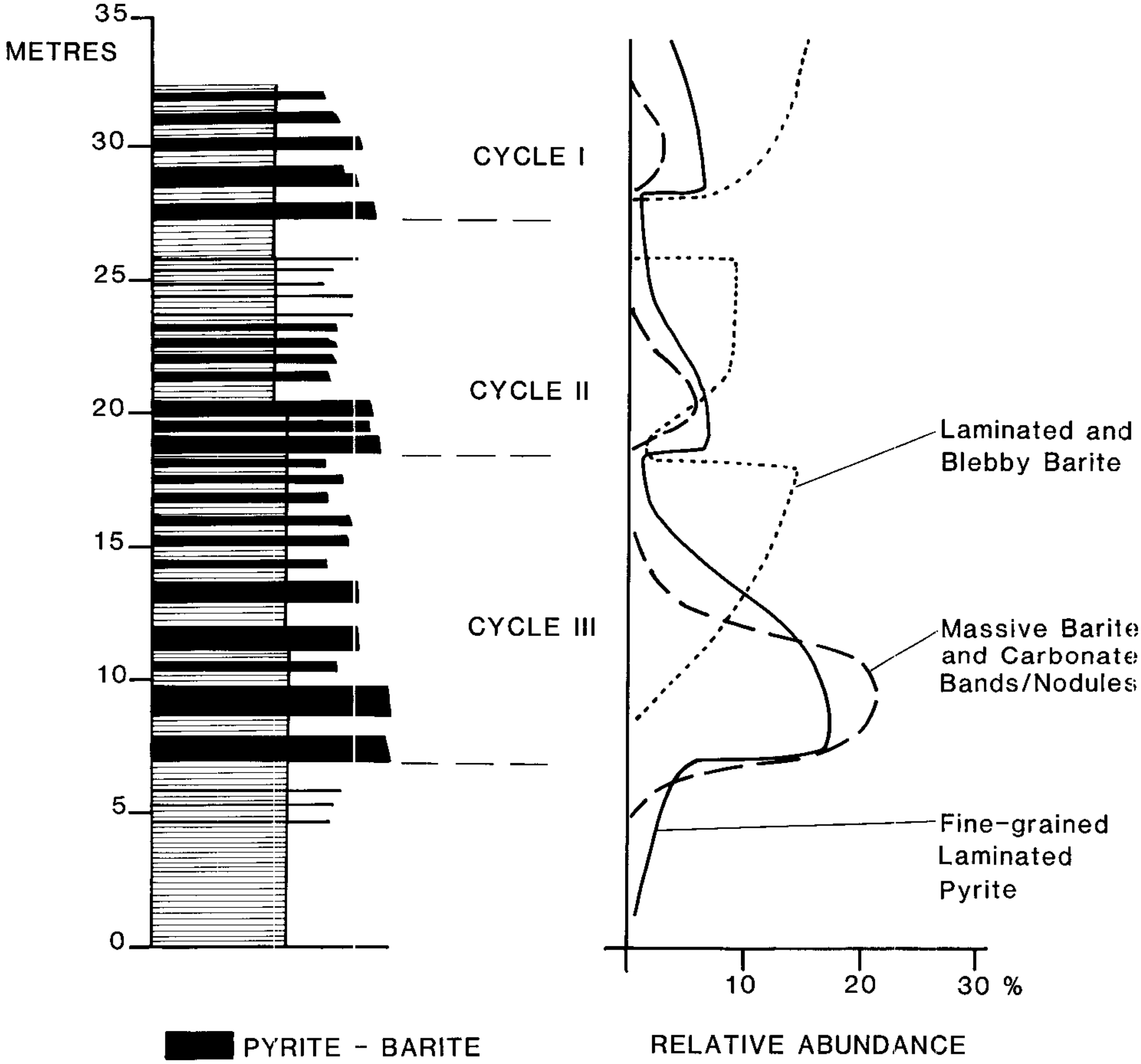

Figure 53-8. Logged section through TH mineralization showing three rhythmic cycles. Variations in the relative abundance of the three principal components are also shown.

The stratiform barite-sulphide mineralization displays distinct cyclic patterns of rhythmic sedimentation. Internal chemical differentiation within individual rhythmite beds has been identified and this can be used to indicate stratigraphic way up. Detailed studies of the mineralization and of its chemistry are continuing.

FUTURE RESEARCH

Future research will be carried out with the following aims:

(1) To define a lithostratigraphy and biostratigraphy (based on conodont dating), with special emphasis on the timing of mineralization and tectonic events controlling the distribution of Devonian basins.

(2) To examine the influence of an early extensional deformation event on controlling the distribution of mineralization within the Gataga area. This aspect will be investigated through further detailed structural and sedimentological research and regional mapping.

(3) To identify a geochemical signature for the Devonian strata in order to locate prospective horizons within the highly deformed black argillites of the Lower Earn Group.

(4) To investigate the mineralization processes using geochemical and isotopic techniques.

ACKNOWLEDGMENTS

This project is funded by a Natural Environment Research Council Grant to Dr. K.R. McClay. Invaluable logistic support was provided by Archer Cathro and Associates and the Gataga Joint Venture, the British Columbia Ministry of Energy, Mines and Petroleum Resources, and by the Geological Survey of Canada through H. Gabrielse and D. Sangster. N. Way and J. Purcell ably assisted in the field. We gratefully acknowledge the assistance of R. Carne in setting up the fieldwork program and for his comments on the geology of the Driftpile Creek area.

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STRUCTURAL GEOLOGY OF THE MILLIE MACK MINE AND A THEORETICAL ORE CONTROL (82K/4)

By G. G. Addie

GENERAL GEOLOGY

The Millie Mac mine is believed to be at the base of a klippe (Hyndman, 1968) of Late Triassic Slocan Group sedimentary rocks which are in contact with volcanic rocks of the Slocan Group and the Lower Jurassic Rossland Group. The base of the klippe consists of sheared graphitic argillite which contains some blocks of slickensided quartz vein material mineralized with galena, sphalerite, arsenopyrite, chalcopyrite, and pyrite. Recent operators used a trommel to collect the vein material which was sent to Ainsworth for milling. Recorded production to 1979 was 340 tonnes which yielded 316 grams gold, 21 599 grams silver, 70 kilograms copper, 45 439 kilograms lead, and 2 392 kilograms zinc. Only a very small fraction of the potential extent of the graphitic argillite has been explored by rotary drilling. This paper describes briefly the surface geology of the mine and offers an interpretation of possible controls of mineralization. The area of study covers approximately 1 square kilometre.

SEDIMENTARY ROCKS

Four distinct sedimentary units are present (Fig. 54-1) and include from oldest to youngest: graphitic argillite (unit 2); siltstones, sandstone, and tuff (unit 3); black argillite (unit 4); and limestone and limy siltstone (unit 5). The basal sedimentary unit is graphitic argillite (unit 2) which is of particular interest because it contains vein fragments which host the ore minerals. This unit is 3 to 10 metres thick; mineralized quartz fragments can occur in shear zones throughout the unit.

Black argillite of unit 4 is generally thin bedded and forms a local marker horizon.

IGNEOUS ROCKS

One biotite lamprophyre dyke was observed; it is assumed to be of Tertiary age.

An andesite layer (unit A) was mapped and is believed to be a sill. The basement andesite (unit 1) contains a considerable amount of breccia, but no economic minerals or veins were seen. Although diamond-drill logs in Assessment Report 9 965 (Mooney, 1981) indicate minor quartz veins within the andesite, no economic values were reported.

QUARTZ VEINS

Quartz vein fragments at the Millie Mack and Billie P workings are similar, however, at the Great Bear open pit, approximately 1 kilometre north of the Millie Mack deposit, quartz veins follow the bedding planes and have not been stretched or broken. At the Billie P workings quartz fragments were found to be oriented parallel to the 'b' axes of folds (Figs. 54-2 and 54-3).

Table 54-1 shows assays of concentrates from the Ainsworth mill (Assessment Report 9 965).

STRUCTURAL GEOLOGY

Figure 54-4 is a stereographic plot of 40 poles to bedding from the Millie Mack mine; the average calculated axis plunges 20 degrees toward 225 degrees. *Some measured fold axes indicated on Figure* 54-1 have this orientation, while some trend nearly east-west. They are doubly plunging producing dome and basin structures. It is of interest that the fold related 'ac' direction with strike 135 degrees is close to the 'possible ore' zone bearing 140 degrees as indicted by rotary drilling.

Figure 54-5 is a plot of 14 poles to bedding from the Billie P east and west pits; The calculated fold axis plunges 5 degrees toward 040 degrees. The calculated 'ac' or tension direction is therefore 139 degrees, practically identical to that found at the Millie Mack mine.

SELF-POTENTIAL TEST (SP)

A self-potential test was made approximately 25 metres west of the Billie P (west) pit using the long-wire method. Results shown on Figure 54-2 indicate that the graphitic argillite has a distinct signature. This type of survey should be carried out to define the exact location of the graphitic argillite throughout the klippe area. Further testing should also be done at the other workings.

ROTARY HOLE DATA

Silver values from rotary drilling at the Millie Mack for two structurally controlled ore zones are indicated in Table 54-2 following.

Table 54-3 shows silver values from rotary drilling of the area that was subsequently mined with tonnages and grades given in Table 54-1.

TABLE 54-1. AINSWORTH MILL ASSAYS

Location	Tons	Gold oz./ton	Silver oz./ton	Copper per cent	Lead per cent	Zinc per cent	Antimony per cent	Arsenic per cent
Billie P (west)	3.732	0.0950	47.7	0.19	4.4	10.3	0.1	1.1
Black Bear	4.0845	0.1950	38.7	0.17	3.3	7.2	0.04	3.3
Billie P (east)	2.2745	0.2180	18.65	0.21	2.4	4.5	0.01	5.1
Millie Mack	1.9495	0.2030	18.55	0.18	2.5	4.5	0.01	4.7
Millie Mack	3.123	0.3740	22.4	0.16	2.5	3.0	0.01	3.9

British Columbia Ministry of Energy, Mines and Petroleum Resources, Geological Fieldwork, 1985, Paper 1986-1.

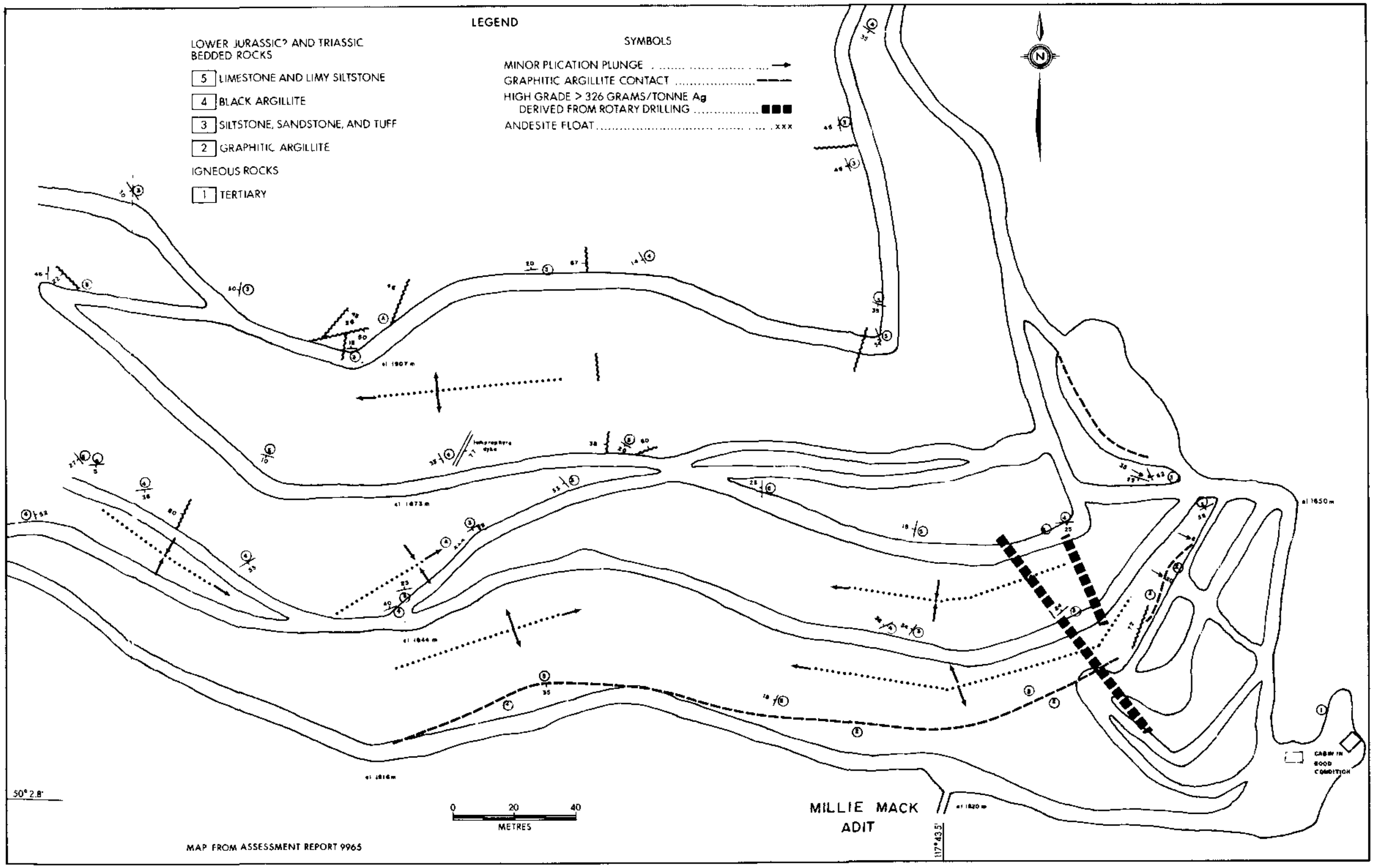

Figure 54-1. Geology of the Millie Mack area.

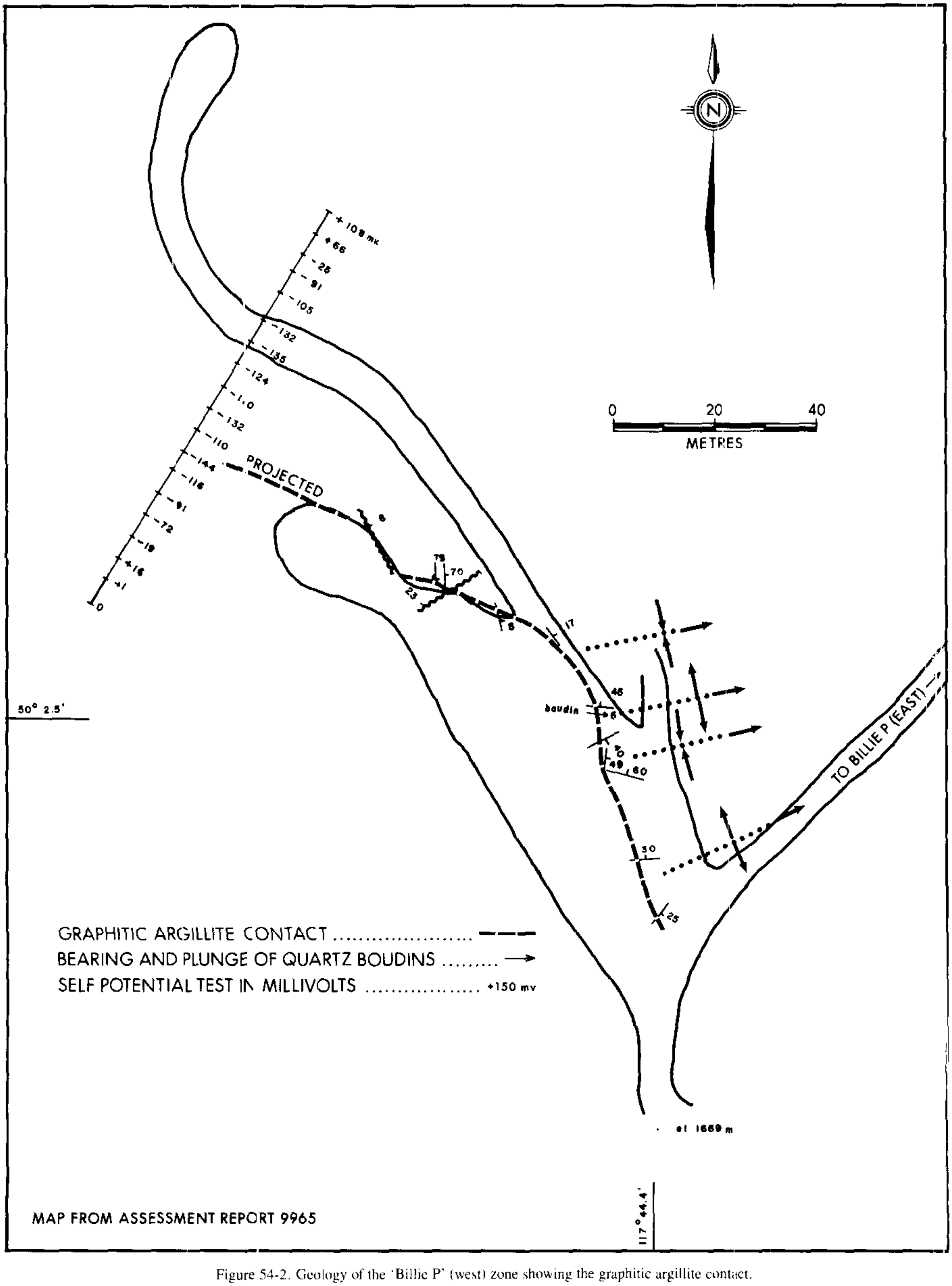

Figure 54-2. Geology of the 'Billie P' (west) zone showing the graphitic argillite contact.

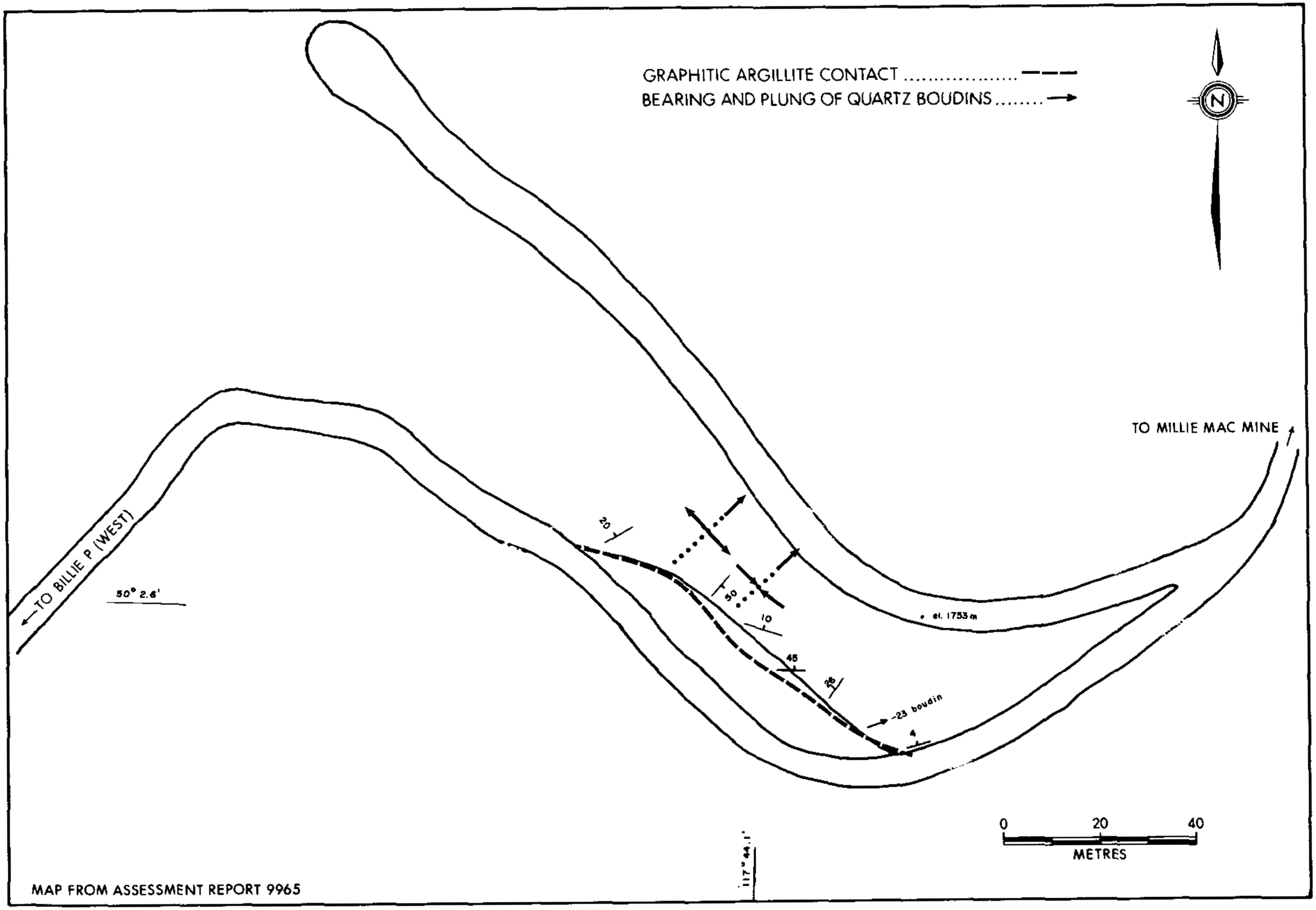

Figure 54-3. Geology of the 'Billie P' (east) zone showing the graphitic argillite contact.

The arithmetic average of the analyses in Table 54-3 is 76.56 grams silver per tonne (2.23 ounces silver per ton). The two net smelter returns from the Millie Mack mine (Table 54-1) averaged 701.9 grams silver per tonne (20.47 ounces silver per ton) after trommel and mill upgrading.

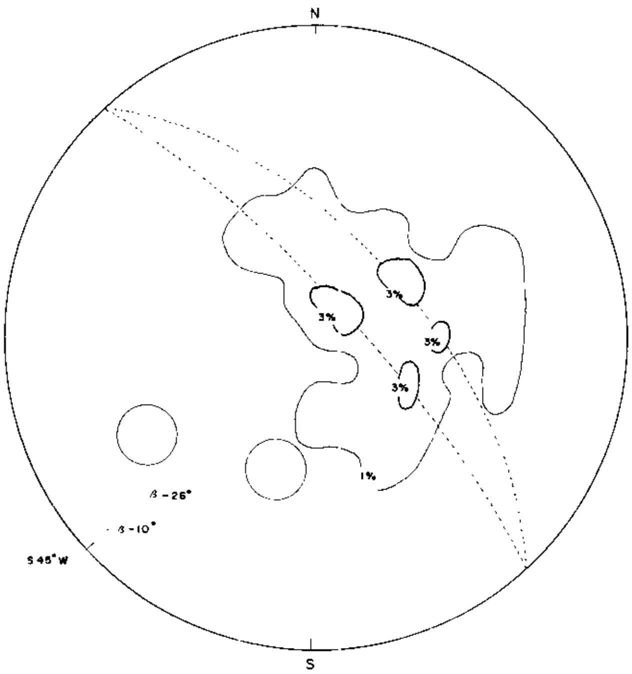

Figure 54-4. Plot of poles to bedding, Millie Mack mine.

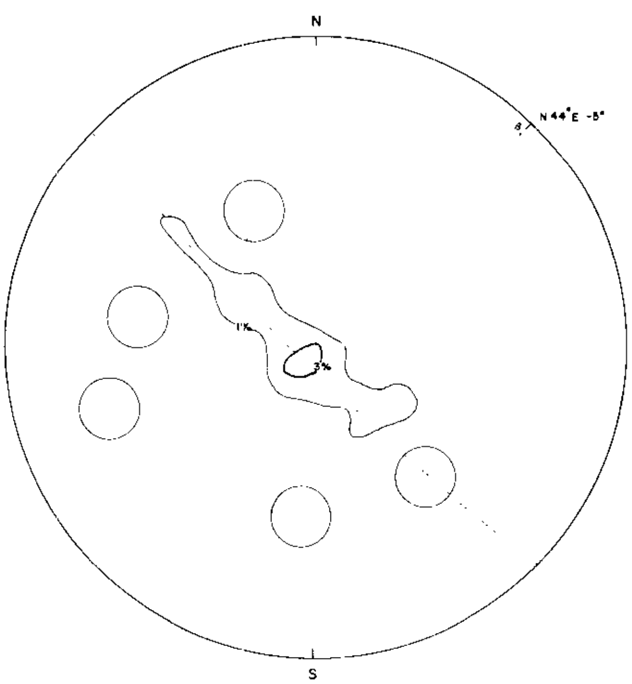

Figure 54-5. Plot of 14 poles to bedding, 'Billie P' east and west pits.

TABLE 54.2

ROTARY DRILL HOLE SAMPLE ASSAYS MILLIE MACK MINE

Rotary Hole No.	Silver Assay grams/tonne
30-80	320.56
10-80	270.85
9-80	633.59
11-80	80.23
28-80	643.19
17-80	146.05

TABLE 54-3

ROTARY HOLE SILVER ASSAYS COVERING RECENTLY MINED AREA, MILLIE MACK MINE

[Best 1.5 metres (5 feet) used]

Rotary Hole No.	Silver grams/tonne
1-80	63
2-80	74.74
3-80	49.37
4-80	54.17
5-80	139.88
6-80	83.66
12-80	49.37
13-80	67.88
14-80	43.88
15-80	65.82
16-80	80.91
17-80	146.05
Average	76.56

CONCLUSIONS

Mapping at the Millie Mack mine indicates folding about northeast-trending axes. The associated 'ac' or tension direction is northwest-southeast, roughly parallel to the trend of the higher grade mineralization as indicated by rotary drilling.

ACKNOWLEDGMENTS

The author wishes to thank Dr. Paul Richardson of David Minerals Ltd. for his cooperation in enabling this project to be done. Thanks are also extended to Paul Elkins who assisted in the field.

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CANADA/BRITISH COLUMBIA COAL DATA PROJECT

By B. J. Thompson

INTRODUCTION

The Geological Branch of the British Columbia Ministry of Energy, Mines and Petroleum Resources renewed an agreement for three years with the Institute of Sedimentary and Petroleum Geology (ISPG) of the Geological Survey of Canada (GSC) in March 1983. The project was initiated in 1978 to aid both provincial and federal governments in coal resource estimations and provide industry with continually updated geological data for exploration and development. With this latest agreement geological as well as non-geological coal data are being collected into a computer-processable format.

DATA COLLECTION

At present the project is in the third year of data collection under the new agreement. The Geological Branch hired a consultant, Jill Thompson (Geocal Consulting), to construct computer files of digitized coal outcrop data. Close to 18 000 outcrop locations from the Quintette, Bullmoose, and Sukunka properties in the Northeast Coalfield have been digitized. The verification process is underway for each of these locations. Within the Geological Branch computer deposit models will use the outcrop data in conjunction with subsurface data to estimate coal reserves and resources. Models for the Northern and Southern Dominion Coal Blocks (Parcels 73 and 82) have been constructed using the Geological Analysis Package designed by Cal Data Ltd (Grieve and Kilby, 1985; Grieve and Kilby, this volume).

The annual update of COALFILE is also part of the agreement (refer to article by C. Kenyon, this volume). Information was coded from the 1984 geological assessment reports as well as the backlog of 1982 and 1983 reports.

A computer model for the Sukunka property is being developed by the GSC as the basis for other geological models of deformed coal deposits in mountainous terrains. The evaluation methodology is described by Hughes (1984). The interpretation of 50 000 metres of lithological and geophysical borehole logs for the Quintette property has been completed by Cal Data Ltd. and entered on the computer at the ISPG in Calgary (Thompson and Matheson, 1985). Cal Data Ltd. was contracted by the GSC to interpret borehole data from the Bullmoose property in the Northeast Coalfield. The South Fork area has been completed and work is progressing in the West Fork area. Carbon Creek is being considered as the next property for borehole interpretation.

DATA EXCHANGE

Over the past year the GSC has supplied the Geological Branch with a nine-track tape of most of the Quintette data and hard-copy maps for the verification process.

The Geological Branch has supplied the GSC with non-geological, location, and analytical data from COALFILE on nine-track tapes. Six floppy diskettes containing the digitized outcrop information were given to the GSC and updates will be sent when the map verification is complete.

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DIATREME BRECCIAS IN BRITISH COLUMBIA* (82G, J, N; 83C; 94B)

By Jennifer Pell
Post-doctorate Fellow, The University of British Columbia**

INTRODUCTION

Over the last decade considerable interest has been expressed in diatreme breccias of possible kimberlitic affinity in British Columbia (Fipke, 1983; Fipke and Capell, 1983; Grieve, 1981 and 1982; Roberts, *et al.*, 1980; Woodcock, 1978; etc.). This interest has been heightened by the reported recent discovery of diamonds in pipes north of Golden (Dummet, *et al.*, 1985; Northcote, 1983a and 1983b).

There are three main areas in which diatreme breccias are known to occur: the Cranbrook-Invermere area, the Columbia Icefield area north of Golden, and the Williston Lake area north of Mackenzie (Fig. 38-1). In all but one case (the Cross diatreme) these breccia pipes occur in a zone within the Western and Main Ranges of the Rocky Mountains which is between 20 and 50 kilometres east of the Rocky Mountain Trench. The diatremes in British Columbia intruded the miogeoclinal sequence of platformal carbonate and clastic rocks prior to deformation. With one notable exception (the Cross diatreme) all are hosted in Cambrian to Devonian sedimentary rocks which are unconformably capped by Middle to Upper Devonian strata (Grieve, 1981; Leech, 1979; Roberts, *et al.*, 1980). The Cross diatreme is located approximately 60 kilometres east of the Rocky Mountain Trench and is hosted by Pennsylvanian sedimentary rocks.

CRANBROOK-INVERMERE AREA (82G and 82J)

Forty or more breccia pipes and related dyke rocks are known to occur within the Bull, White and Palliser River drainages, east of Cranbrook and Invermere (Pighin, Fipke, personal communication). A number were visited for this study; four were mapped in detail and will be described here.

THE SUMMER 1 DIATREME (82G/11)

The Summer 1 diatreme is one of two small intrusive bodies found at the intersection of Galbraith and Summer Creeks, approximately 40 kilometres northeast of Cranbrook. It has previously been reported on by Grieve (1981). The Summer diatreme forms a rusty weathering, 50-metre-high resistant knoll hosted in rocks mapped by Leech (1960) as Late Cambrian McKay Group. In the vicinity of the diatreme the McKay Group consists of thin-bedded grey micritic limestone, argillaceous limestone, and intraformational limestone conglomerate. In only one place is the contact between the limestones and the diatreme exposed (Fig. 38-2) and there the contact is subparallel to bedding in the limestones. This is most likely a locally developed phenomenon, as the overall outcrop pattern (Fig. 38-2) indicates that the body must be discordant. The limestones within 0.5 metre of the exposed contact are highly brecciated and material similar to the diatreme matrix forms veinlets in the limestone breccia. No thermal metamorphic effects are evident.

The diatreme itself is a breccia throughout. It consists of angular to subrounded clasts in a medium green to grey matrix which is locally calcareous. The matrix is foliated, with the foliation striking southerly to southwesterly and/or west to northwesterly. The matrix is predominantly chlorite and serpentine (Grieve, 1981) with or without carbonate. Rare chrome diopside xenocrysts were noted. The clast:matrix ratio is in the order of 50:50, with clasts ranging from granule to cobble size. The largest and most numerous are angular limestone, limestone conglomerate, and shale fragments up to 70 centimetres in size; these comprise 90 per cent of all the clasts. The remaining 10 per cent are buff dolostones, crinoidal limestones, red-weathering thinly laminated dolostones, granites, granitic gneisses, phlogopite-chrome diopside-marbles, fine-grained intermediate to felsic volcanic rocks, and autobreccia fragments. Resistant (silicified ?) reaction rims were noted around many clasts.

Adjacent to the main diatreme (Fig. 38-2) are possibly related dykes (and sills ?). These dykes have a very fine-grained light to medium green matrix with dark green serpentine-filled ocelli. Subrounded quartzitic and granitic clasts, up to 2 centimetres in size, are locally present.

The majority of the clasts present in the main diatreme are limestones similar to, and likely derived from, the host McKay Group. Crinoidal limestone clasts are also present. Crinoidal limestones are not characteristic of the Cambrian McKay limestones and are most likely derived from younger formations. The Summer diatreme is itself deformed (foliated) and is therefore likely to have intruded the original miogeoclinal succession prior to deformation.

If this is the case, the Summer diatreme must have intruded crinoidal limestone-bearing formations which overlay the McKay Group, and blocks of these younger rocks collapsed into the breccia pipe. This suggests that the diatreme is considerably younger than its host rocks.

THE BLACKFOOT DIATREME (82G/14)

The Blackfoot diatreme crops out at 2 650 metres elevation on ridges east of the headwaters of Blackfoot Creek, approximately 65 kilometres northeast of Cranbrook. It is a recessive, green-weathering body discordant with rocks mapped by Leech (1960) as Ordovician to Silurian Beaverfoot-Brisco Formation. Folds are evident in the host rocks in the vicinity of the diatreme, where there is a deviation from the regional steep westerly dips (Fig. 38-3). The Beaverfoot-Brisco Formation in the hangingwall is characterized by thick-bedded, massive, medium grey limestones containing rugosan corals and light grey limestones in which chain corals (favosites and halosites type) are present. Thin-bedded to laminated, non-fossiliferous, purplish weathering limestones and shaly limestones are present in the footwall. The contacts between the diatreme and the limestones are well exposed (Fig. 38-3). As with the Summer diatreme, no thermal metamorphic effects are evident.

The Blackfoot diatreme is a composite or branching pipe-like body consisting of pale green breccia with generally small (up to 10 centimetres) subrounded to subangular clasts. The largest xenoliths present are purple-grey to buff-weathering limestones likely derived from the Beaverfoot-Brisco Formation. The clasts generally comprise up to 50 per cent of the diatreme and are predominantly

* This project is a contribution to the Canada/British Columbia Mineral Development Agreement.

** Presently at the University of Windsor, Ontario.

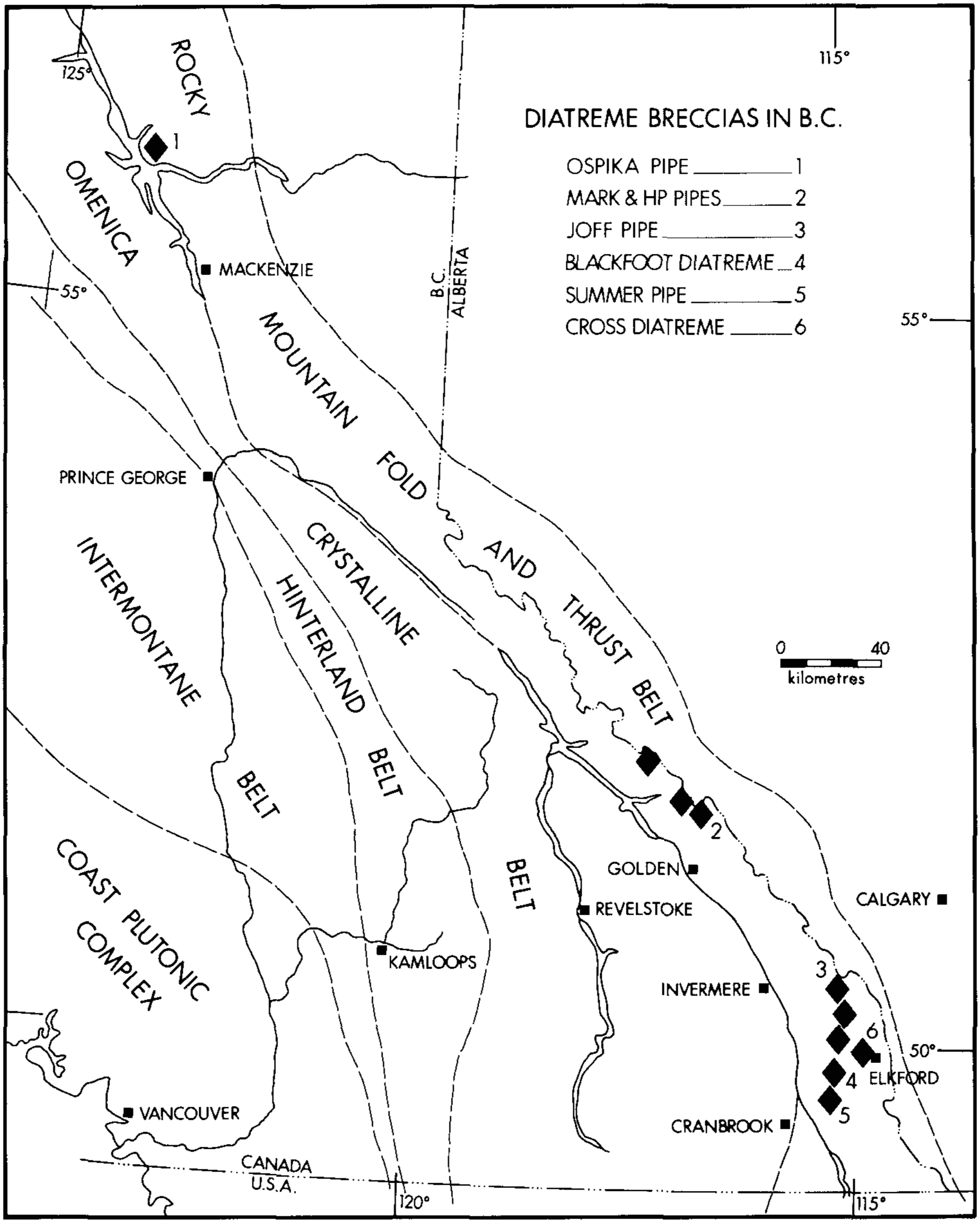


Figure 38-1. Distribution of Diatreme Breccias in British Columbia.

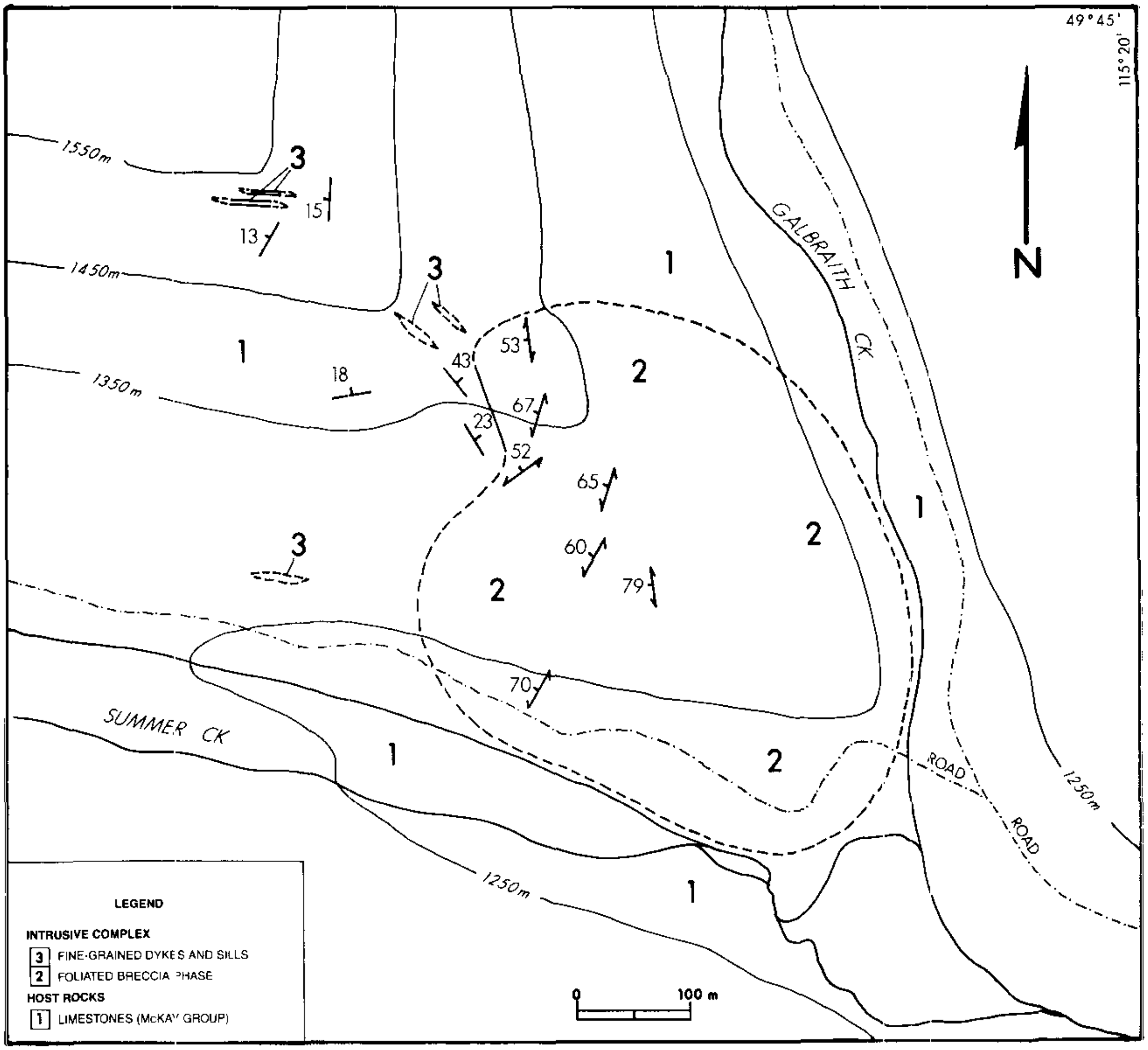


Figure 38-2. Geology of the Summer 1 pipe.

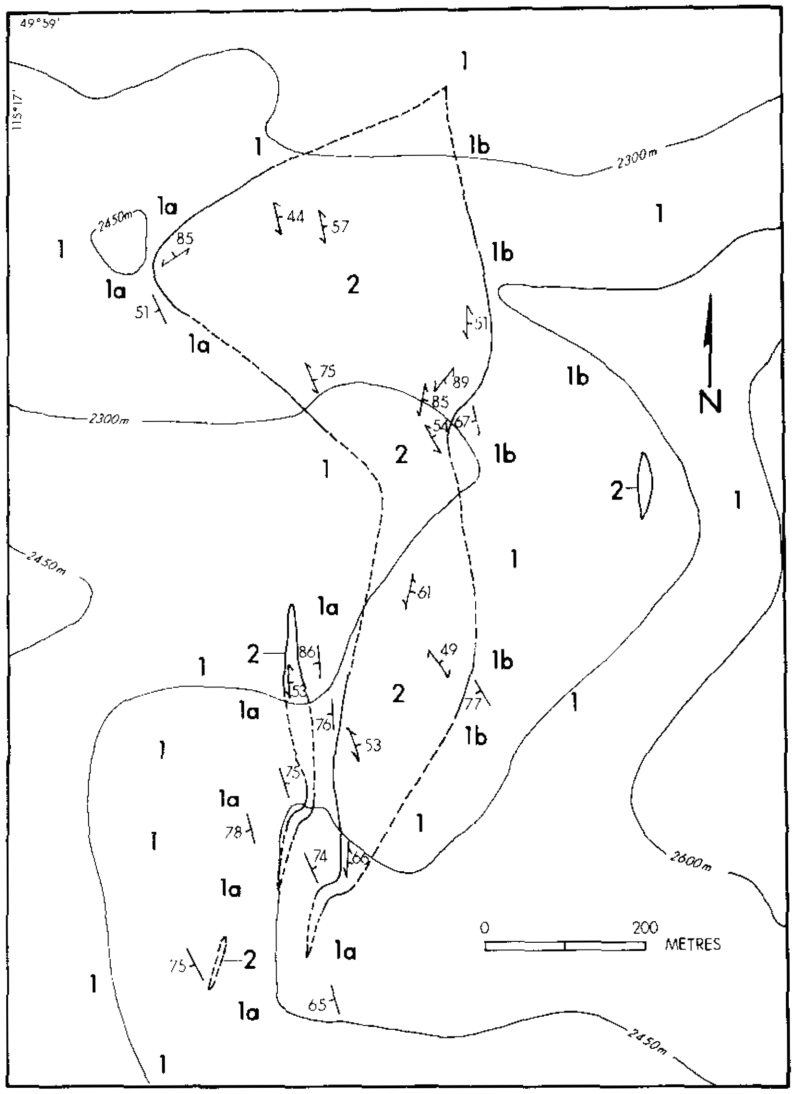
sedimentary in origin (largely limestone, some shale and dolostone fragments). Exotic material includes abundant chromite nodules, chrome diopside xenocrysts, and possible eclogite nodules. Autobreccia fragments are also common. The matrix of the diatreme is pale green consisting largely of chlorite, sericite, and carbonate. Massive, fine-grained, dark green dykes cut the main pipe.

The Blackfoot diatreme is intensely foliated near its margins and fragments have been flattened in the plane of the foliation. The centre of the diatreme is moderately to strongly foliated. Foliation is generally parallel or subparallel to the margins of the diatreme (Fig. 38-3). Locally a kinking of the dominant foliation is developed. The intense foliation suggests that the diatreme has been the site of locallized shear.

THE JOFF PIPE (82J/11)

A number of small diatremes have been reported (D. Pighin, personal communication) south of the Palliser River on ridges west of Joffrey Creek, approximately 55 kilometres east of Invermere. Two bodies, exposed at 2 750 metres in elevation, were examined. Both intrude east-dipping units (Fig. 38-4) which stratigraphically underlie Middle to Upper Devonian Formations (Leech, 1979) The immediate footwall rocks in the vicinity of the main diatreme are massive, thick bedded, medium grey limestones which contain rugosan corals. These rocks may be correlative with the Ordovician-Silurian Beaverfoot Formation. Buff dolostones, sandy cross-bedded dolostones and sandstones, well-bedded siltstones, and dolomitic siltstones comprise the hangingwall strata. These lithologies are not characteristic of the Beaverfoot Formation and may be equivalent to Middle Devonian Cedared, Burnais, and Harrogate Formation strata.

The main pipe (Fig. 38-4) is very similar to the Blackfoot diatreme, consisting of small (up to 10 centimetres) subrounded to subangular fragments in a strongly foliated green matrix. Fragments are predominantly limestone, dolostone, and shale. Exotic material, such as chromite nodules, are present, but less abundant than in the Blackfoot diatreme. Within a few metres of the eastern contact of



INTRUSIVE ROCKS

2 DIATREME BRECCIA

HOST ROCKS

1 LIMESTONES, SHALY LIMESTONES (BEAVERFOOT-BRISCO FORMATION)
(a) MASSIVE GREY FOSSILIFEROUS LIMESTONES
(b) THIN-BEDDED PURPLISH LIMESTONE AND SHALY LIMESTONE

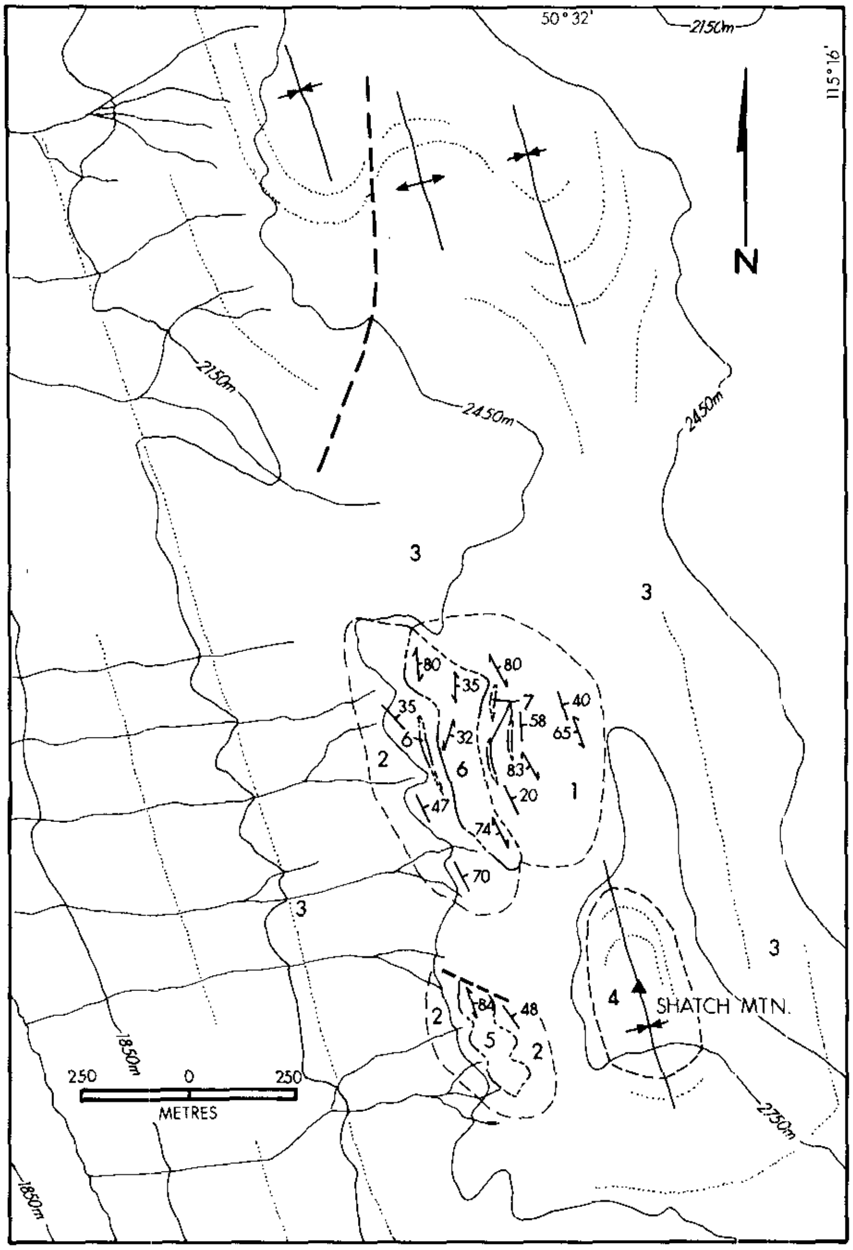
Figure 38-3. Geology of the Blackfoot diatreme.

the main diatreme the Middle Devonian (?) hangingwall sediments have been intensely hematized, appearing brick red in outcrop, in contrast to their normal buff colours. Discontinuous layers rich in subangular lithic fragments are interbedded with the altered sedimentary rocks (Plate 38-1). Moderate to well-developed graded bedding is present in the fragmental layers. The clasts in these layers are similar in composition and variety to those in the main diatreme. These graded fragmental horizons most likely represent an extrusive (tuffaceous?) phase of the main diatreme interbedded with Middle Devonian (?) sedimentary rocks.

The southern intrusive body (Fig. 38-4) is medium to dark green, fine-grained, and massive. Its margins have been highly brecciated and hematized. It contains no clasts, but small (2 to 3-millimetre) rounded serpentine nodules are locally developed. The relationship between the southern intrusive and the main diatreme is, as yet, unclear.

THE CROSS DIATREME (82J/2)

The Cross diatreme is exposed at an elevation of 2 200 metres on the north side of Crossing Creek, 8 kilometres northwest of the town of Elkford. It is 60 kilometres east of the Rocky Mountain Trench, or approximately 20 kilometres east of the centreline of the zone containing the other intrusions in the Cranbrook-Invermere area. It has previously been reported on (Grieve, 1981; 1982; and Roberts *et al.*, 1980) and therefore will only be briefly described here.



LEGEND

SEDIMENTARY SEQUENCE

MIDDLE AND/OR UPPER DEVONIAN

4 BASAL UNIT: SANDSTONE DOLOMITE, MUDSTONE, SOLUTION BRECCIA

ORDOVICIAN AND SILURIAN AND/OR MIDDLE DEVONIAN ?

3 UNDIVIDED

2 BUFF DOLOSTONE, SANDY CROSSBEDDED DOLOSTONES, SILTSTONES, SANDSTONES

1 THICK-BEDDED GREY FOSSILIFEROUS LIMESTONE

INTRUSIVE AND RELATED SEQUENCE

7 EXTRUSIVE PHASE GRADED TUFF BRECCIA LAYERS

6 FOLIATED BRECCIA PHASE

5 MASSIVE PHASE

Figure 38-4. Geology of the Joff pipe, Shatch Mountain area.

The Cross diatreme intrudes Pennsylvanian Rocky Mountain Group strata (Hovdebo, 1957). It outcrops on a steep face and an area of approximately 55 by 15 metres is exposed. Its western contact is well exposed and clearly crosscuts shallow-dipping crinoidal dolostones and dolomitic sandstones. A small shear zone forms the eastern contact. No thermal effects on the wallrocks were observed.

The diatreme has a medium grey-green to dark green groundmass composed mainly of calcite, serpentine, mica, and talc (Grieve, 1982). Clast content varies from 20 per cent to locally as much as 40 or 50 per cent. The inclusions are angular to subrounded and from granule (millimetre) to boulder (metre) size, although most of the outcrop is characterized by fragments up to 10 centimetres in size. Limestone, dolostone, and shale clasts dominate, but rounded ultramafic (peridotite ?) nodules are also common. Xenocrysts of olivine, pyroxene (some chrome diopside), and garnet have been reported (Grieve, 1982). Strongly foliated zones are developed at the western and eastern margins of the diatreme. A hematite-rich zone is developed in the more massive central portion of the outcrop. In this zone hematite fills fractures and coats and partially replaces clasts.

GOLDEN-COLUMBIA ICEFIELDS AREA (82N, 83C)

A number of diatremes have been located in an area straddling the British Columbia/Alberta border 50 to 90 kilometres north to northwest of Golden (Fipke, 1983; Northcote, 1983a, 1983b). Microdia-

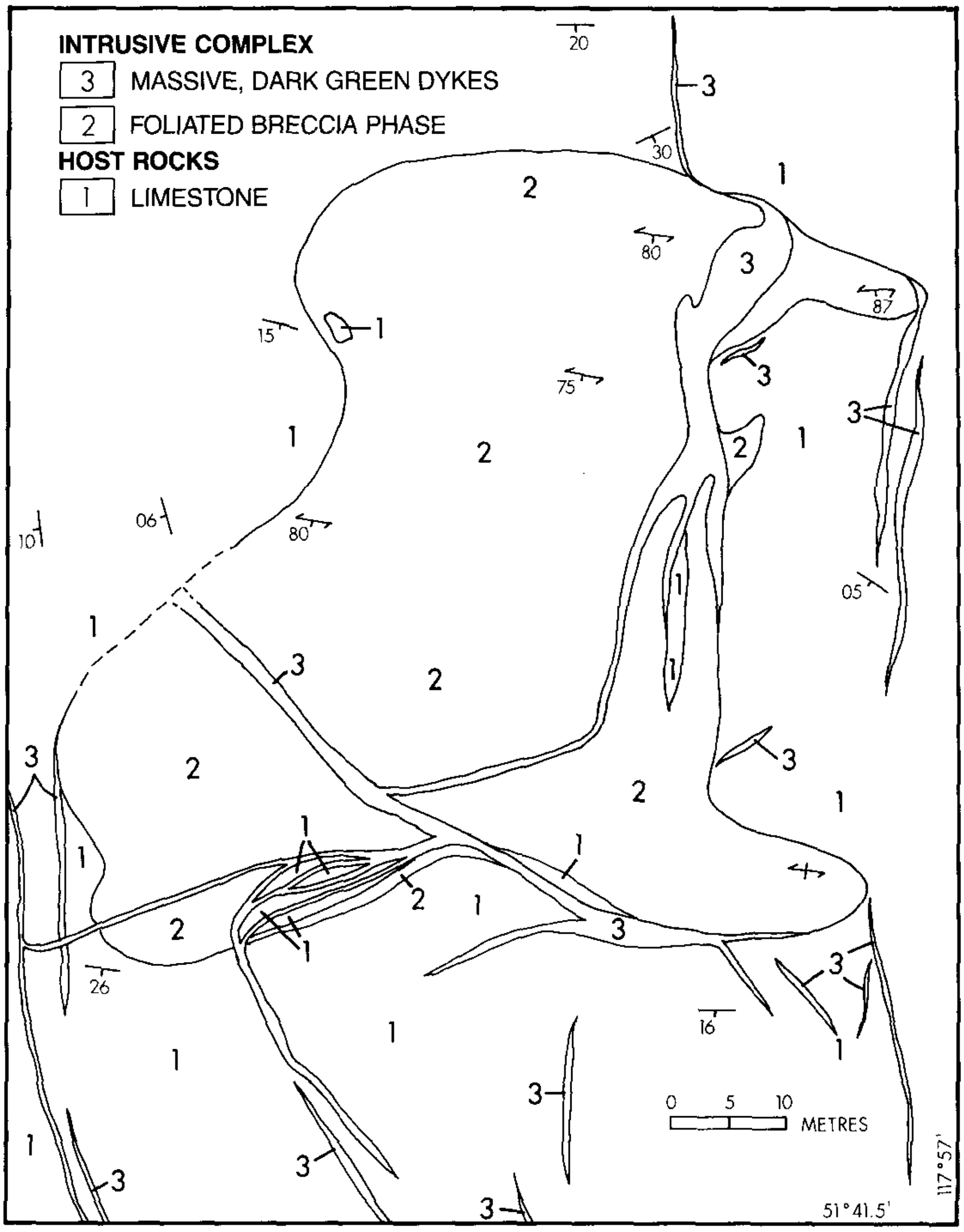


Figure 38-5. Geology of the HP pipe, south of the Campbell Icefield area.

monds have been recovered from heavy mineral separates taken from two of the pipes in this swarm (Northcote, 1983a, 1983b). The terrane north of Golden is rugged and the diatremes are exposed at elevations of 2 200 to 3 000 metres. Two of the diatremes were visited during the 1985 field season.

THE MARK DIATREME (82N/15)

The diatreme examined is the largest of seven pipes on the Mark claims (Northcote, 1983a) and one in which a microdiamond was found. It is exposed on steep cliffs between 2 700 and 3 000 metres in elevation and occupies an estimated 10-hectare area (Northcote, 1983a). The contacts are not well exposed, covered either by glaciers or talus.

The diatreme is well foliated and medium brown to rusty red weathering. It does not stand out in marked contrast with the buff-weathering fossiliferous and nodular limestones and dolostones of the Ordovician Skoki Formation (Norford, 1979) which it intrudes; therefore, it is difficult to locate from the air.

The Mark pipe is characterized by the presence of numerous (approximately 40 per cent) small subrounded clasts in a light green to grey matrix. Most of the clasts are 5 centimetres or smaller, with rare subangular xenoliths up to 15 centimetres in size. Limestones, dolostones, shales, and minor quartzites comprise the majority of the breccia fragments. Xenocrysts of augite and chrome diopside are sparsely distributed throughout. Chromite and ilmenite grains have also been identified in heavy mineral separates (Northcote, 1983a). Chrome micas (mariposite) are disseminated in the matrix of the pipe and occur as coatings on quartzite clasts. Massive, dark green, fine-grained dykes cut the diatreme and surrounding sedimentary rocks.

THE HP PIPE (82N/10)

The HP pipe is the most southerly diatreme so far recognized in the Columbia Icefield-Golden area. It is located approximately 50 kilometres due north of the town of Golden; exposed at an elevation of 2 400 metres, near the toe of the Campbell Icefield. The HP pipe is small, covering an area of only 40 by 80 metres; however, it is exposed in a flat, recently deglaciated basin which offers nearly 100 per cent exposure and is therefore ideal for study.

The HP pipe has sharp, steeply dipping contacts with the horizontal to shallow-dipping grey Cambrian limestone beds which host it (Fig. 38-5). It has a light to medium green, well-foliated carbonate-serpentine-rich matrix and contains abundant (approximately 40 per cent) breccia fragments. Angular to subrounded xenoliths of limestone and shale, 1 to 30 centimetres in size, predominate; subrounded ultramafic (pyroxenite ?) nodules (Plate 38-2) and fine-grained autobreccia fragments are also common. Xenocrysts of phlogopite, chrome diopside, and black pyroxene are abundant and can be up to 5 centimetres in size. Picroilmenite, chromite, and pyrope grains have been identified in heavy mineral separates (Fipke, personal communication).

The main breccia pipe has a well-developed foliation which is at a high angle to its eastern and western margins (Plate 38-3 and Fig. 38-5). The clast-rich, foliated phase is cut by dark green, fine-grained, massive dykes (Plate 38-4 and Fig. 38-5) which are generally free of xenoliths but may contain pyroxene and phlogopite xenocrysts. The margins to these dykes are sharp to gradational with the breccia.

WILLISTON LAKE AREA (94B)

OSPIKA PIPE (94B/5)

Only one breccia pipe has so far been recognized in British Columbia north of Prince George. It is a small diatreme (roughly 50 metres across) located on Cominco's Aley claims, approximately 140 kilometres north-northwest of Mackenzie (*see* also Pell, this volume) on the east side of Williston Lake between the Peace Reach and the Ospika River.

The pipe intrudes Ordovician carbonates of the Skoki Formation It is a massive to foliated red-brown-weathering breccia with approximately 30 per cent angular to subrounded fragments. Fragments are a few millimetres to 0 5 metre in size; the larger fragments are all dolomitic with prominent reaction rims or silicified margins The fine-grained light green to grey matrix also contains xenocrysts of phlogopite, black pyroxene, and chrome diopside. Fluorite is present near the margins of the diatreme. Clast and xenocryst-rich breccia dykes, 50 centimetres wide, crop out on ridges approximately 0.5 kilometre from the main breccia pipe. These dykes do not appear, at surface, to be continuous with the diatreme, but are very similar both in matrix and clast composition. The time relationship between the lamprophyre dykes with diatreme breccia and the carbonatite complex on the Aley claims is unclear.

CONCLUSIONS

With the exception of the Cross diatreme, all the diatreme breccia pipes in British Columbia have intruded Cambrian to Middle Devonian sedimentary rocks. These pipes are all very similar, characterized by a high percentage of xenoliths, most of which are derived from nearby sedimentary rock units. Exotic material (granite, chromite, pyroxenite, eclogite) and xenocrysts of chrome, diopside, black pyroxene, and phlogopite may be present. These diatremes can be subdivided into two classes based on weathering characteristics and the nature of the matrix: (1) green-weathering, strongly foliated diatremes with a light green calcareous matrix; and (2) rusty weathering, well-foliated bodies with a light green to greenish grey matrix that is, at least in part, non-calcareous. Summer, Mark, and Ospika Pipe fall into this latter class.

No absolute dates have been obtained on the diatremes; such work is currently in progress. Stratigraphic evidence suggests that the Joff pipe is Middle Devonian, the other pipes may be of similar age.

The Cross diatreme is unique among the breccia pipes in British Columbia. It crops out east of the main zone of diatremes and intrudes Pennsylvanian strata. A Lower Permian age (244 Ma) was obtained on the Cross diatreme, using Rb/Sr methods (Grieve, 1982). The matrix of the Cross diatreme is generally much darker in colour and it contains more numerous large ultramafic nodules than the other diatremes.

Some geologists (*see* Grieve, 1982) feel that the Cross diatreme is the only true kimberlite discovered to date in British Columbia. The presence of diamonds in some of the other pipes suggests that they, too, are of kimberlitic affinity although the definition of a "true kimberlite" may be too narrow to include them.

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Plate 38-1A. Extrusive (tuff?) facies of the Joff pipe. Layer of diatreme 'ejecta' is interbedded with laminated dolomitic siltstones. Pencil points up.

Plate 38-1B. Close-up of extrusive facies of the Joff pipe. Graded bedding is well developed in the lithic layer. Pencil points down.

Plate 38-2A. Large limestone block in HP diatreme breccia. Dark rounded ultramafic xenoliths are also present.

Plate 38-2B. Rounded ultramafic (pyroxenite) nodule amidst angular white limestone fragments and small dark pyroxene and phlogopite xenocrysts.

Plate 38-3. Foliated diatreme in contact with limestone. The foliation is at a high angle to the contact here.

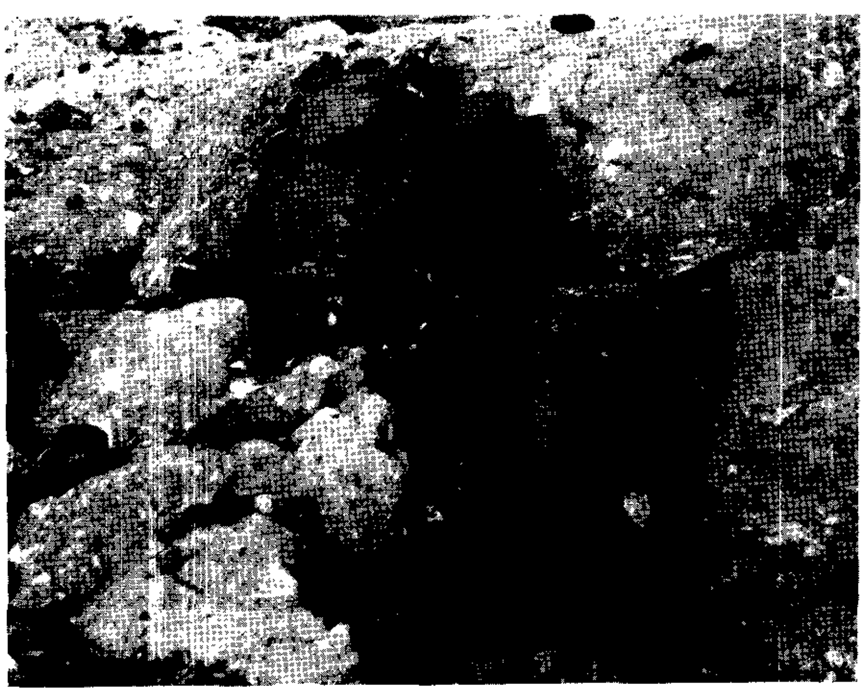

Plate 38-4. Clast-free dyke cutting main breccia pipe.