1986

Geology and Mineral Deposits of the Unuk River-Salmon River-Anyox Area

By Edward W. Grove

Bulletin 63

Province of British Columbia
Ministry of
Energy, Mines and
Petroleum Resources
Hon. Jack Davis, P.C., *Minister*

Canadian Cataloguing in Publication Data

Grove, Edward W.
Geology and mineral deposits of the Unuk River-Salmon River-Anyox area

(Bulletin, ISSN 0226-7497 ; 63)

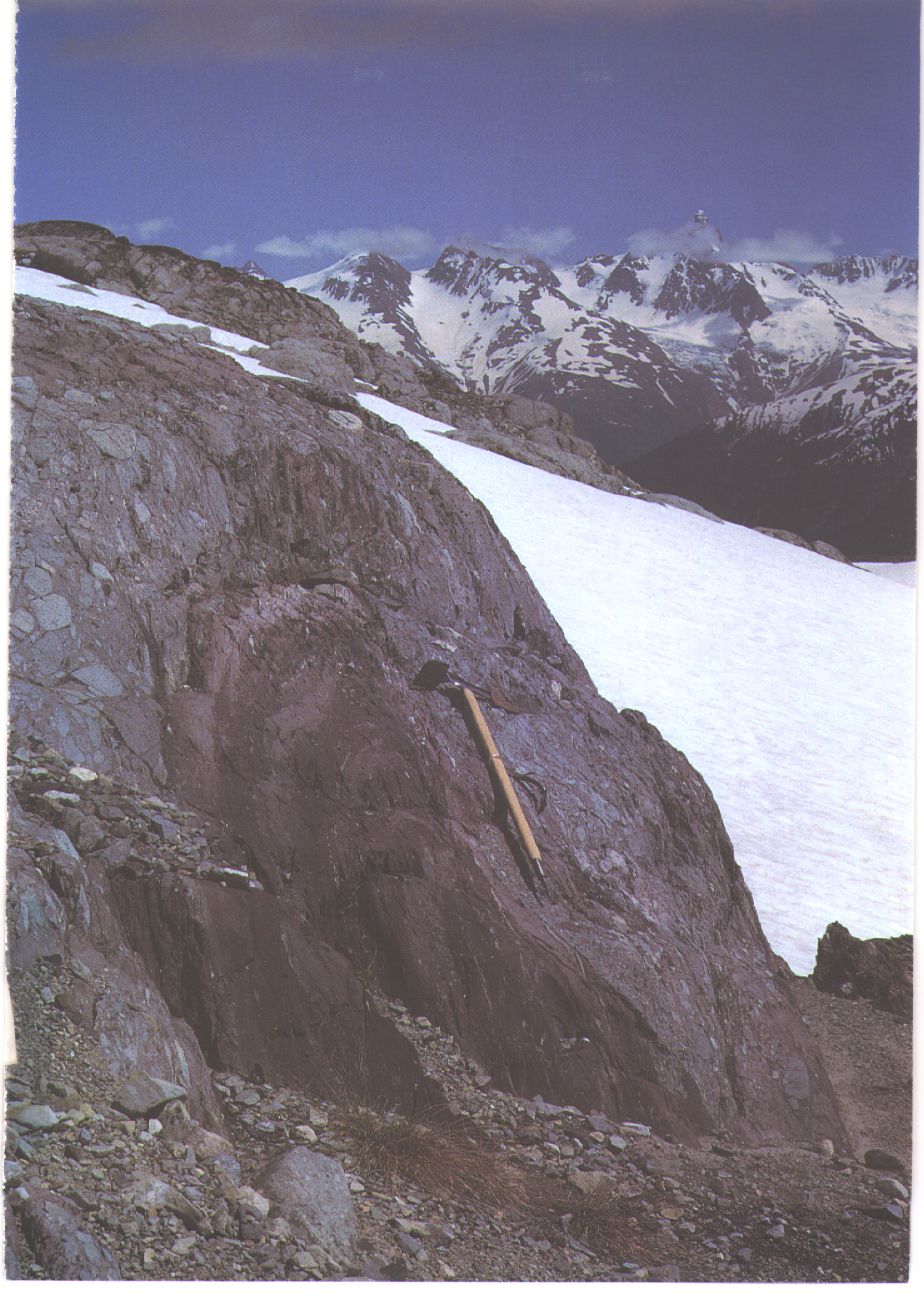
Bibliography: p.
ISBN 0-7718-8530-X

1. Geology — British Columbia — Kitimat-Stikine. 2. Geology, Economic — British Columbia — Kitimat-Stikine. 3. Mines and mineral resources — British Columbia — Kitimat-Stikine. I. British Columbia. Ministry of Energy, Mines and Petroleum Resources. II. Title. III. Series: Bulletin (British Columbia. Ministry of Energy, Mines and Petroleum Resources) ; 63.

QE187.G76 1986   557.11'1   C86-092173-5

MINISTRY OF ENERGY, MINES AND PETROLEUM RESOURCES
VICTORIA, BRITISH COLUMBIA
CANADA

DECEMBER 1986



Frontispiece
Betty Creek strata, Bear River Ridge, looking east to Mount Otter in the Cambria Range.

GEOLOGY AND MINERAL DEPOSITS OF THE UNUK RIVER-SALMON RIVER-ANYOX AREA

FOREWORD

The regional geologic study presented in this bulletin began as a mineral deposit study suggested by the Stewart Village Council in the hope of stimulating the local mineral based economy. Bulletin 58, *Geology and Mineral Deposits of the Stewart Area*, 1971, was the first of a projected series of reports on the area.

Work at the Granduc copper-silver deposit northwest of Stewart culminated in mine production in late 1970. Along with the opening of Granduc, the Stewart economy surged with the completion of the Cassiar-Stewart Highway and the road link to Terrace and outside British Columbia.

Stewart has lost the marine link to Vancouver and 'boat days' but now has a paved airport, a paved highway system to the outside, and paved roads in town. Asbestos shipments from Cassiar through Stewart and tourism have provided new work and the current gold-silver boom has revived the local mining industry.

At the end of the exploration phase at Granduc in 1965, Dr. G. W. H. Norman (Newmont) suggested to the writer that the Stewart study be extended to include the Granduc area. Newmont's field notes, maps, and samples were made available and the regional study started in 1966 in the Bowser River and South Unuk area. The obvious continuity of strata through the region from the Iskut River to Alice Arm indicated the need to include the whole area in a single comprehensive study. The fieldwork was completed in 1970 and the first draft of this report was completed in 1973.

Two other regional studies adjacent to and relevant to this study have been published prior to the release of this bulletin. These include geology of the Hyder area, along the west margin of the Portland Canal, mapped by J. G. Smith (*United States Geological Survey*, Bull. 1425, 1977); a study of porphyry deposits of west-central British Columbia by N. C. Carter (*B.C. Ministry of Energy, Mines and Petroleum Resources*, Bull. 64, 1981). A variety of reports, including several theses, concerning various mineral deposits in the general area have also been completed in recent years.

One major inconsistency in stratigraphic nomenclature has not been resolved. The terms Bowser Group and Bowser Assemblage used in older publications to designate marine sediments of various ages have not been continued in this bulletin. The term Nass Formation, introduced by R. G. McConnell (1913), has been used within the Hazelton Group to refer to Upper Jurassic units in the general report area, including Bowser Lake. Tipper and Richards (*Geological Survey of Canada*, Bull. 270, 1976) introduced the new term Bowser Lake Group to identify Late Jurassic-Early Cretaceous marine sediments in the Hazelton area without defining a type section at Bowser Lake.

The complex Silbak Premier gold-silver deposits and others of the same type are still controversial and have gone through the classification cycle from hydrothermal related to plutons, to remobilized massive sulphide deposits, to the revised plutonic-volcanic type with complex hot spring associations. Significantly, work still persists on deposits found by prospectors 50 to 80 years ago. New deposits found in the general area are the molybdenum-gold-silver types found in acidic Tertiary stocks or plugs localized along the mineral zone shown on Figure 17 in this bulletin. These were all found by prospectors checking new exposures revealed by recent glacial ablation at Bitter Creek and at the head of Surprise Creek (Falconbridge). Recent glacial ablation has also been largely responsible for the new gold-silver developments along the Iskut River within the extension of the Lower Jurassic Unuk River Formation volcanic and volcaniclastic members.

ADDITIONAL SELECTED REFERENCES

Alldrick, D. J. (1985): Stratigraphy and Petrology of the Stewart Mining Camp (104B/1), *B.C. Ministry of Energy, Mines & Pet. Res.*, Geological Fieldwork, 1984, Paper 1985-1, pp. 316-342.

Carter, N. C. (1981): Porphyry Copper and Molybdenum Deposits, West-Central British Columbia, *B.C. Ministry of Energy, Mines & Pet. Res.*, Bull. 64, 150 pp.

Danner, W. R. (1960): Paleozoic Eugeosynclinal Sequences of Southwestern British Columbia and Northwestern Washington, *Geol. Soc. Am.*, Bull., Vol. 71, No. 12, Pt. 2.

———. (1960): Revision of the Geology of the San Juan Islands, Washington, *Geol. Soc. Am.*, Bull., Vol. 71, No. 12, Pt. 2.

Galley, A. (1981): Volcanic Stratigraphy and Gold-Silver Occurrences on the Big Missouri Claim Group, Stewart, British Columbia, *University of Western Ontario*, M.Sc. Thesis.

Gilbert, Robert (1969): Some Aspects of the Hydrology of Ice Dammed Lakes: Observations on Summit Lake, British Columbia, *University of British Columbia*, M.A. Thesis.

Smith, J. G. (1977): Geology of the Ketchikan D-1 and Bradfield Canal A-1 Quadrangle, Southeastern Alaska; *U.S. Geol. Surv.*, Bull. 1425.

Sharp, R. J. (1980): The Geology, Geochemistry and Sulphur Isotopes of the Anyox Massive Sulphide Deposits, *University of Alberta*, M.Sc. Thesis.

Tipper, H. W. and Richards, T. A. (1976): Jurassic Stratigraphy and History of North-Central British Columbia, *Geol. Surv., Canada*, Bull. 270.

GEOLOGY AND MINERAL DEPOSITS OF THE UNUK RIVER-SALMON RIVER-ANYOX AREA

SUMMARY

This report represents new data on the geology of this region, much of which is relevant to the tectonic evolution of the Western Cordillera and to the concepts of metallogenesis in northwestern British Columbia. The study area includes part of the contact of the eastern Coast Plutonic Complex with the west-central margin of the successor Bowser Basin. Sedimentary, volcanic, and metamorphic rocks bordering the Coast Plutonic Complex range in age from Paleozoic to Quaternary. Geologically, geographically, and economically the country rocks of the area form a well-defined entity that the writer has called the Stewart Complex.

Several distinct periods of metamorphism, plutonism, volcanism, and sedimentation marked by deformation and erosion have been identified. The intensity of deformation has apparently decreased since the mid-Triassic Tahltanian orogeny, although plutonism has increased in activity since the Triassic and reached a climax in the Tertiary along the eastern margin of the Coast Plutonic Complex. Neogene volcanic activity marked by alkali olivine basalt flows has occurred periodically along major north-south, northeasterly, and east-west fractures.

Within this orogenic cycle metallogenesis is related to volcanic, sedimentary, and plutonic processes during each major tectonic phase, and these processes have combined to produce broad mineral zoning and a large array of mineral deposits which characterize this portion of the Western Cordillera. The numerous fissure vein and replacement vein deposits in the Stewart Complex, including the Silbak Premier mine, comprise a common group of simple ore and gangue minerals. The major massive sulphide deposits include the Granduc property at Granduc Mountain, and the Hidden Creek, Double Ed, Redwing, and Bonanza properties at Anyox. Porphyry deposits include the molybdenum deposit at Kitsault and the copper-molybdenum property at the Mitchell-Sulphurets Creeks.

TABLE OF CONTENTS

CHAPTER 5—ECONOMIC GEOLOGY STUDIES IN THE STEWART COMPLEX —Continued

APPENDICES

TABLES

FIGURES

FIGURES—Continued

PHOTOGRAPHS

Plates

1

INTRODUCTION

The Stewart Complex is in northwestern British Columbia between latitudes 55 degrees 15 minutes and 56 degrees 45 minutes north, and longitudes 129 degrees 15 minutes and 130 degrees 45 minutes west. This study presents and discusses data on the geology of this region which is relevant to the tectonic evolution of the Western Cordillera and to the concepts of metallogenesis in northwestern British Columbia (Fig. 1).

The geological maps complementing this study include the 1:100 000-scale map of the Stewart Complex (Fig. 2), which is in three sheets (North sheet, Unuk River; Central sheet, Salmon River; and South sheet, Anyox). The geological maps are indexed on Figures 1 and 13, to show their order and relationships. The maps are accompanied by geological cross-sections (Fig. 3).

This geological study commenced in 1964 and continued until 1970. Initial work in the Stewart area was completed utilizing the few available roads. In 1966 work continued north of Stewart into the Bowser Basin aided by part-time helicopter transport to move camps and to make a few traverses. In 1967 a month was spent in the Anyox area until a short-term helicopter contract was negotiated for the Unuk River section. The last reconnaissance work was completed during 1968 using a small boat on Portland Canal and Observatory Inlet.

Most of the area north of Stewart and between Alice Arm and Bear Pass was mapped using British Columbia Government air photographs. Base maps on a scale of 1 inch to one-half mile were compiled for the Unuk River section and maps at a scale of 1 inch to one-half mile published by the British Columbia Department of Lands and Forests were used in the rest of the area. Detailed topographic maps were not available for much of the region and the Federal Government 1 inch to 4 mile maps provided the only available contour information.

Location and Accessibility: The town of Stewart at the head of Portland Canal, which is near the centre of the map-area, has been the main locus of activity since 1900. The means of transportation to outlying points in the area are now by barge and by aircraft. The Cassiar-Stewart Highway, proposed to link the north coast with the British Columbia interior, has been completed for quite some time and a forestry road from Terrace, which penetrates as far as the Nass River at Meziadin Lake, has been joined to the Stewart road by a small bridge across the river near the lake. The Granduc mine, near the junction of the North and South Leduc Glaciers, has been connected to the concentrator site at Summit Lake by a 19-kilometre tunnel, which in turn connects to Stewart by way of a 50-kilometre, all-weather road. Other mine access roads in the area include the Kitsault River road which joins the old Torbrit and Dolly Varden mines to Alice Arm.

Previous Work: Mineral exploration was started in the general area about 1885 when placer miners on their way out of the Cariboo prospected Observatory Inlet and its arms north of the Nass River. Subsequently the Unuk River, Stewart, Portland Canal, Anyox, and Alice Arm districts became the focus of extensive prospecting, and in 1905 Fred

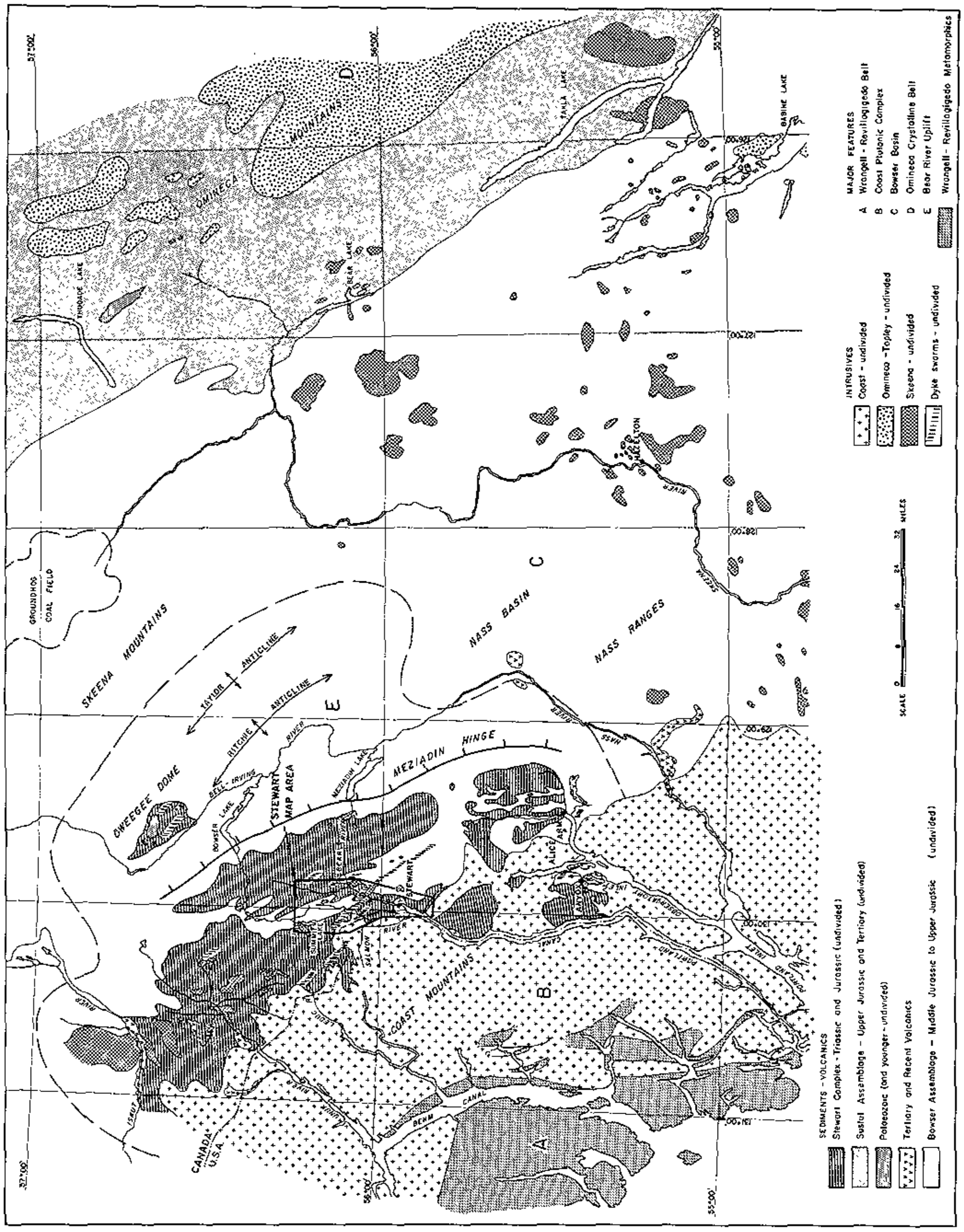


Figure 1. Geological features in a portion of northwestern British Columbia and southeastern Alaska.

Eugene Wright, while investigating the geology of southern Alaska, was directed to explore the Unuk River which flows into Behm Canal. His results were put at the disposal of the British Columbia Department of Mines and published in the 1906 Annual Report (*Minister of Mines, B.C.*, Ann. Rept., 1906, pp. H68-H74). It was not until 1924 that this area was reported on directly by George Clothier, resident engineer, and in 1932, J. T. Mandy produced a report and geologic map for the Unuk River area. At Stewart geological investigations commenced in 1906 with a report by H. Carmichael, Provincial Assayer. The first comprehensive geological study in the Portland Canal area was produced by

R. G. McConnell (1913) of the Geological Survey of Canada. This was followed in 1919 by J. J. O'Neill's work which was incorporated into a study of the Salmon River district by S. J. Schofield and G. Hanson (1922). Later Hanson studied the Bear River and Stewart map-area (1929) and incorporated these projects into a regional study of the Portland Canal area which included the then active Stewart, Alice Arm, Anyox, and Maple Bay mining camps. This report has served the industry as the major reference to the geology and mineral deposits of the Portland Canal area. At Hyder, Alaska, Westgate (1922) and Buddington (1929) of the United States Geological Survey made geological studies of the Alaskan portion of the Portland Canal. Buddington and Chapin (1929) also produced the first comprehensive study of the geology and mineral deposits of southeastern Alaska including small parts of adjacent British Columbia.

All of the above works, plus many descriptions in subsequent Annual Reports of the British Columbia Minister of Mines, have helped lay the foundation for the geological studies that have followed in recent years. The Geological Survey of Canada Map 9-1957, Operation Stikine, is the most recent attempt to compile the geology of the area north of Portland Canal between latitudes 56 degrees and 59 degrees along the east margin of the Coast Plutonic Complex. In 1959 Pan American Petroleum Corporation examined and compiled the geology of a large block of ground in the Bowser Basin from latitudes 54 degrees 45 minutes to 58 degrees between longitudes 126 degrees 20 minutes and 130 degrees 20 minutes providing useful regional concepts.

W. R. Bacon (1956) of British Columbia Department of Mines mapped the international boundary section between Salmon Glacier-Summit Lake and Mount Willibert including the Granduc mine area tying together for the first time the Leduc River and Portland Canal geology. In 1959 and 1960 geologists, directed by G. W. H. Norman of Granduc Mines, Limited, mapped the Unuk River area from Granduc north to Tom Mackay Lake in detail with special reference to the mineral deposits. These maps, on a scale of 1 inch equals one-half mile, were used in compilations of the western half of the Unuk River sheet for this study.

These major projects combined with special property reports by members of the British Columbia Department of Mines during the 1940's and 1950's, constituted the available information on the geology of parts of the map-area.

Since 1960 the Bowser Basin and the adjoining Coast Mountains area has undergone almost continuous exploration for metals and hydrocarbons. Properties such as the Granduc and B.C. Molybdenum mines have become economic and new mineral deposits have been located in previously inaccessible locations and also where recent glacial retreat has exposed new ground for prospecting. The geology and mineral deposits of the Alice Arm section have been studied by N. C. Carter, formerly of the British Columbia Department of Mines and Petroleum Resources. This material has been published since 1964 in the Annual Reports of the British Columbia Minister of Mines and Petroleum Resources.

The Hyder, Alaska, quadrangle, first compiled by Buddington (1929), was restudied by members of the United States Geological Survey, Alaskan Mineral Resources Branch in 1967-1968 under the direction of J. G. Smith.

Scope of the Study: The main purpose of this study was to determine the general geological setting of the mineral deposits and mineralized areas and to relate both to the broader regional framework. Areas with important mineral deposits or significant mineralization have received considerably more attention than the apparently unmineralized sections. The geology of most of the area was mapped at 4 inches to 1 mile and 2 inches to 1 mile and compiled at a scale of 1 to 100 000.

The regional setting has been determined from study of published and unpublished reports and discussions with other workers in the area. Subdivision of the stratigraphic succession and correlation between the various areas have been difficult because of rapid facies changes, many local disconformities, lack of fossils in critical areas, and the extensive snow and ice cover. Recent work has shown the essential tectonic unity of the whole Jurassic sequence which includes all of the rocks currently known as the Bowser and Hazelton Groups. The term Bowser Group has been rejected because it has been used previously in Alaska for other rocks. It is expected that the new terminology presented in this report will establish a stratigraphic basis for other studies in this region.

The writer has traversed most of the Stewart Complex and examined the major mineral deposits and mineralized areas. The various rock units have been examined by both macroscopic and microscopic methods. The texture and mineralogy of the various ore minerals have been examined in polished sections and also by X-ray diffraction methods. Fossil assemblages have been examined and identified by W. R. Danner at The University of British Columbia and by paleontologists of the Geological Survey of Canada in Ottawa.

Terminology: The report generally presents accepted rock classifications such as found in Williams, *et al.*, (1954). For the epiclastic volcanic rocks, terminology follows the classification of Fisher (1961, 1966). Metamorphic rocks are classified according to the facies concept outlined by workers such as Barth (1962), Mehnert (1968), and Miyashiro (1967); certain locally important units, the cataclasites, are described utilizing the definitions of Knopf (1931) and Spry (1969).

The nomenclature of the stratigraphic units has been presented within the terms outlined in the code of the *American Commission on Stratigraphic Nomenclature* (1961, 1970).

ACKNOWLEDGMENTS

The fieldwork and research were sponsored by the British Columbia Department of Mines and Petroleum Resources. The study formed the basis of the writer's Ph.D. thesis at McGill University, Montreal, Quebec.

I wish to express my gratitude to Dr. J. S. Stevenson who guided and critically reviewed the thesis, and to supervisors Drs. E. W. Mountjoy and W. H. McClean. Drs. J. A. Elson, V. A. Saull, R. G. Webber, R. F. Martin, and H. Helmstaedt provided valuable critical comment and helpful suggestions.

This report has been condensed by various members of the Geological Survey Branch but primarily by D. J. Alldrick and W. J. McMillan. Maps and figures were the responsibility of J. Armitage.

Thin sections and polished sections were prepared by R. Player, Lapidary, Mineralogical Branch, and chemical analyses were made by analysts of the British Columbia Ministry of Energy, Mines and Petroleum Resources.

Geologists J. T. Fyles, N. Haimila, and R. V. Kirkham assisted the writer during parts of the 1966 and 1967 field seasons. Capable assistance was also provided by field assistants Brian Moore, Wolfgang Schamberger, Robert Thorburn, Allan Mann, Kenneth Bradley, Robert Lamb, Bruce Palmiere, Barry Richards, Keith Hooey, and Geoffrey Field during the field seasons from 1964 to 1968.

REFERENCES

Aiken, J. D. (1959): Atlin Map-area, British Columbia, *Geol. Surv., Canada*, Mem. 307.

American Commission on Stratigraphic Nomenclature (1961): Code of Stratigraphic Nomenclature, *Amer. Assoc. Pet. Geol.*, Bull., Vol. 45, No. 5, May 1961, pp. 645-665.

Armstrong, J. E. (1944a): Smithers, British Columbia, *Geol. Surv., Canada*, Preliminary Map, Paper 44-23.

——— (1944b): Hazelton, British Columbia, *Geol. Surv., Canada*, Preliminary Map, Paper 44-24.

Bacon, W. R. (1956): Preliminary Map, Granduc Area, *B.C. Ministry of Energy, Mines & Pet. Res.*

Badgley, P. C. (1965): Structural and Tectonic Principles, *Harper and Row*, New York.

Baer, A. J. (1969): Model of Evolution of the Bella Coola-Ocean Falls Region, Coast Mountains, British Columbia, *Cdn. Jour. Earth Sci.*, Vol. 5, No. 6, Dec. 1968, pp. 1429-1441.

Barth, T. F. W. (1962): Theoretical Petrology, *John Wiley and Sons*, New York, p. 416.

Bartholomew, P. (1971): Criteria of Metasomatism in Skarn Bodies, *Soc. Mining Geol. Japan*, IAGOD Vol., Spec. Issue 3, pp. 373, 374.

Bell, H. S. (1940): Armoured Mud Balls — Their Origin, Properties and Role in Sedimentation, *Jour. Geol.*, Vol. 48, pp. 1-31.

Belloussov, V. V. (1960): The Conditions of Fold Formation, *Internat. Geol. Cong.*, Rept. 21st Sess., pp. 326-334.

Bonatti, E. (1967): Mechanisms of Deep-Sea Volcanism in the South Pacific, *in* Researches in Geochemistry, Vol. 2, P. H. Abelson, Ed., *John Wiley and Sons*, New York.

Borchert, H. (1951): Die Zonengliederung der Mineraloparagenesen in der Erdkruste, Geol. Rundshau, 39, 81-94, *in* Geochemistry of Hydrothermal Ore Deposits, H. L. Barnes, Ed., *Holt, Rinehart and Winston, Inc.*, New York, Toronto, London.

Brew, D. A. (1968): The Role of Volcanism in Post-Carboniferous Tectonics of Southeastern Alaska and Nearby Regions, North America, *23rd Internat. Geol. Cong.*, Vol. 2, pp. 107-121.

Brew, D. A., Loney, R. A., and Muffler, J. L. P. (1966): Tectonic History of Southeastern Alaska, in Tectonic History and Mineral Deposits of the Western Cordillera, *C.I.M.*, Spec. Vol. 8, pp. 149-170.

Bubela, B. and McDonald, J. A. (1969): Formation of Banded Sulphides, *Nature*, Vol. 221, pp. 465, 466.

Buddington, A. F. (1929): Geology of Hyder and Vicinity, Southeastern Alaska, *U.S. Geol. Surv.*, Bull. 807.

——— (1959): Granite Emplacement with Special Reference to North America, *Geol. Soc. Amer.*, Bull., Vol. 70, pp. 671-747.

Buddington, A. F. and Chapin, T. (1929): Geology and Mineral Deposits of Southeastern Alaska, *U.S. Geol. Surv.*, Bull. 800.

Burton, W. D. (1926): Ore Deposition at Premier, B.C., *Econ. Geol.*, Vol. 21, No. 6, Sept., 1926, pp. 586-604.

Campbell, R. B. (1966): Tectonics of the South Central Cordillera of British Columbia, *in* Tectonic History and Mineral Deposits of the Western Cordillera, *C.I.M.*, Spec. Vol. No. 8, pp. 61-71.

Carlisle, D. (1963): Pillow Breccias and Their Aquagene Tuffs, Quadra Island, British Columbia, *Jour. Geol.*, Vol. 71, pp. 48-71.

Carter, N. C. (1964): Geology of the Lime Creek Area, *Minister of Mines, B.C.*, Ann. Rept., 1964, pp. 24-44.

——— (1968): Ace, Galena (Alice Arm), *Minister of Mines, B.C.*, Ann. Rept., 1968, pp. 56-68.

Carter, N. C. and Grove, E. W. (1972): Geological Compilation of the Stewart, Anyox, Alice Arm, and Terrace Areas, *B.C. Ministry of Energy, Mines & Pet. Res.*, Prelim. Map No. 8.

Clark, L. A. (1971): Volcanogenic Ores: Comparison of Cupriferous Pyrite Deposits of Cyprus and Japanese Kuroko Deposits, *Soc. Mining Geol. Japan*, IAGOD Vol., Spec. Issue 3, pp. 206-215.

Cooke, H. C. and Johnston, W. A. (1932): Gold Occurrences of Canada, Summary Account, *Geol. Surv., Canada*, Ec. Geol. Series No. 10.

Dawson, G. M. (1877): Report on Explorations in British Columbia, *Geol. Surv., Canada*, Rept. Prog., 1875-1876.

Dickinson, W. R. (1968): Circum-Pacific Andesite Types, *Jour. Geolphys. Res.*, Vol. 73, pp. 2261-2269.

——— (1970): Relations of Andesites, Granites, and Derivative Sandstones to Arc-Trench Tectonics, *Rev. Geophys. and Space Physics*, Vol. 8, No. 4, pp. 813-860.

Dolmage, V. (1920): The High-Grade Silver Ores of the Stewart District, British Columbia, *Cdn. Min. Jour.*, Vol. XLI, No. 22, June 4, 1920, pp. 454-458.

Douglas, R.J.W. (Ed.) (1970): Geology and Economic Mineral Deposits of Canada, *Geol. Surv., Canada*, Ec. Geol. Rept. No. 1.

Duffell, S. and Souther, J. G. (1964): Geology of Terrace Map-Area, British Columbia, *Geol. Surv., Canada*, Mem. 329.

Dunham, K. (1971): Introductory Talk: Rock Association and Genesis, *Soc. Mining Geol. Japan*, IAGOD Vol., Spec. Issue 3, pp. 167-171.

Fisher, R. V. (1961): Proposed Classification of Volcaniclastic Sediments and Rocks, *Geol. Soc. Amer.*, Bull., Vol. 72, No. 9, pp. 1409-1414.

——— (1966): Rocks Composed of Volcanic Fragments and Their Classification, *Earth Sci. Rev.*, I, pp. 287-298.

Fitzgerald, E. L. (1960): Geological Evaluation of the Stikine River Area, British Columbia, *Pan Amer. Pet. Corp.*, private report.

Frebold, H. and Tipper, H. W. (1970): Status of the Jurassic in the Canadian Cordillera of British Columbia, Alberta, and Southern Yukon, *Cdn. Jour. Earth Sci.*, Vol. 7, No. 1, pp. 1-21.

Gabrielse, H. (1962): Cry Lake, British Columbia, *Geol. Surv., Canada*, Map 29-1962.

Gabrielse, H. and Souther, J. J. (1962): Dease Lake, British Columbia, *Geol. Surv., Canada*, Map 21, 1962.

Gilluly, J. (1972): Radiometric Age Dates in the North American Cordillera, Seminar, *University of British Columbia*, Jan. 1972.

Grobler, N. J. and Whitfield, G. G. (1970): The Olivine-Apatite-Magnetite and Related Rocks in the Villa Nora Occurrence of the Buchveld Igeneous Complex, *in* Symposium on the Bushveld Igneous Complex and other Layered Intrusions, *Geol. Soc. S. Africa*, Spec. Publ. 1.

Grove, E. W. (1965a): Summit Lake, *Minister of Mines, B.C.*, Ann. Rept., 1965, pp. 48, 49.

——— (1965b): Bromley Glacier, *Minister of Mines, B.C.*, Ann. Rept., 1965, pp. 52-55.

——— (1968a): Unuk River, *Minister of Mines, B.C.*, Ann. Rept., 1968, pp. 44-46.

——— (1968b): Mess Creek, *Minister of Mines, B.C.*, Ann. Rept., 1968, pp. 39-41.

——— (1971): Geology and Mineral Deposits of the Stewart Area, Northwestern British Columbia, *B.C. Ministry of Energy, Mines & Pet. Res.*, Bull. 58, 219 pp.

——— (1973): Geology and Mineral Deposits of the Stewart Complex, British Columbia, *McGill University*, Ph.D. Thesis, 434 pp.

Gunning, H. C. (1959): Origin of Massive Sulphide Deposits, *C.I.M.*, Bull., Vol. 52, No. 570, pp. 610-613.

Hamilton, W. (1969): The Volcanic Central Andes, A Modern Model for the Cretaceous Batholiths and Tectonics of Western North America, A. R. McBirney, Ed., *State of Oregon, Dept. of Geol. and Min.*, Ind. Proc. Andesite Conf., Int. Upper Mantle Project, Scientific Rept. 16, pp. 175-184.

Hamilton, W. and Myers, W. B. (1967): The Nature of Batholiths, *U.S. Geol. Surv.*, Prof. Paper 554-C, 30 pp.

Hanson, G. (1921): Upper Kitsault Valley, British Columbia, *Geol. Surv., Canada*, Sum. Rept., 1921, Pt. A.

——— (1922): Reconnaissance Between Skeena River and Stewart, British Columbia, *Geol. Surv., Canada*, Sum. Rept., 1922, Pt. A, pp. 29-45.

——— (1929): Bear River and Stewart Map-areas, Cassiar District, British Columbia, *Geol. Surv., Canada*, Mem. 159.

——— (1931): Bowser River Area and North Part of Portland Canal Area, British Columbia, *Geol. Surv., Canada*, Sum. Rept., Pt. A, pp. 14-21.

——— (1932): Varved Clays of Tide Lake, British Columbia, Trans., *Royal Soc. Can.*, Sec. IV, pp. 335-343.

——— (1935): Portland Canal Area, British Columbia, *Geol, Surv., Canada*, Mem. 175.

Haughton, S. H. (1969): Geological History of Southern Africa, *Geol. Soc. S. Africa.*

Hawkes, D. D. (1962): Erosion of Tidal Flats near Georgetown, British Guiana, *Nature*, Vol. 196, No. 4519, pp. 128-130.

Hietanen, A. (1967): On the Facies Series in Various Types of Metamorphism, *Jour. Geol.*, Vol. 75, pp. 187-214.

Holland, Stuart S. (1964): Landforms of British Columbia, A Physiographic Outline, *B.C. Ministry of Energy, Mines & Pet. Res.*, Bull. 48.

Horikoshi, E. (1965): Kuroko-Type Exhalative-Sedimentary Mineral Deposits, *Jour. Mining Inst.*, Kyushu, 33, pp. 332-340 (in Japanese).

Hutchinson, C. E. and Searle, D. L. (1971): Stratabound Pyrite Deposits in Cyprus and Relations to Other Sulphide Ores, *Soc. Mining Geol. Japan*, IAGOD Vol, Spec. Issue 3, pp. 198-205.

Hutchison, W. W. (1970): Metamorphic Framework and Plutonic Styles in the Prince Rupert Region of the Central Coast Mountains, British Columbia, *Cdn. Jour. Earth Sci.*, Vol. 7, No. 2, pp. 376-405.

James, D. E. (1971): Plate Tectonic Model for the Evolution of the Central Andes, *Geol. Soc. Amer.*, Bull., Vol. 82, pp. 3325-3346.

Jeffrey, W. G. (1966): E and L, *Minister of Mines, B.C.*, Ann. Rept., pp. 31-34.

Jeletsky, J. A. (1970): Some Salient Features of Early Mesozoic History of Insular Tectonic Belt, Western British Columbia, *Geol. Surv., Canada*, Paper 69-14.

Jones, J. G. (1969): Pillow Lavas as Depth Indicators, *Amer. Jour. Sci.*, Vol. 267, No. 2, pp. 181-195.

Kajiwari, Yoshimichi (1970): Some Limitations on the Physico-Chemical Environment of Deposition of the Kuroko Ore, *in* Volcanism and Ore Genesis, Tatsuo Tatsumi, Ed., *University of Tokyo Press.*

Kerr, F. A. (1948): Lower Stikine and Western Iskut River Areas, British Columbia, *Geol. Surv., Canada*, Mem. 246.

Kirkham, R. V. (1968): Mineralogical and Geochemical Study of the Zonal Distribution of Ores in the Hudson Bay Range, British Columbia, Ph.D. Thesis, *University of Wisconsin*, 153 pp.

Kistler, R. W., Evernden, J. F., and Shaw, H. R. (1971): Sierra Nevada Plutonic Cycle: Pt. I, Origin of Composite Granitic Batholiths, *Geol. Soc. Amer.*, Bull., Vol. 82, pp. 853-868.

Klotz, O. J. (1907): Recession of Alaska Glaciers, *Geol. Jour.*, Vol. 30, pp. 419-421.

Knopf, E. B. (1931): Retrogressive Metamorphism and Phyllonitization, *Amer. Jour. Sci.*, Ser. 5, Vol. 21, pp. 1-27.

Krauskopf, K. B. (1971): The Source of Ore Metals, *Geochim. et Cosmochim. Acta*, Vol. 35, pp. 643-659.

Krumbein, W. C. and Garrels, R. M. (1952): Origin and Classification of Chemical Sediments in Terms of pH and Oxidation-Reduction Potentials, *Jour. Geol.*, Vol. 60, No. 1, pp. 1-30.

Kuno, H. (1959): Origin of Cenzoic Petrographic Provinces of Japan and Surrounding Areas, *Volcanol.*, Bull., Vol. 20, pp. 37-76.

——— (1966): Lateral Variation of Basalt Magma Types Across Continental Margins and Island Arcs, *Volcanol.*, Bull., Vol. 29, pp. 195-222.

Lambert, I. B. and Bubela, B. (1970): Banded Sulphide Ores: The Experimental Production of Monomineralllic Sulphide Bands in Sediments, *Min. Dep.*, Vol. 5, pp. 97-102.

Lamphere, M. A., Loney, R. A., and Brew, D. A. (1965): Potassium-argon Ages of Some Plutonic Rocks, Tenakee Area, Chichagof Island, Southeastern Alaska: *U.S. Geol. Surv.*, Prof. Paper 525-B, pp. B108-B111.

McConnell, R. G. (1913): Portions of Portland Canal and Skeena Mining Division, Skeena District, B.C., *Geol. Surv., Canada*, Mem. 32.

——— (1914): Geological Section Along the Grand Trunk Pacific Railway from Prince Rupert to Aldermere, British Columbia, *Geol. Surv., Canada*, Sum. Rept., 1912.

McDonald, J. A. (1967): Metamorphism and its Effects on Sulphide Assemblages, *Min. Dep.*, Vol. 2, pp. 200-220.

McKee, E. D., Crosby, E. J., and Berryhill, H. L. (1967): Flood Deposits, Bijou Creek, Colorado, *Jour. Sediment. Petrol.*, Vol. 37, pp. 829-851.

Marcus, M. G. (1960): Periodic Drainage of Glacier-dammed Tulsequah Lake, British Columbia, *Geograph. Rev.*, Vol. 50, No. 1, Jan. 1960, pp. 89-106.

Mathews, W. H. (1959): Vertical Distribution of Velocity in Salmon Glacier, British Columbia, *Jour. Glaciology*, Vol. 3, No. 26, pp. 448-454.

Matsukuma, Toshinori and Horikoshi, Ei (1970): Kuroko Deposits in Japan, a Review *in* Volcanism and Ore Genesis, Tatsuo Tatsumi, Ed., *University of Tokyo Press*, pp. 153-180.

Mehnert, K. R. (1968): Migmatites and the Origin of Granites, *Elsevier*, Amsterdam, p. 393.

Misch, P. (1966): Evolution of the Northern Cascades of Washington State, *in* Tectonic History and Mineral Deposits of the Western Cordillera, *C.I.M.*, Spec. Vol. 8, pp. 101-148.

Miyashiro, A. (1961): Evolution of Metamorphic Belts, *Jour. Petrology*, Vol. 2, Pt. 3, pp. 277-311.

——— (1967): Orogeny, Regional Metamorphism, and Magmatism in the Japanese Islands, *Geol. Soc. Denmark*, Bull., Vol. 17, Pt. 4, pp. 390-446.

Monger, T. W. H. and Hutchinson, W. W. (1971): Metamorphic Map of the Canadian Cordillera, *Geol. Surv., Canada*, Paper 70-33.

Mookherjee, A. (1970): 'Metamorphic' and 'Metamorphosed' Sulfide Deposits, *Econ. Geol.*, Vol. 65, pp. 886-893.

Moore, J. G. (1959): The Quartz Diorite Boundary Line in the Western United States, *Jour. Geol.*, Vol. 67, No. 2, pp. 198-210.

——— (1962): The Quartz Diorite Line in Northwestern North America, *U.S. Geol. Surv.*, Prof. Paper 450-B, pp. E89-E93.

——— (1965): Petrology of Deep-sea Basalt near Hawaii, *Amer. Jour. Sci.*, Vol. 263, pp. 40-52.

Naldrett, A. J. (1970): Phase Layering and Cryptic Variation in the Sudbury Nickel Irruptive, *in* Symposium on the Buchveld Igneous Complex and other Layered Intrusions, *Geol. Soc. S. Africa*, Spec. Publ. 1, pp. 532-546.

Nelson, N. E. (1948): Hidden Creek Mine, *in* Structural Geology of Canadian Ore Deposits, *C.I.M.*, Jubilee Vol., pp. 125-128.

Ney, C. S. (1966): Distribution and Genesis of Copper Deposits in British Columbia, *in* Tectonic History and Mineral Deposits of the Western Cordillera, *C.I.M.*, Spec. Vol. 8, pp. 295-304.

Nishiwaki, C., Matsukuma, T., and Uashima, Y. (1971): Neogene Gold-Silver Ores in Japan, *Soc. Mining Geol. Japan*, IAGOD Vol., Spec. Issue 3, pp. 407-417.

Nolan, T. B. (1935): The Underground Geology of the Tonapah Mining District, Nevada, *University of Nevada*, Bull., Vol. 29, No. 5.

Norman, G. W. H. (1962): Faults and Folds across Cordilleran Trends at the Headwaters of Leduc River, Northern British Columbia, Petrologic Studies, *Geol. Soc. Amer.*, Buddington Vol., p. 313.

Norman, G. W. H. and McCue, J. (1966): Relation of Ore to Fold Patterns at Granduc, B.C., *in* Tectonic History and Mineral Deposits of the Western Cordillera, *C.I.M.*, Spec. Vol. 8, pp. 305-314.

O'Neill, J. J. (1919a): Salmon River District, Portland Canal Mining Division, B.C., *Geol. Surv., Canada*, Sum. Rept., Pt. B, pp. 7-11.

——— (1919b): Preliminary Report on the Economic Geology of the Hazelton District, British Columbia, *Geol. Surv., Canada*, Mem.10.

Park, C. F., Jr. and MacDiarmid, R. A. (1964): Ore Deposits, San Francisco, *W. H. Freeman*.

Philpotts, A. R. (1967): Origin of Certain Iron-Titanium Oxide and Apatite Rocks, *Econ. Geol.*, Vol. 62, No. 3, pp. 303-315.

Pitcher, M. G. (1960): Fusilinids of the Cache Creek Group Stikine River Area, Cassiar District, British Columbia, Canada, *Brigham Young University Research Studies*, Geol. Ser., Vol. 7, No. 7.

Post, A. (1969): Distribution of Surging Glaciers in Western North America, *Jour. Glaciology*, Vol. 8, No. 53, pp. 222-240.

Prinz, M. and Poldervaart, A. (1964): Layered Mylonite from Beartooth Mountains, Montana, *Geol. Soc. Amer.*, Bull., Vol. 75, pp. 741-744.

Rigby, J. K. (1969): Geological Reconnaissance of the Sustut Basin and Eastern Margin of the Bowser Basin, British Columbia, *Union Oil Company of Canada*, private report.

Rittman, A. (1962): Volcanoes and Their Activity, *John Wiley and Sons*, New York.

Roddick, J. A. (1966): Coast Crystalline Belt of British Columbia, *in* Tectonic History and Mineral Deposits of the Western Cordillera, *C.I.M.*, Spec. Vol. 8, pp. 73-82.

——— (1970): Douglas Channel-Hecate Strait Map-area, *Geol. Surv., Canada*, Paper 70-41.

Roddick, J. A., Wheeler, J. O., Gabrielse, H., and Souther, J. G. (1967): Age and Nature of the Canadian Part of the Circum-Pacific Orogenic Belt, *Tectonophysics*, Vol. 4, pp. 319-337.

Sakamoto, Takao (1950): The Origin of the Pre-Cambrian Banded Iron Ores, *Amer. Jour. Sci.*, Vol. 248, pp. 449-474.

Schofield, S. J. (1921): The Ore Deposits of British Columbia, *C.I.M.*, Trans., Vol. 24, pp. 86-98.

Schofield, S. J. and Hanson, G. (1922): Geology and Ore Deposits of Salmon River District, British Columbia, *Geol. Surv., Canada*, Mem. 132.

Schwellnus, C. M. (1938): Vermiculite Deposits in the Palabora Area, N.E. Transvaal, Dept. of Mines, *Union of S. Africa*, Bull. No. 11.

Shepard, F. P. (1960): Mississippi Delta: Marginal Environments, Sediments and Growth, *in* Recent Sediments, Northwest Gulf of Mexico, *Amer. Assoc. Petrol. Geol.*, Tulsa, pp. 56-81.

Shilo, N. A., Sidorov, A. A., Goncharov, V. I., and Naiborodin, V. I. (1971): The Temperature Conditions and the Depths of Formation of Gold-ore Deposits, *Soc. Mining Geol. Japan*, IAGOD Vol., Spec. Issue 3, pp. 356-359.

Simons, D. B., Richardson, E. W., and Nordin, C.F., Jr. (1965): Sedimentary Structures Generated by Flow in Alluvial Channels, *in* Primary Sedimentary Structures and Their Hydrodynamic Interpretation, *Soc. Ec. Pal. and Min.*, Spec. Paper No. 12, pp. 34-52.

Souther, J. G. (1970a): Volcanism and its Relationship to Recent Crustal Movements in the Canadian Cordillera, *Cdn. Jour. Earth Sci.*, Vol. 7, No. 2, pp. 553-568.

——— (1970b): Cordilleran Volcanic Study 1969, Telegraph Creek, B.C. *in* Rept. of Activities, Pt. A., 1969, *Geol. Surv., Canada*, Paper 70-1, Pt. A, pp. 50-53.

——— (1971): Geology and Mineral Deposits of Tulsequah Map-Area, British Columbia, *Geol. Surv., Canada*, Mem. 362.

Souther, J. G. and Armstrong, J. E. (1966): North Central Belt of the Cordillera of British Columbia, *in* Tectonic History and Mineral Deposits of the Western Cordillera, *C.I.M.*, Spec. Vol. No. 8, pp. 171-189.

Spry, A. (1969): Metamorphic Textures, *Pergamon Press Ltd.*, Oxford.

Stanton, R. L. (1959): Mineralogical Features and Possible Mode of Emplacement of the Brunswick Mining and Smelting Orebodies, Gloucester County, N.B., *C.I.M.*, Bull., Vol. 62, pp. 643-681.

——— (1960): General Features of the Conformable 'Pyritic' Orebodies, *C.I.M.*, Vol. 63, pp. 24-29.

——— (1964): Mineral Interfaces in Stratiform Ores, *C.I.M.*, Trans., Vol. 67, pp. 45-79.

Stikine River Area, Cassiar District, British Columbia (1957), *Geol. Surv., Canada*, Map 9-1957.

Sullivan, C. J. (1970): Relative Discovery Potential, Principal Economic Metals, *C.I.M.*, Bull., Vol. 63, pp. 773-783.

Sutherland Brown, A. (1969): Aiyansh Lava Flow, B.C., *Cdn. Jour. Earth Sci.*, Vol. 6, No. 6.

Sutherland Brown, A., Cathro, R. J., Panteleyev, A., and Ney, C. S. (1971): Metallogeny of the Canadian Cordillera, *C.I.M.*, Bull., Vol. 64, No. 709, pp. 37-61.

Taylor, L. A. (1970): The System Ag-Fe-S: Phase Equilibria and Mineral Assemblages, *Min. Dep.*, 5/1, pp. 41-58.

Theodore, Ted G. (1970): Petrogenesis of Mylonites of High Metamorphic Grade in the Peninsula Ranges of Southern California, *Geol. Soc. Amer.*, Bull., Vol. 81, pp. 435-450.

Tipper, H. W. (1963): Nechako River Map-Area, British Columbia, *Geol. Surv., Canada*, Mem. 324.

——— (1971): Smithers Map-Area, British Columbia, Rept. of Activities, *Geol. Surv., Canada*, Paper 72-1, Pt. A, pp. 39-41.

Turner, F. J. (1968): Metamorphic Petrology, *McGraw-Hill Co.*, p. 403.

Vokes, F. M. (1969): A Review of the Metamorphism of Ore Deposits, *Earth Sci. Rev.*, Vol. 5, pp. 99-143.

Weeks, L. G. (1957): Origin of Carbonate Concretions in Shales, Magdelena Valley, Columbia, *Geol. Soc. Amer.*, Bull, Vol. 68, pp. 95-102.

Westgate, L. G. (1922): Ore Deposits of the Salmon River District, Portland Canal Region, Alaska, *U.S. Geol. Surv.*, Bull. 722C, pp. 117-140.

White, W. H. (1939): Geology and Ore-deposition of Silbak Premier Mines Ltd., *University of British Columbia*, Unpubl. M.Sc. Thesis.

——— (1959): Cordilleran Tectonics in British Columbia, *Amer. Assoc. Pet. Geol.*, Bull., Vol. 43, No. 1, pp. 60-100.

——— (1966): Cordilleran Tectonics in British Columbia, *in* Tectonic History and Mineral Deposits of the Western Cordillera, *C.I.M.*, Spec. Vol. No. 8, pp. 349-353.

White, W. H., Harakal, J. E., and Carter, N. C. (1968): Potassium-Argon Ages of Some Ore Deposits in British Columbia, *C.I.M.*, Bull., Vol. 61, pp. 1326-1334.

Williams, H., Turner, F. J., and Gilbert, C. M. (1954): Petrography, *W. H. Freeman and Company.*

Woodcock, J. R., Bradshaw, B. A., and Ney, C. S. (1966): Molybdenum Deposits at Alice Arm, British Columbia, *in* Tectonic History and Mineral Deposits of the Western Cordillera, *C.I.M.*, Spec. Vol. No. 8, pp. 335-340.

Wright, F. E. (1906): Unuk River Mining Region, *Minister of Mines, B.C.*, Ann. Rept., 1906, pp. 68-74.

2

PHYSIOGRAPHY AND GLACIATION

Physiography: The map-area is a mountainous region dissected by stream erosion and modified by glaciation; most lies within the Boundary Ranges of the Coast Mountains. The boundary between the adjoining Skeena Mountains and Nass Basin has been shown by Holland (1964) to trace a curving line extending north from the Nass River, east to Kinskuch Lake, past the west end of Meziadin Lake to the east end of Bowser Lake to intersect the Iskut River. The map-area lies in the border zone between the Nass Basin and Boundary Ranges.

In the vicinity of the international boundary northwest of Stewart a large portion of the area is covered by permanent icefields, through which many nunataks project. Most of the terrane below 1 800 metres elevation presents a crudely rounded appearance while the mountains above that show serrate ridges, horn peaks, and alpine glaciers. Local relief varies considerably from a few thousand metres in the Nass Basin to 1 800 metres along the fjords with the maximum of over 2 400 metres along the Bowser River. The highest peaks in the area are north and east of Stewart. These include Mount Jancowski (2 990 metres), Mount Patullo (2 730 metres), and Mount Mitre (2 710 metres), as well as many more peaks and ridges which exceed 2 100 metres. This topograhic high lies east of the main 'granite' contact (Fig. 1) and forms a crudely ovoid upland area extending from Kitsault Lake to the south, northerly through the Mount Jancowski-Mount Mitre massif, to the Unuk River-Treaty Creek boundary.

Within the general map-area the major fjords and valleys trend northerly to northeasterly and are interconnected by easterly dissections. The areas above the low valleys and divides are covered by extensive icefields and most of the valleys contain glaciers. In general, permanent snow and ice cover most of the highland from Kitsault Lake to the Unuk-Treaty divide.

Drainage: Large streams channel runoff and meltwaters from the study area either directly into the coastal fjords or by circuitous paths into the Nass River system. Most of the major rivers in the coastal area follow deeply dissected narrow valleys leading from the major icefields and glaciers. Near the fjords the valleys broaden and are generally floored by flat gravel plains incised by the braided stream channels. At the river mouths, broad marine deltas extend into the tidal waters.

Most of the similar streams along the coastal section drop precipitously from the ridge tops and icefields almost directly into the fjords, have little or no bottom sands and gravels, and seldom form deltas. Inland, along the major rivers, the tributary streams generally have high gradients and are channeled along rock structures. Many of these streams carry a considerable load of detritus and alluvial fans have been built along the lower sections near the valley bottoms.

Glaciological Studies: The common occurrence of U-shaped and hanging valleys, the rounded nature of the low hills, and numerous lakes and drumlin-like forms in the Nass Basin indicate extensive glaciation. Ice from the Boundary Ranges and Skeena Mountains moved along the Bell-Irving trench into the Nass Basin to escape along the Nass River. Ice moving from the highland west to the coast flowed into the fjords along the present coastal drainage system. During the present stage of glacial retreat, which is still continuing, drainage reversals occurred as the topography evolved; Tide, Summit, and Strohn Lakes are examples. Marine estuarine deposits exposed along the Bear and the Salmon River valleys form benches along the slopes which indicate an overall recent isostatic uplift of about 150 metres. At Anyox, along the west side of Granby Bay, a series of marine beaches or terraces is now about 200 metres above sea level.

Studies in coastal areas of adjacent Alaska (Klotz, 1907) and nearby Stikine (Kerr, 1948) indicated a glacial recession up until the 1860's, then a short rapid ice front advance, followed by a recession which has continued to the present. Presumably the glacial events in the Stewart district followed this pattern.

The distribution of present-day snowfields and glaciers in the Western Cordillera indicates to a degree major centres of the Pleistocene Cordilleran ice-sheet. The extensive icefields that still exist northwest of Alice Arm in the Boundary Ranges indicate one of the major centres of accumulation.

At present most of the glaciers in the map-area are retreating at about 50 metres per year in the terminal areas, exposing fresh rock outcrop for prospecting. The Granduc mine, located in 1951 on the edge of the South Leduc Glacier, was ice covered only three years previously in 1948, which indicated the importance of deglaciation to mineral exploration in this region (Fig. 4). Information gathered from old photographs and maps, together with observations, suggests that glacial ablation in the southern Boundary Ranges has been continuous but at various rates since about 1900.

The self-dumping, ice-dammed lakes found in the Coast Mountains formed as the result of the retreat of a tributary arm from the trunk glacier (Marcus, 1960, p. 90). Three large glacier-dammed lakes are known in the map-area.

On the basis of deep ice drilling results on the Salmon Glacier just east of Summit Lake, Mathews (1959) found that the average surface velocity of the Salmon Glacier was 91 metres per year, with an overall velocity of 77 metres per year. The 1970-1971 movement

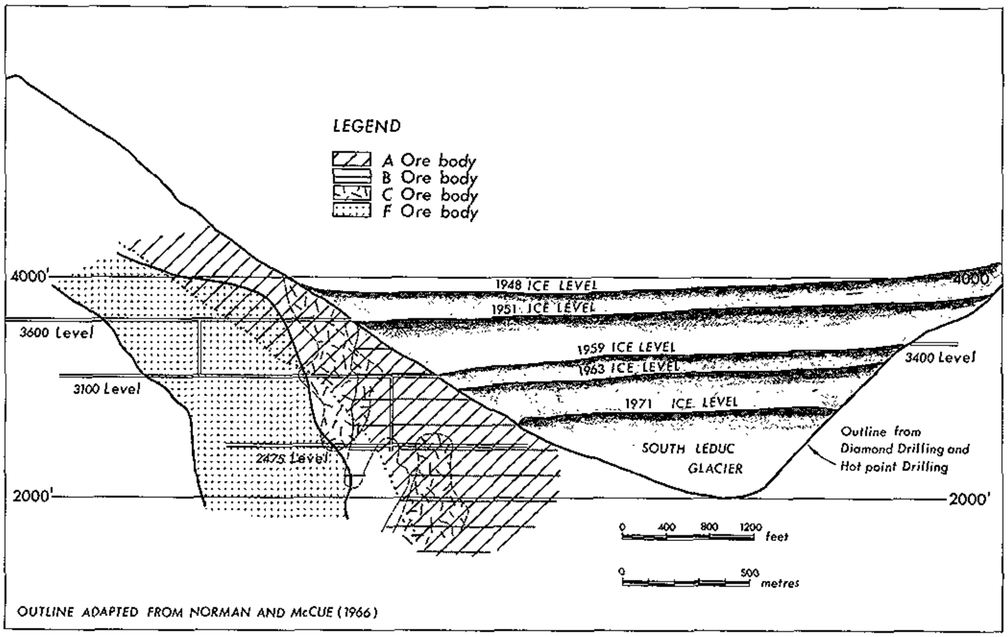


Figure 4. Recent levels of glacial ablation, South Leduc Glacier.

of Salmon Glacier measured 800 metres; this fits the lower limit suggested by Post (1969) for surging glaciers. The surface of Salmon Glacier exhibits both large-scale and small-scale folds in the medial moraines; the area at the ice barrier has a chaotic broken surface. The data suggest that Salmon Glacier is a surging glacier that has probably surged periodically since 1922. Many other glaciers in this general area also surged during the 1970-1971 period, including the South Leduc, Berendon, and Frankmackie.

As the present Salmon Glacier retreats, it leaves behind a flat-floored gravel valley bottom which is reworked by the issuing river; smaller glaciers have little or no load and leave only polished rock flanked by marginal moraines. Transported talus is prominent on the ice of larger glaciers and is also plastered along steep valley walls where glaciers recently melted. Other glacial deposits include lake sediments at Tide Lake Flats and those exposed for a short time under Summit Lake when it emptied.

Hanson (1932) showed the presence of at least 5 metres of varved clays at Tide Lake and recent erosion has cut deeper exposing at least 15 metres of thinly laminated sediments. Hanson's suggestion that the Tide Lake varved sediments represented 2 000 years accumulation is probably large, considering the fact that glacial ice filled the Tide Lake valley only 500 years ago.

3

GENERAL GEOLOGY

Introduction: The Unuk River-Salmon River-Anyox map-area includes part of the contact of the eastern Coast Plutonic Complex with the west-central margin of the successor Bowser Basin. Geologically, geographically, and economically the country rocks of the area form a well-defined entity that the writer has called the Stewart Complex. Sedimentary, volcanic, and metamorphic rocks bordering the Coast Plutonic Complex range in age from Middle Triassic to Quaternary. The detailed stratigraphy of the entire area is not completely known, principally because of the extensive icefields, the poor accessibility, and the complex nature of the Mesozoic succession. North of Stewart, fossil evidence coupled with certain marker horizons has been used to outline and separate Triassic and Jurassic formations. Permian rocks were not specifically studied, although thick Permian carbonate units occur along the Iskut River and immediately east of the Bell-Irving River at Oweegee Peak (Fig. 1). In the map-area south of Stewart, fossils are rare; in the Kitsault River section, Hanson (1931) and Carter (personal communication) collected undiagnostic Mesozoic fossils. South of Stewart, identification of Hazelton Group formations is still tentative because it is based on structural and lithological similarities and homotaxy.

The nature of the Permian-Triassic boundary was not determined in the map-area. To the north toward Telegraph Creek, where both Permian and Triassic rocks are well exposed, the nature of the Permian-Triassic boundary is still uncertain, even though the Permian rocks which probably underlie part of the Bowser Basin have been studied by several petroleum exploration companies. Fusilinid studies on thick carbonate rocks exposed along the Scud River (Pitcher, 1960) indicate an Early and Middle Permian assemblage. Thickening of the section by folding and faulting is probable. In summarizing a study of the Bowser Basin, Fitzgerald (1960) stated that 'the Mississippian, Pennsylvanian, and Permian rocks overlie an older intensely folded highly metamorphosed sequence and are themselves separated by an internal unconformity at the base of the Permian.' The Paleozoic rocks are generally overlain unconformably by Triassic rocks which are predominantly agglomerate, tuff, and andesitic flows with a probable total thickness of 400 metres. At Oweegee Dome the Permian carbonate units have been deformed and eroded, and are overlain unconformably by Upper Triassic black shales.

Within the Stewart Complex, Upper Triassic rocks are found only along the Iskut-Unuk River section. The Upper Triassic strata, which include diagnostic fossil assemblages, are predominantly green epiclastic volcanic units. These include volcanic breccias, marbles, sandstones, and siltstones which form prominent horizons near the top of the sequence. The known Triassic succession in this area has a thickness of at least 900 metres.

Triassic rocks are overlain in the area by sedimentary, volcanic, and green epiclastic volcanic rocks of the Jurassic Hazelton Group. The contact varies from place to place; it is generally disconformable to unconformable. All the Jurassic rocks in the map-area are included in the Hazelton Group. It is divisible into four major lithostratigraphic divisions represented by one Early Jurassic, two Middle Jurassic, and one Late Jurassic formation. The Lower Hazelton is a predominantly volcaniclastic sequence marked by extensive

TABLE 1. CORRELATION OF ROCK FORMATIONS OF VARIOUS INVESTIGATORS IN THE PORTLAND CANAL REGION

ERA	PERIOD AND EPOCH	McCONNELL, 1913	SCHOFIELD AND HANSON, 1922	HANSON, 1929	BUDDINGTON, 1929	HANSON, 1935	GROVE, 1972	PERIOD AND EPOCH	ERA
CENOZOIC	Quaternary	Superficial deposits	Pleistocene and Recent	Recent and Pleistocene	Pleistocene and Recent	Recent and Pleistocene	Surficial deposits, basalts	Quaternary	CENOZOIC
	Tertiary					Tertiary-basaltic lava flows	(Sustut Group)	Tertiary	
MESOZOIC		Later diorite porphyry dykes	Lamprophyre dykes Quartz diorite dykes Augite porphyrite stock	Dykes	Coast Range intrusive	Dykes	(Skeena Group)	Upper	CRETACEOUS
			Coast Range Batholith Premier sills	Coast Range intrusives Augite porphyrite and related intrusives		Coast Range intrusives		Lower	
		Nass Formation	Nass Formation	Nass Formation	Not Mapped	Hazelton Group	Nass Formation	Upper	JURASSIC
		Bear River Formation	Salmon River Formation	Bear River Formation			Salmon River Formation	Middle	
			Bear River Formation				Betty Creek Formation		
		Bitter Creek Formation	Not Mapped	Bitter Creek Formation	Hazelton Group		Unuk River Formation	Lower	
		Not Mapped	Not Mapped	Not Mapped	Not Mapped	Not Mapped	Takla Group	Upper	TRIASSIC

pillow volcanic members as well as widespread, thin marble lenses. This sequence has been delimited by field mapping and paleontological data north of Stewart, but correlations to the south, at Anyox and Alice Arm, are based on homotaxy. The thick Triassic and Lower Jurassic Hazelton sequences are lithologically monotonous and similar, hence difficult to separate without structural and fossil information. The lower Middle Jurassic unit has been traced from the Unuk River to Alice Arm; it forms one of the few easily recognizable stratigraphic units in the Stewart Complex and may represent the most prominent Jurassic unit within the Bowser Basin. These rocks generally overlie the Lower Hazelton and Triassic with angular discordance. The lower Middle Jurassic unit, the Betty Creek Formation (Grove, 1971), consists of a thick succession of red and green epiclastic volcanic rocks that rest unconformably on Lower Jurassic and older rocks.

The Betty Creek Formation is overlain conformably to disconformably by the upper Middle Jurassic, mainly marine, thinly bedded Salmon River Formation, which includes siltstones, greywackes, and minor volcanic units. The Salmon River Formation is in turn overlain by the marine Nass Formation which forms most of the outcrops in the western Bowser Basin. Elsewhere in the Bowser Basin the Nass Formation and its equivalents are overlain by significant thicknesses of marine to continental sedimentary rocks of Cretaceous or Tertiary age called the Skeena Group. These rocks have not been positively identified near Stewart.

Small Quaternary volcanic piles and flows are scattered throughout the Stewart Complex but are areally limited compared to those found in the northern part of the Bowser Basin.

The west side of the study area is dominated by the Coast Plutonic Complex. The plutons of this extensive belt are known to include Middle Jurassic and Tertiary intrusions. Within the map-area granodiorite is the dominant rock type of the major intrusions; these are flanked by numerous smaller satellite diapiric and tadpole-like plutons named the Skeena intrusions (Grove, 1968a; Fig. 1). They include a large variety of rock types and appear to range in age from Late Triassic to Tertiary. Extensive dyke systems are prominent features in the Stewart Complex and range in age from Jurassic to Tertiary. Along the undulating main contact of the Coast Plutonic Complex a number of prominent re-entrants are marked by the presence of gneisses, migmatites, and some pegmatites.

Deformational metamorphism is important and formed cataclasite and shear zones that are largely restricted to competent Triassic and Lower Jurassic rocks. The shear zones are generally accompanied by extensive, weathered alteration zones.

SEDIMENTARY AND VOLCANIC ROCKS

Nomenclature of Mesozoic Rocks in Northwestern British Columbia: Two group names, Hazelton and Takla, which once dominated Mesozoic nomenclature and to which most Western Cordilleran Mesozoic rocks were assigned, have in recent years been joined by the term Bowser Group. Initially these group names were applied on the basis of spatial relationships to the original areas, but in the general absence of definitive fossil assemblages the names have been applied on the basis of comparable lithology.

Results of geological studies in the Stewart Complex have made it possible to redefine the nomenclature for Mesozoic rocks in northwestern British Columbia. Detailed geological studies in the Smithers area by R. V. Kirkham (personal communication) corroborated the writer's results. On the basis of this new information H. W. Tipper of the Geological Survey of Canada selected part of the Smithers area to restudy the Mesozoic succession. Nomenclature, redefinition of the Hazelton Group, and new lithostratigraphical units are discussed following.

Nomenclature of Mesozoic Rocks in the Portland Canal Area: A summary stratigraphic correlation chart listing the main contributors to Mesozoic nomenclature for parts of the Portland Canal area is shown in Table 1. Hanson (1935) suggested that the name

Hazelton Group be applied to the sedimentary-volcanic succession and that the Nass and Bitter Creek sedimentary formations, as originally designated by McConnell (1913), were a single, continuous series. He also suggested retaining the name Bear River Formation for all volcanic rocks in the area. Locally, the use of the formation names as well as Hanson's concept of the Hazelton Group persisted until 1957.

Map 9-1957, Stikine River Area (*Geological Survey of Canada*), includes part of the Portland Canal area. Hanson's suggestion that the Bear River Formation volcanic rocks and Bitter Creek-Nass Formation sedimentary rocks were discrete was confirmed, but as a result of Operation Stikine and the reconnaissance work at Bowser Lake, the concept of an areally extensive sedimentary unit named the Bowser Group, resting unconformably upon the Hazelton Group, was introduced. This nomenclature was adopted throughout central and northwestern British Columbia and subsequently adopted by Tipper (1963), Duffell and Souther (1964), and others.

Regional mapping of the Stewart Complex lying between the Iskut River and Alice Arm was completed in 1968, resulting in a significant revision of the geology of the area. The nomenclature devised for the Stewart Complex is applicable to much of the western margin of the Bowser Basin as evidenced by lithostratigraphic relationships and fossil assemblages. The composite stratigraphic section for the Stewart map-area, shown on Figure 5, represents part of the complete succession in the Stewart Complex and illustrates the revised terminology.

TRIASSIC

Triassic (and older ?) rocks occur as large areas within the Columbian Intermontane Belt of the Western Cordillera, but occur only as small areas within the Coast Plutonic Complex and in the Insular Fold Belt (Fig. 6). In central and northwestern British Columbia the known record of Early and Middle Triassic strata is fragmentary and the age of these rocks has commonly been inferred on the basis of apparent relationships to the Permian carbonate units. The general absence of fossils and markers within the Triassic assemblage outlined in the Unuk River map-area has made it difficult to break this sequence into viable map units. Map 9-1957, Stikine River Area, portrays undivided Triassic rocks (map unit 6) in the salient west of the Unuk River, between the Iskut River and the Alaskan boundary. These areas represent pendants within the Coast Plutonic Complex or areas directly bordering the complex. The section along the Unuk River north of Granduc mine was mapped by Norman (personal communication); new fossil assemblages show that the McQuillan Ridge and Harrymel Creek sections, shown on Map 9-1957 as Jurassic volcanic and intrusive rocks respectively, include Upper Triassic strata. The extent of this belt of Triassic rocks along the Unuk River has since been expanded.

Apparently, Upper Triassic rocks, including eugeosynclinal volcanic rocks, pelites, and limestones, were widespread (Brew, *et al.*, 1966). The Upper Triassic assemblage is particularly well known in the Insular Fold Belt along the axis of the Alexander subtrough in southeastern Alaska, the Queen Charlotte Islands, and Vancouver Island (Brew, 1968; Jeletzky, 1970).

In northwestern British Columbia, Kerr (1948) subdivided Upper Triassic strata of the Taku River area into the King Salmon Group of clastic sedimentary rocks, the Stuhini Group of mainly volcanic rocks, and the Honakta Formation limestone. Souther (1971) remapped the Tulsequah area and modified the Upper Triassic nomenclature in that area. He extended the definition of the Stuhini Group to include all Upper Triassic volcanic and sedimentary rocks lying above a Middle Triassic unconformity and below the Norian Sinwa Formation.

Distribution: In the Stewart Complex, a northerly trending, wedge-shaped belt of Upper Triassic rocks extends along the Unuk River from McQuillan Ridge north about 50 kilometres to the Iskut River. This belt includes rocks which were shown on Map 9-1957 as

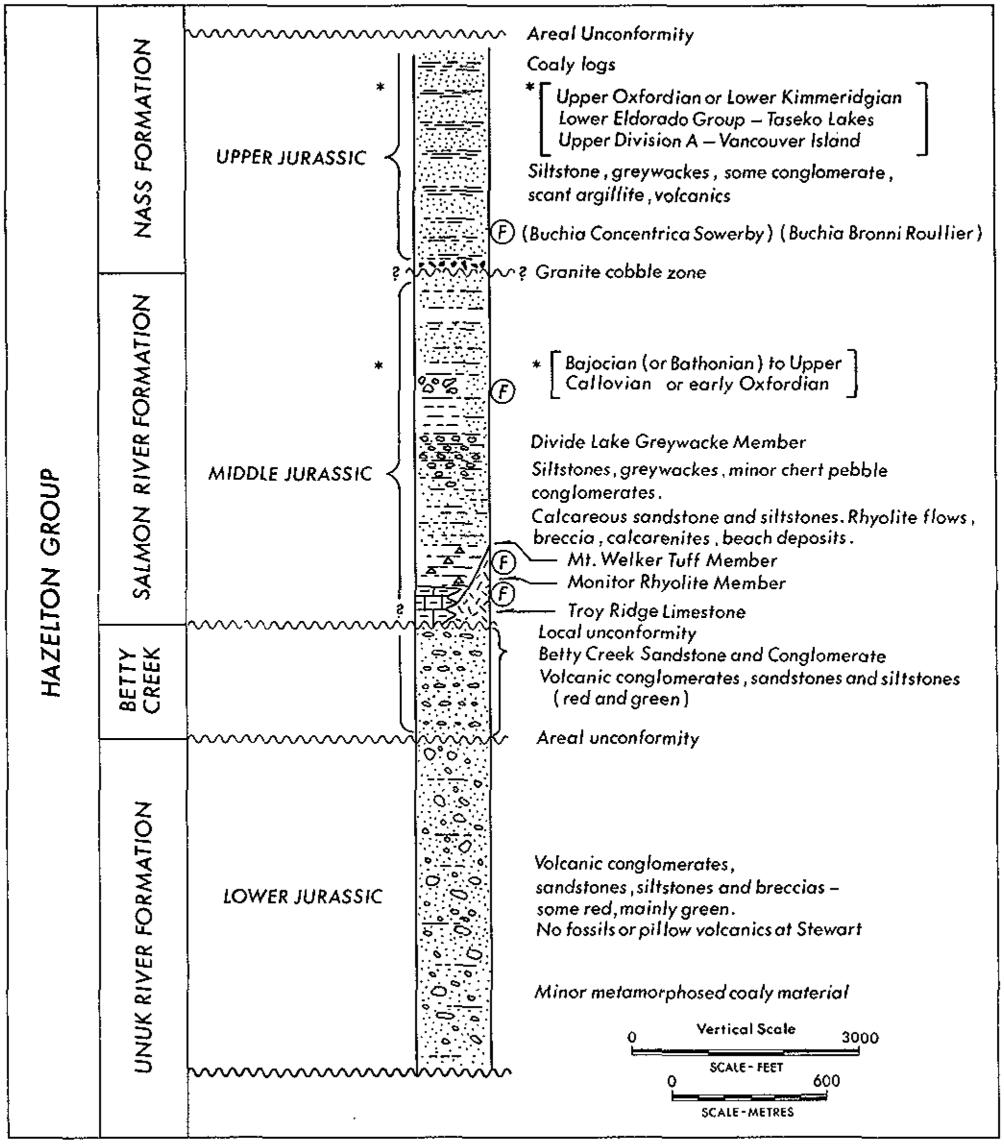


Figure 5. General stratigraphic column, Stewart area.

Jurassic and Upper Jurassic to Lower Cretaceous sedimentary, volcanic, and intrusive rocks. These Upper Triassic rocks are cut by the Unuk River and exposure is limited by extensive permanent snow and ice. Below the snow line the vegetation is dense and outcrop is restricted to steep gullies, canyons, and cliffs.

Lower Jurassic rocks have been identified between Len King and Fewright Creeks, but these were previously mapped as Triassic (Map 9-1957). Similarly, Triassic rocks shown at the head of Len King Creek are included in the Lower Jurassic on the basis of new fossil evidence. Well-documented Triassic sequences extend north of the Iskut River map-area and west along both sides of the Iskut River.

Lithology: The scarcity of fossils and the absence of any persistent marker horizon make correlation of the Upper Triassic rocks in the Unuk River area difficult. On McQuillan Ridge the mappable succession comprises a thick assemblage of interbedded green

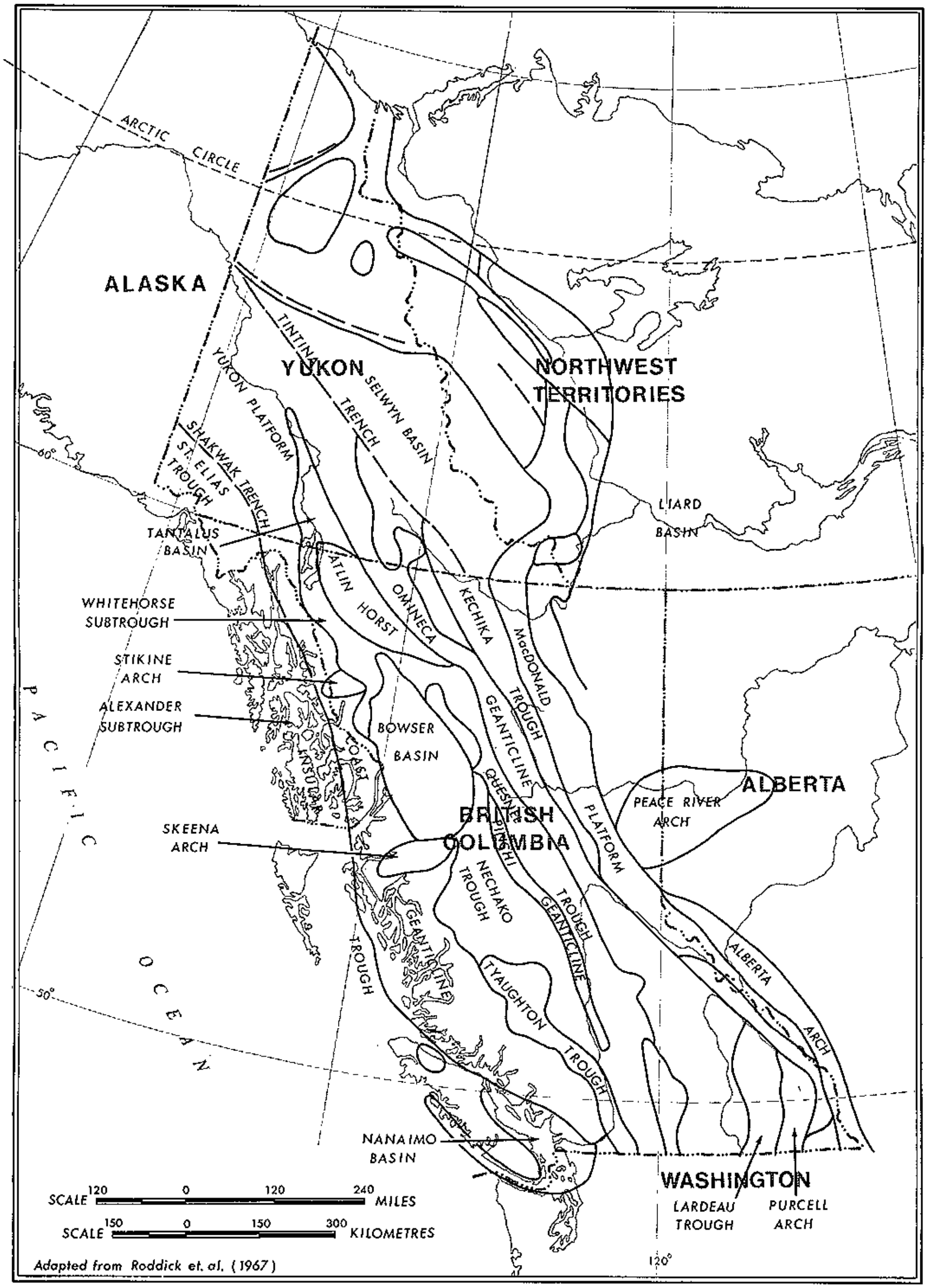


Figure 6. Tectonic framework of the western Canadian Cordillera.

volcanic conglomerates, sandstones, and siltstones with andesitic and basaltic volcanic rocks, and thin lenticles of grey carbonate, calcarenite, and quartzite, which are prominent along the upper ridge. Crystal and lithic tuffs, thin-bedded grey cherts, and quartz sandstones are intercalated with the epiclastic volcanic rocks. The rocks of McQuillan Ridge are folded; the major structure represents an upright northeasterly trending, open anticlinal fold or dome. This structure is truncated by Tertiary plutons and the west-central part of the ridge is penetrated by at least one pluton of probable Late Triassic age. Access to the complete stratigraphic succession is limited to the flanks and axial zone at the head of Cebuck Creek. The bulk of the rocks bounded by the flanks of Unuk River and Gracey Creek are thick-bedded grey-weathering, green volcanic conglomerates and sandstones with intercalated lenticular andesite flows, thinly banded calcareous siltstones and volcanic sandstones, and minor amounts of crystal and lithic tuffs. Bedding in the epiclastics is thinner toward the top of the ridge in the axial section of the fold and thin-banded, grey cherty limestone lenses are more abundant. At the head of Cebuck Creek several quartzite lenses up to 25 metres thick, intercalated within volcanic conglomerate and sandstone, form part of the carbonate-rich section.

The unaltered epiclastic volcanic rocks are largely composed of fresh andesitic fragments within a matrix of rock fragments, plagioclase and quartz clasts. Augite fragments are common, with quartz and plagioclase fragments in the matrix of several fine-grained epiclastic units in which the rock clasts are porphyritic andesite. The volcanic conglomerates and sandstones are characterized by rapid facies changes, local unconformities, channeling, and occasional graded bedding which gives the rocks a banded appearance. The carbonate lenses consist of grey sugary calcite and generally conform to bedding in the enclosing sedimentary rocks. The lenses are typically less than 150 metres long and rarely exceed 10 metres in thickness; most have an irregular nature presumably as a result of local boudinage. The section at McQuillan Ridge includes about 1 000 metres of section of predominantly sedimentary material.

One group of fossils was collected by Norman from the east side of McQuillan Ridge above Gracey Creek. Poorly preserved fragments of pelecypods and ammonites found in thin-bedded volcanic conglomerates included specimens tentatively identified as *Halobia* sp. which indicates a possible Karnian age.

The Upper Triassic belt extends north of McQuillan Ridge along the west side of Harrymel Creek toward the Iskut River. As along McQuillan Ridge, exposures are limited to creeks, some ridge lines, and open areas below ice and snow. The sequence appears to be considerably more disrupted than at McQuillan Ridge, as evidenced by overturned plunging folds north of Len King Creek and convergent structures outlined immediately west of Harrymel Creek. The lack of distinctive marker units leaves the structure generally unresolved.

Like the lower part of the McQuillan Ridge succession, country rocks in the King Creek section are monotonous, crudely bedded, green volcanic conglomerates and sandstones, generally as steep-dipping, northeast-trending lenticular units. Lithic wackes and siltstones intercalated in the sequence form discrete units a few hundred metres thick and comprise up to 40 per cent of the section. Apparent thicknesses are probably misleading; small-scale folds occur and outcrop is discontinuous.

Toward Cinder Mountain, at a higher level in the succession, limestone lenses, calcarenite, and siltstone units with intercalated epiclastic volcanic rocks dominate the section. A folded limestone unit immediately southeast of Cinder Mountain is one of the few large limestone members within known local Upper Triassic rocks. North of Cinder Mountain the sequence consists of poorly exposed, generally northeasterly trending volcanic conglomerates and breccias.

Several fossil collections were made from calcareous shales and siltstones south of Cinder Mountain. *Monotis subcircularis*, of probable Norian age, was found above the thick limestone lens near Cinder Mountain and the belemnite, *Aulacoceras* sp., was collected by Norman 3 kilometres south of Cinder Mountain.

Structural Relationships: The internal structural relationships of Upper Triassic rocks in the Unuk River area are not well known because of the lack of lithological control. Convergent lenticular units, particularly west of Harrymel Creek, strongly suggest that the succession is not internally conformable. The small structural remnant of Norian strata is obviously unconformable to the underlying Karnian succession.

Relationships of the Upper Triassic strata with Hazelton Group rocks, various plutons, and various volcanic rocks are fairly clear. The Upper Triassic rocks are overlain on the east and west by Lower Jurassic Hazelton Group rocks with both disconformable and unconformable relationships. Deformation along the Gracey Creek-Harrymel Creek contact between rocks of similar aspect causes some problems as to the exact location of the contact. Structural remnants of the Middle Jurassic Betty Creek Formation are generally flat lying and rest with distinct unconformity on Upper Triassic units near Nickel Mountain.

The McQuillan Ridge area has been intruded by several small plutons. The south contact with plutonic rocks also marks the main eastern margin of the Coast Plutonic Complex. The small plutons along the Unuk River are probably of Late Triassic age. Mapping along the west slope of McQuillan Ridge revealed several swarms of dykes, some of which appear to predate the main phases of the Tertiary Coast Plutonic Complex.

Metamorphism: The belt of Upper Triassic country rocks has suffered several phases of metamorphism and local deformation related to periodic plutonism. Contact or thermal metamorphism, expressed as narrow ragged aureoles, is marked by induration, variable recrystallization, and the presence of fine to coarse-grained, green-brown hornblende. These thermal zones are well developed along the eastern contacts of the two small quartz diorite plutons of probable late Upper Triassic age and along the length of the margin of the Coast Plutonic Complex. Hornblende porphyroblasts are visible in outcrop up to 100 metres from the intrusive contact in volcanic conglomerates and sandstones where, in certain instances, sedimentary clast grain size appears to have been faithfully reproduced in the metamorphosed graded beds. Well-formed dark brown hornblende crystals up to 1 centimetre long occur in the volcanic sandstones, whereas in the siltstones the grain size of the acicular amphibole averages 3 to 5 microns. The amount of metamorphic hornblende varies considerably from about 5 per cent to almost 95 per cent in thin laminae which represent metamorphosed calcareous siltstone. Hornblende also developed in thermal aureoles along the south end of McQuillan Ridge where the Upper Triassic sequence has been transected by the extensive Tertiary biotite granodiorite plutons. This zone is generally about 50 metres wide and is also marked by local deformation. Both fine-grained brown biotite and green-brown hornblende formed; induration and variable recrystallization were noted. At Flory Lake, on the west side of McQuillan Ridge, several generations of granodiorite to diorite dyke swarms criss-crossed the predominantly andesitic volcanic conglomerates, sandstones, and siltstones. Metamorphism in these rocks is limited to induration of contact zones for a few metres from dyke contacts. In these zones incipient tremolite-actinolite developed at several stages. Early basic dykes cut by later granodiorite dykes show limited induration but pyroxene was not altered.

In general, amphibolite-grade metamorphism in the Upper Triassic rocks along McQuillan Ridge and Harrymel Creek can be related to several periods of plutonism as evidenced by direct spatial relationships. North of Cinder Mountain there is a narrow zone of altered volcanic conglomerates and breccias in which green-brown hornblende has also developed at macroscopic scale. These rocks are overlain directly by unaltered Lower Jurassic strata to the east and are gradational with Upper Triassic volcanic conglomerates, sandstones, and siltstones to the west. There are no exposures of any pluton of mappable size in the section and the younger dykes are relatively widely spaced. These altered rocks are weakly gneissic but are not strongly deformed. Structural relations with the southerly part of the Upper Triassic belt are obscured by ice, snow, and recent volcanic flows. This section may therefore represent an uplifted, eroded segment of regionally metamorphosed strata of Triassic or older age.

Origin: Upper Triassic epiclastic rocks of the Unuk River area are composed mainly of angular, poorly sorted andesitic material. Porphyritic andesite and basalt flows intercalated within the succession are texturally comparable to the transported clastic fragments in the epiclastic rocks. The occurrence of both augite-plagioclase basalt lenses and augite clasts in the sedimentary sequence also suggests rapid transport of clastic material directly into the basin of deposition from adjacent volcanic highlands. The rapid lateral changes in thickness and lithology, the visible interdigitation of sedimentary beds and volcanic flows, and the presence of local unconformities suggest active tectonic conditions during deposition of the Upper Triassic strata.

Age and Correlation: *Monotis* was identified by Professor W. R. Danner of The University of British Columbia in material from Harrymel Creek and McQuillan Ridge.

This meagre fossil evidence coupled with the structural interpretation suggests that the bulk of the Upper Triassic rocks in the Unuk River belt are of a Karnian age. The small area of probable Norian rocks appears to represent a synformal calcareous unit unconformably overlying the folded older units.

On the basis of available evidence the extensive early Upper Triassic strata of the Unuk River area that yielded the diagnostic fossil *Halobia* are probably correlatives of Souther's (1971) King Salmon Formation, which he placed within the Stuhini Group. They are also probably correlatives of the Takla Group of the Nechako River area outlined by Tipper (1963). The name McQuillan Ridge member is proposed for early Upper Triassic strata in Unuk River-Salmon River-Anyox map-area.

Norian strata near Cinder Mountain are lithologically similar to Souther's Sinwa Formation, which yielded the diagnostic *Monotis subcircularis* Gabb and *Halorites* cf. *H. americanus*. The Sinwa Formation and its equivalents have proved to be one of the more useful marker units in northwestern British Columbia. The Sinwa Formation, named by Kerr (1948), commonly consists of grey, usually petroliferous, white-weathering limestone which varies in thickness from a few metres to more than 600 metres (Souther, 1971, p. 30). It has been correlated with Norian limestone units both north and east of the Taku River section. In the Atlin map-area Aiken's (1959) Carboniferous limestone has been re-examined and is now correlated to the Sinwa Formation (Souther, *op. cit.*). To the east, in the Dease Lake map-area (Gabrielse and Souther, 1961) and in the Cry Lake map-area (Gabrielse, 1962), thin limestone members of Norian age are correlated with the Sinwa Formation.

Takla Group Problem: In the Stewart Complex, Upper Triassic sedimentary rocks have been identified only where diagnostic fossil assemblages have permitted lithological control. Upper Triassic and Lower Jurassic rocks in this section of the Bowser Basin are strikingly similar in general lithology so that lithologic correlation without paleontological control is inadvisable. Although the Sinwa Formation limestone has widespread application as a horizon marker, it has not been useful in the southern half of the Bowser Basin area because of the generally lenticular nature of most Upper Triassic limestone members (Fig. 8). The presence of prominent Lower Jurassic limestone units also introduces problems in correlation.

Recent work in the Smithers map-area by Tipper (1971) has confirmed Kirkham's conclusion (1968) that the Upper Triassic section compares lithologically to the Takla and Nicola Groups of the Quesnel Trough. These Upper Triassic units include massive grey limestones, dark green pyroxene-bearing basaltic breccias and tuffs, argillite, conglomerate, and andesitic feldspar porphyries or breccias; this stratigraphy, marked by extensive outpourings of pyroxene-bearing lavas, has few similarities to the Unuk River section, where porphyritic augite basalts form only a minor part of the succession. To the north at Mess Creek near Telegraph Creek, the Upper Triassic succession includes predominantly porphyritic augite basalts (Grove, 1968b). Farther north, at Tulsequah, Souther's (*op. cit.*) Stuhini Group includes two assemblages of volcanic and volcanic-sedimentary rocks each apparently related to separate loci of volcanism with broad overlaps and many rock types common to both.

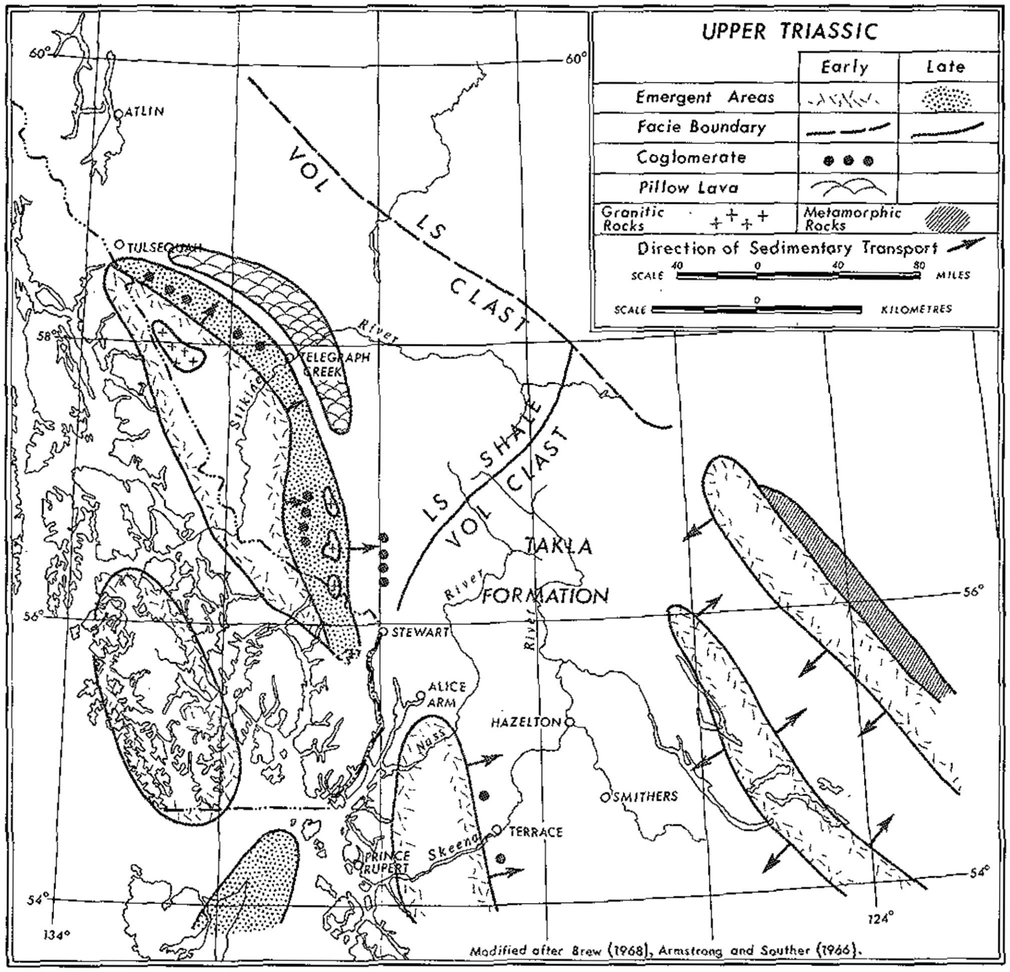


Figure 8. Paleogeographic map, Upper Triassic, northwestern British Columbia.

In view of the very limited detailed information available on the Upper Triassic assemblages in northwestern British Columbia, it is not yet meaningful to make broad regional correlations. As Tipper has indicated (personal communication) the current usage of the term Takla Group follows Armstrong's (1944b) definition and will be used until further work allows refinement of the terminology. In the Stewart Complex, Upper Triassic and Lower Jurassic strata are separated.

JURASSIC

HAZELTON GROUP

The Hazelton Group in the Stewart Complex includes, in ascending order, the Unuk River Formation, the Betty Creek Formation, the Salmon River Formation, and the Nass Formation (*see* Table 1). The assemblage includes ubiquitous clastic sedimentary units intimately intercalated with volcanic flows, epiclastic volcanic rocks, pyroclastic rocks, and interbedded limestones. The rocks are predominantly andesitic or derived from andesitic flows. The Unuk River Formation is a thick accumulation of thick-bedded epiclastic volcanic conglomerates, sandstones, marine siltstones, pillow lavas, and carbonate lenses. The unconformably overlying Betty Creek Formation is a well-bedded unit which comprises red and green volcanic breccias, conglomerates, and sandstone, and includes andesitic flows and pillow lavas. It is overlain with general conformity by the Salmon River Formation which consists of thin-bedded, colour-striped, marine siltstone and greywacke. The uppermost unit, the Nass Formation, is again a dominantly thin-bedded, colour-banded unit, much like the Salmon River Formation upon which it rests disconformably.

The general characteristics of the assemblage are the intermediate or andesitic composition of the various units, the commonly fresh nature of the primary rock components, and the texture of the clastic members. These features have been obscured in many places within the Stewart Complex by polyphase plutonism, metamorphism, alteration, and widespread mineralization.

The Hazelton Group is best exposed at the northern end of the Stewart Complex in the Unuk River and Treaty Creek areas, which unfortunately are almost inaccessible, except by helicopter during rare periods of good weather. No complete exposures of the group are known near Stewart, Alice Arm, or Anyox in the southern part of the complex. The only definitive fossil zones found are also north of Stewart. The Unuk River Formation is of Late Hettangian, Late Pliensbachian, and Early to Middle Toarcian age (Early Jurassic). The Betty Creek Formation is of Middle Bajocian age. The Salmon River Formation is of Late Middle Bajocian to Early Callovian age. The Nass Formation, within the confines of the Stewart Complex, is of Early Oxfordian to Late Kimmeridgian age; because diagnostic fossil assemblages are lacking, the formation may include rocks as young as Albian.

UNUK RIVER FORMATION (MAP UNITS 11 AND 12)

The Lower Jurassic Unuk River Formation is a stratified volcanic-sedimentary sequence. Scattered areas of uppermost Unuk River Formation in the Stewart and Portland Canal districts of the Stewart Complex were mapped in the past by early workers as Bear River Formation or as Hazelton Group (Table 1). The lithology, age, and structural relations of the formation are now fairly well known, particularly the uppermost part of the sequence.

Within the Stewart Complex the formation is best exposed in the Unuk River area where this formation as well as the Upper Triassic rocks are strongly deformed. The base of the formation has not been identified outside the Unuk River-Treaty Creek area. The type locality for the formation is along the east side of the Unuk River (Fig. 2A). The formation, which is a mappable unit throughout the Stewart Complex, is distinguished on the basis of lithologic characteristics.

Lithology: The Unuk River Formation consists of thick-bedded epiclastic volcanic rocks and lithic tuffs, with closely associated pillow lavas, carbonate lenses, and thin-bedded siltstones. The colour of the rocks grades from bright brick red to apple green and includes greys, mottled purples, and maroons. Thin, massive volcanic flows are found as part of the sequence, but are generally limited in extent and difficult to trace. Most of the sedimentary rocks are composed of angular clasts which are fairly fresh and exhibit poor sorting. The early workers in the Portland Canal district generally referred to these variously as greenstones, tuffs, porphyries, and volcanic fragmentals. The formation is moderately folded and extensively faulted.

Lower Member: The Unuk River Formation is subdivided into three members. The lower member is best exposed along the axial zone of the regional dome outlined between Treaty Creek and Jack Glacier, and west of Twin John Peaks at West McTagg Glacier (Fig. 9). The section immediately west of Treaty Glacier, representing the lowermost exposed part of this member, includes intercalated massive volcanic breccias, porphyritic and andesitic volcanic flow rocks with well-bedded, grey epiclastic volcanic conglomerates, lithic tuffs, and volcanic sandstones containing thin lenses of black argillaceous siltstone and colour-banded sandstones. Many of the thin sedimentary units are calcareous and include poorly preserved fossil fragments. The volcanic flow rocks are generally pyritic, extensively altered, and occasionally malachite stained. Alteration is probably related to a swarm of northerly to northeasterly trending syenodiorite dykes that cut through the section.

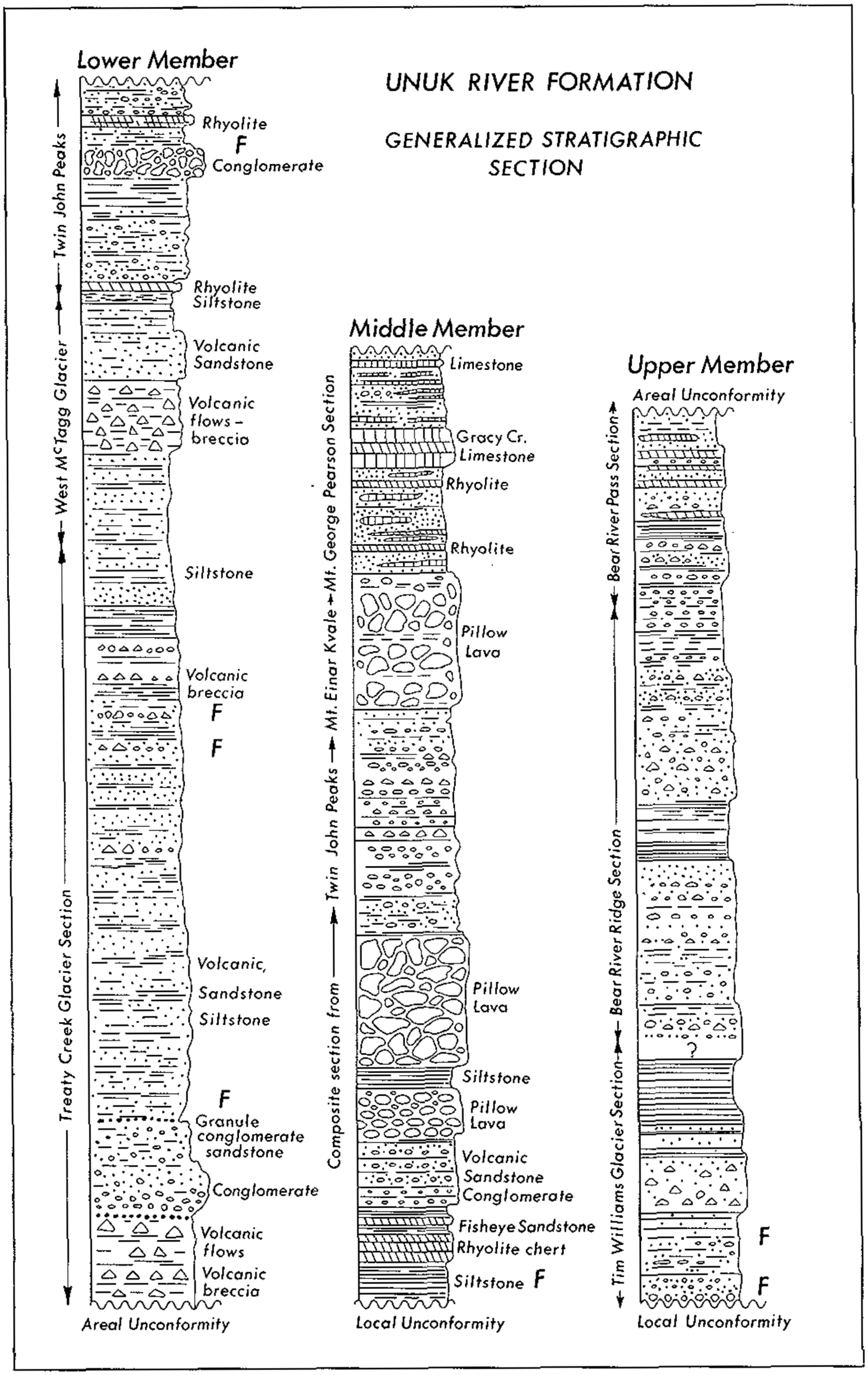


Figure 9. Stratigraphic column, Lower Jurassic, Unuk River Formation.

Toward the northwest, above the thick conglomerate and basal volcanic rocks, the section is dominated by alternating, evenly bedded, dark siltstones and grey-green volcanic sandstones with occasional bands of volcanic conglomerate and thinly striped tuffaceous bands. The rocks are cut by dykes and are generally indurated and highly fractured, with common, narrow graphitic faults. The strata are planar bedded and rarely show sedimentary structures. Alternating centimetre-thick, fine-grained dark siltstone bands are intercalated with grey-green sandstone, greywacke, and volcanic conglomerate layers which are generally less than 3 metres thick, suggesting a rhythmically deposited sedimentary sequence. Apparent graded bedding in the greywacke units was studied in thin sections; this 'grading' reflected a variable content of carbonaceous material, not changes in grain size. Toward the upper part of this section volcanic conglomerates contain well-rounded, fossiliferous (bryozoa) limestone boulders up to 0.5 metre in diameter, and round mud concretions; in contrast conglomerates in the lower part of the section contained occasional fragments of biotite-hornblende granodiorite gneiss. At Jack Glacier, the sedimentary rocks are overlain by a thick pyroclastic sequence comprising green andesitic volcanic agglomerate; green, buff, and red lithic tuff; and intercalated finely banded volcanic sandstone and siltstone. The agglomerates lens out to both east and southwest; they are gradational upward into volcanic conglomerates, sandstones, and siltstones. The agglomerates are overlain by alternating, well-banded volcanic sandstones and siltstones which are, in part, gradational easterly into massive thick volcanic breccia and volcanic conglomerate.

To the west, at Bruce Glacier, the planar bedded volcanic sandstones, siltstones, and volcanic breccias are conformably overlain by a thinly banded, graphitic, argillaceous siltstone unit which is 50 to 250 metres thick. This siltstone has been traced from near the toe of Bruce Glacier, south past the east side of Twin John Peaks into Sulphurets Creek, where it is overlain by Middle Jurassic sedimentary rocks (Fig. 2A). The overlying thick, uniform blanket of green, poorly stratified, weakly foliated andesitic volcanic conglomerate has been traced about 25 kilometres from Storie Creek south across Sulphurets Creek into the Ted Morris Glacier area and to the edge of the icefield. This conglomerate is overlain by a thick, well-stratified, mainly red lithic tuff, in which rare west-plunging scour channels occur (Plate I). This in turn is overlain by a poorly sorted polymictic conglomerate 100 to 150 metres thick in which cobbles and boulders of well-rounded hornblende diorite and basalt lie in a red, crudely laminated, pebbly sandstone matrix. This coarse conglomerate crops out intermittently along the east side of Twin John Peaks for a distance of about 13 kilometres. The overlying, well-stratified, green andesitic volcanic conglomerates and intercalated lithic tuffs occur as irregular erosion remnants. West of Twin John Peaks, along the east wall of the Unuk-South Unuk River valley, the lower member of the Unuk River Formation is unconformably to disconformably overlain by fossiliferous strata of the middle member.

The lower member, measured across the northwesterly flank of the major Brucejack Dome, includes a total of about 8 500 metres of volcanic and sedimentary rocks, cut by swarms of small dykes and small plutons. Individual layers are lenticular; overlapping and transitional lateral relationships reflect facies changes.

The andesitic agglomerates and volcanic breccias within the sequence may have been the source of laterally gradational, compositionally equivalent volcanic conglomerates and sandstones. The volcanic sandstones, greywackes, lithic wackes, and siltstones are immature sediments which lack well-defined sedimentary structures. They are lithologically monotonous grey, planar bedded, fine-grained deposits which suggest either cyclic sedimentation or interrupted sedimentation. The red and green lithic wacke, lithic tuff, and massive greywacke beds in the upper part of this succession are also characterized by moderate lateral extent and planar bedding. There are, however, significant numbers of basalt and augite clasts in the upper red and green assemblage, as well as local, thin flows of moderately altered augite basalt. Conglomerates in the upper section also contain many pebbles and cobbles of augite basalt, indicating local extrusion and

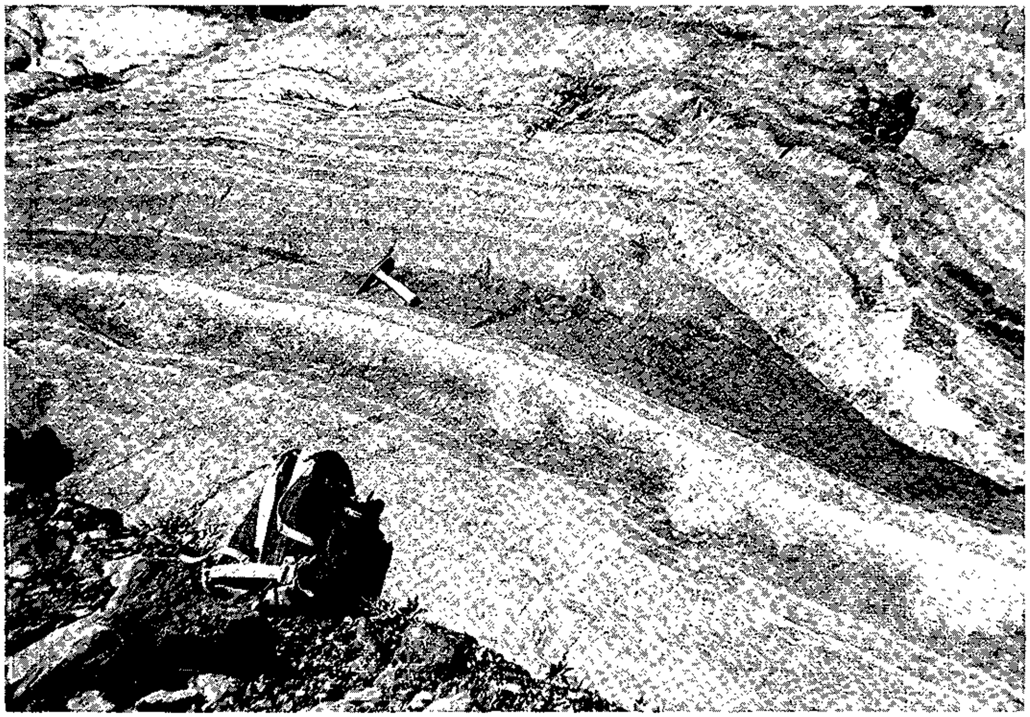


Plate I. Lithic tuff, Unuk River strata, looking west.

rapid erosion and burial. The boulder conglomerate that overlies the red and green tuffs and conglomerates contains abundant fresh hornblende diorite, augite basalt, andesite, chert, and quartz pebbles, cobbles, and boulders in a brick red matrix, suggesting closely related deposition and erosion.

Provenance and Depositional Environment: General close association and rapid lateral facies changes of the volcanic and volcaniclastic units demonstrate the close genetic relationship between the volcanic flows, volcanic breccias, conglomerates, immature sandstones, and tuff units. Limestone boulders in the conglomerate zone were derived from a Permian source to the west, as were gneiss fragments in the lower conglomeratic units (Fig. 10). Extensive, thinly banded rhyolite and associated chert near Twin John Peaks in the upper part of this sequence were deposited during a local change from marine sedimentation to explosive volcanism. Red boulder conglomerate at the top of this succession includes cobbles of hornblende diorite similar to Late Triassic rocks exposed 13 kilometres to the southwest along McQuillan Ridge.

The apparently tabular, altered andesitic units that form the lower part of this member may represent volcanic flows rather than sills. Alternating planar sedimentary units dominate the succession. Beds in flysch sequences, consisting of alternating fine sand to silt and shale units, are commonly bounded with parallel surfaces, although such planar strata are not restricted to flysch units. Field and flume studies (Simons, *et al.*, 1965) show that planar beds characterize both the upper and lower flow regimes. The presence of armoured mud balls in the conglomerates suggests that these beds were deposited under shallow marine conditions (Bell, 1940; Hawkes, 1962). The few sedimentary structures suggest that the members of this succession were eroded from a rapidly uplifted, andesitic highland, and shed into a shallow marine environment. Ammonites, pelecypods, and other fossils identified in the lower member of the Unuk River Formation are interpreted to represent a near shore, mainly neritic environment (Danner, personal communication).

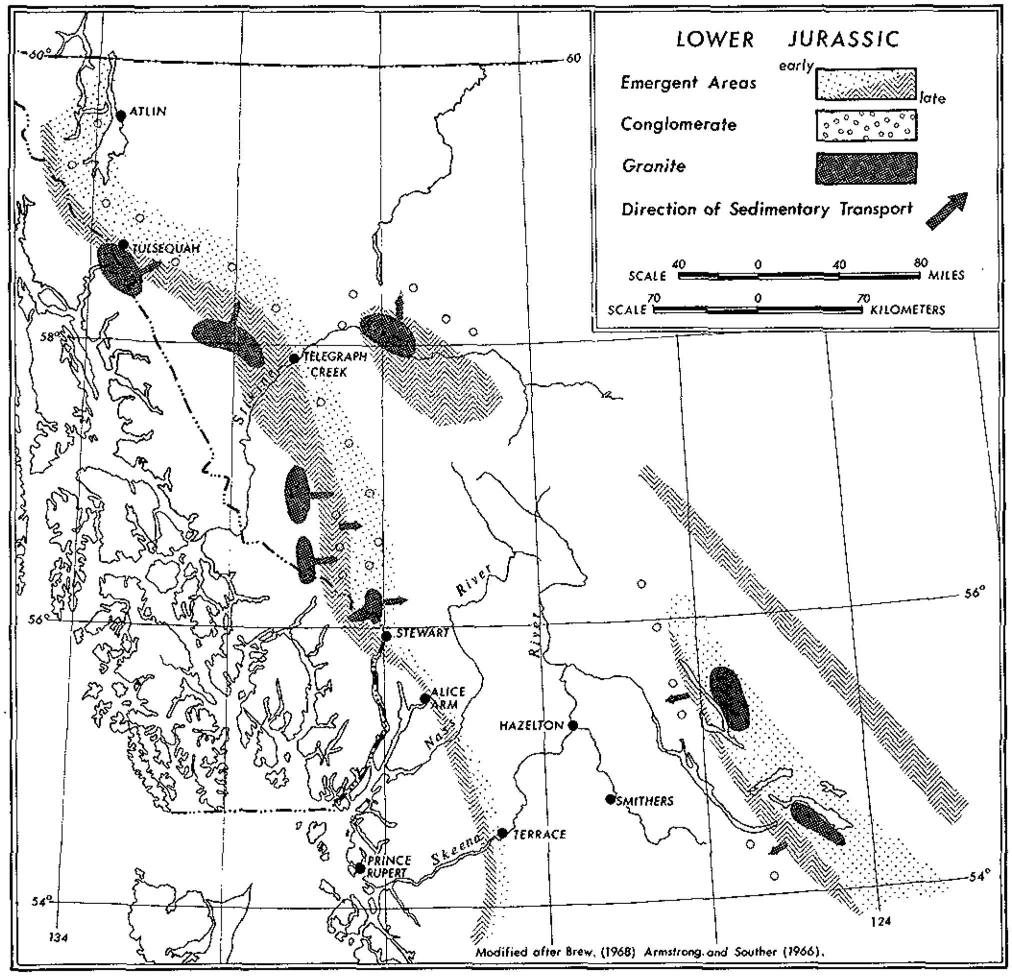


Figure 10. Paleogeographic map, Lower Jurassic, northwestern British Columbia.

Age: Rocks of the lower member of the Unuk River Formation contain an abundance of poorly preserved fossils. The collections have been examined by Professor W. R. Danner of The University of British Columbia who kindly made tentative identification and assessed their environment, and by Dr. H. Frebold of the Geological Survey of Canada, who examined the collections in detail. The dateable collections apparently represent Hetangian fauna; they are characterized by the presence of *Psiloceras canadense* Frebold and *Weyla* sp.

Along the crest of Twin John Peaks the lower member is unconformably overlain by the middle member of the formation; along strike the relationship changes to a disconformity at the south limit of the red conglomerates. Further south the middle and lower members are conformable. In the Storie Creek section a canoe-shaped trough of the Early Bajocian Betty Creek Formation overlies the lower member; elsewhere there are thin slabs of Betty Creek and blanket-like deposits of Salmon River Formation.

Middle Member: The middle member of the Unuk River Formation is exposed in the deformed section between Shirley Mountain, near Tom Mackay Lake, and Mount George Pearson. The succession presented is a composite section compiled from the Twin John Peaks-Mount Madge and Mount Einar Kvale-Mount George Pearson geological sections. Portions of the distinctive basal Twin John Peaks strata have been mapped east of Mount

George Pearson, where scattered nunataks are exposed; these indicate the extensive lateral continuity of the strata and provide stratigraphic control.

Conglomerates at the top of the lower member are channeled, eroded, and overlain by extensive thinly banded, black to buff carbonaceous siltstones that can be traced from Bruce Glacier south past Twin John Peaks into the icefield at Unuk Finger Mountain. The unit contains abundant moderately well-preserved fossils including large specimens of *Weyla* sp., as well as *Arieticeras* sp. indet., which suggests a Late Pliensbachian age. Tops in this section were determined from channel scouring, the presence of intraformational conglomerates, and graded bedding. The siltstone and underlying conglomerates were intruded by the Twin John Peaks hornblende diorite plug and show weak induration and foliation along contact margins. The siltstone is overlain by bright green volcanic tuffs, comparable to those in the lower member (Plate I); it is gradational into a thick epiclastic volcanic conglomerate and sandstone unit which includes the 150-metre-thick Fisheye sandstone which consists largely of spherulitic rhyolite and chert clasts (Plate II). This sandstone is best developed north of Twin John Peaks where it is laterally gradational with rhyolite breccia and finely banded rhyolite. The massive rhyolite breccia extends south past Twin John Peaks into the Sulphurets Creek area. Equivalent spherulitic rhyolite-chert sandstones have also been mapped in the icefield east of Mount George Pearson. Comparable rhyolitic units have been described by Buddington and Chapin (1929) in southeastern Alaska.

In thin section, the well-banded glassy white rhyolites and rhyolite breccias are seen to be altered to an irregular inhomogenous mixture of sericite and carbonate in which rare lath-like unzoned plagioclase (An_{20-25}) and rounded clear quartz phenocrysts are preserved. Rock fragments, chert, and minor pyrite are recognizable, but other primary structures or textures are obliterated. The apparent glassy nature of the hand specimens is false in thin section, and the fine banding so well displayed in the outcrops is related to microscopic ribbons of recrystallized quartz occurring as *en echelon* streaks through a felted matrix.

The Fisheye sandstones north of Twin John Peaks are only slightly altered and deformed. The 'eyes' in the rock occur either as separate, slightly flattened ovoids marked by lenticular central cavities and colourless grey chert fillings or as necklace-like aggregates enmeshed in a sandy, banded feldspathic matrix (Plate II). In thin section the eyes comprise an outer zone of closely packed beaded quartz, 1 to several centimetres thick, with infillings of plumose chalcedonic quartz. The weakly foliated matrix in the rock is mainly slightly altered sodic plagioclase.

The unit has been dated by fossils as probably Pliensbachian. It is unconformably overlain by Early Bajocian sediments, therefore folding of the Unuk River Formation was during Toarcian to Aalenian time. Toward the Lee Brant pluton, alteration and deformation in the rhyolite section increase. Alteration and deformation of this unit are complex and can be related to a basic pre-Middle Jurassic intrusion at Twin John Peaks, to pre-Bajocian regional folding, and to Tertiary plutonism. In addition, the degree of dynamic metamorphism increases toward the South Unuk cataclasite zone.

The Fisheye sandstone is overlain by a thinly striped, indurated, foliated carbonaceous siltstone, which is disconformably overlain by a generally featureless massive green volcanic conglomerate. A thick sequence of pillowed volcanic rocks (Figs. 2A and 2B) extend from Granduc Mountain to Twin John Peaks. It occurs as lenses within the green conglomerate sequence and near Twin John Peaks the lavas are intercalated in an extensive siltstone unit. The pillow lavas form discrete lenses up to 10 kilometres long and from about 200 to 2 000 metres thick. Although generally massive, the pillowed units include thinly laminated cherty lenticles, local siltstone lenses, and some limestone. Sedimentary structures in the enclosing volcaniclastic rocks and in local sedimentary lenses within the lavas indicate that the succession is upright; tops face west.

The pillowed units are a conspicuous part of the middle Unuk River Formation; they are uniform in structure and composition throughout. Individual pillows are tightly packed,

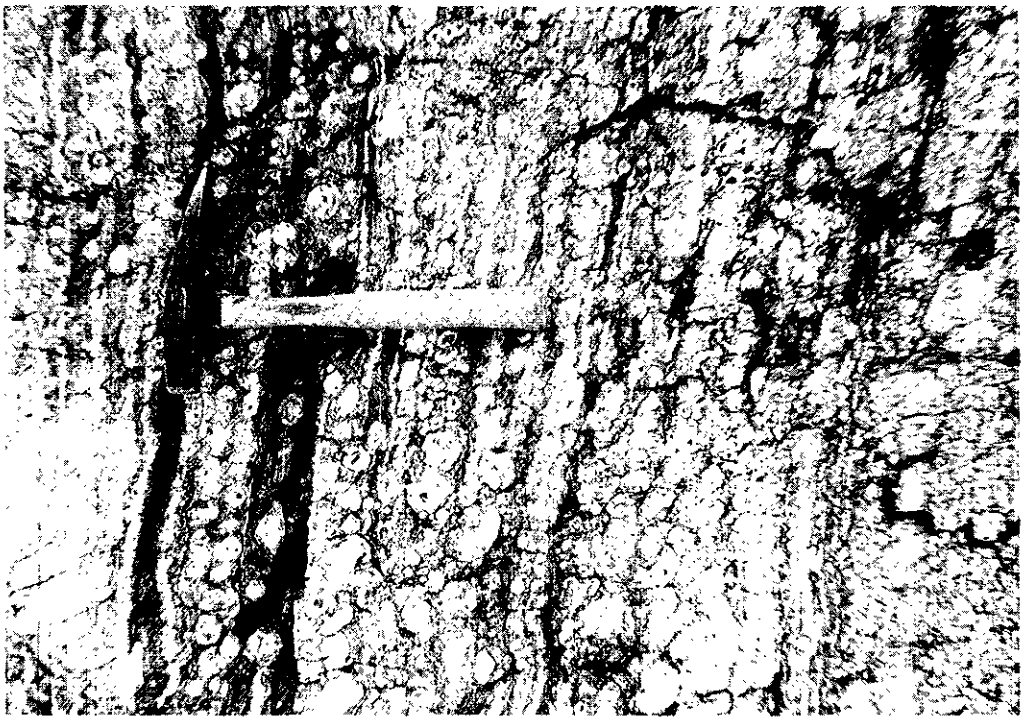


Plate II. Spherulitic (Fisheye) sandstone, Unuk River strata, Twin John Peaks area.

typically ellipsoidal, and average 1 metre in diameter. Pillows have a narrow, chilled rind or margin; openings within the pillows may be filled by vuggy coarse-grained quartz and epidote. The pillows are crudely jointed and although a weak radial pattern appears to dominate, the pillow margin has closely spaced, concentric joints. The pillows are highly vesicular; the vesicles or amygdules have generally coalesced, but individually are generally about 2 millimetres in diameter. In thin section even the freshest looking material is devitrified to a felted mass of cryptocrystalline amphibole, plagioclase, quartz, and epidote. It was not possible to determine the original mineralogy optically, but similarities in preserved textures and mineral remnants are similar to those of local andesitic basalt flows.

West of Twin John Peaks, at the northern extent of the zone of pillow lava lenses, the pillows lie in a fine-grained grey limestone matrix (Plate III). The pillows in the margins of the flows are 30 to 60 centimetres in diameter, with well-developed glassy, concentrically layered margins in part veined by the limestone matrix. These small pillows are mainly globular, amygdaloidal, highly altered, and isolated (Carlisle, 1963), in contrast to the bulk of the units, which consist of closely packed pillows.

The pillow lava units along the South Unuk River appear to be conformable within the largely andesitic volcanic conglomerate and graphitic siltstone sequence. This sequence also includes thinly banded, rhyolite lenses, thin recrystallized grey limestone bands, 30 to 120-centimetre-thick quartzite lenses, and thin-bedded quartz pebble conglomerates. The overlying succession includes a thick assemblage of thinly layered lenses of green to brown andesitic lithic and crystal tuffs, volcanic sandstone, banded chert and rhyolite, quartzite, volcanic conglomerate, and a multitude of limestone beds. The thickest limestone, the Gracey Creek lens, forms a 180-metre-thick band traceable from Sawyer Glacier north to Lee Brant Creek. Like most of the limestone lenses, it exhibits some local folding and boudinage. Where they are intercalated with carbonaceous siltstone and greywacke units some of the white and blue-grey limestone lenses have thin marginal zones partly or largely composed of fine-grained blue-grey gypsum plates. In general, the

Plate III. Pillow lava with limestone matrix, Unuk River strata.

limestone bands are recrystallized and characterized by a white-buff to blue-grey mottling. Partial chemical analyses of the limestones show that they contain less than 1 per cent MgO and very little iron.

The main characteristic of the middle member is the abundance of pillow lavas and limestone, which comprise 20 to 30 per cent of the section, and the diversity of the sequence. Rhyolite, chert, quartzite, volcanic tuff, siltstone, conglomerate, and thin, altered andesitic volcanic flows also occur. The rocks are generally grey or green in colour and have been moderately altered and deformed. Small plutons and numerous dykes cut the succession.

Provenance and Depositional Environment: The similarity of the basal sedimentary and volcanic rocks in this member to the upper part of the lower member suggests a continuation of periodic andesitic and basaltic volcanism with concommitant rapid erosion and deposition.

Pillow lavas are generally accepted as having been extruded under submarine conditions and Moore (1965) suggested that the vesicularity and bulk density of pillow lavas show a systematic change with depth. Jones (1969) pursued the use of pillow lavas as water depth indicators in Iceland. The average vesicle diameter measured in Unuk River pillow lavas is about 2 millimetres, which from the combined Moore-Jones plot of vesicular diameter against inferred depth (Jones, *op. cit.*, p. 188), indicates a water depth of about 300 metres.

Perhaps the gradation from large, closely packed pillows at Mount Madge, to small globular isolated pillows near Twin John Peaks along the northerly margin of the flows indicates the paleoslope down which the pillows rolled into limy mud. The rhyolites, rhyolite breccias, and spherulitic rhyolite zones are gradational and intercalated with tuffaceous units; they were deposited after the shallow water red and green strata. In sharp contrast to the dominantly red top of the lower member, middle member units are mainly grey and green. The carbonaceous shales, siltstones, and volcanic sandstones associated with the limestone lenses may indicate (Weeks, 1957) that decomposition of organic matter raised the pH locally and caused precipitation of limestone. There was also accompanying sulphate deposition, now partly represented by gypsum. Quartz pebble conglomerates and sandstones associated with the limestone and rhyolite are mature, reworked, possibly beach deposits, like those described by Shepard (1960) for the Mississippi Delta. The evidence suggests formation in a protected lagoonal or coastal barrier environment near a volcanic highland that intermittently supplied volcanic flows and volcaniclastics. The concentration and accumulation of the thick mixed sequence imply a crudely balanced rhythmic process.

Age: The basal section of the middle Unuk River Formation includes a moderately well-defined Pliensbachian fossil assemblage and is directly overlain in the Tom Mackay Lake section by Early Bajocian sediments. The relation to Toarcian members of the succession is poorly defined because of faulting, cataclastic deformation, and erosion along the western limit of the map-area, and by the ice cover southeast of the Treaty Glacier section.

Upper Member: The upper member of the Lower Jurassic Unuk River Formation has been separated from the middle and lower members on the basis of structural relationships and limited paleontological evidence. It is the most extensive of the three members and occurs west of Harrymel Creek between the Unuk and Iskut Rivers (shown on Map 9-1957 as mainly Upper Jurassic-Lower Cretaceous and as Triassic sediments and granodiorite). Another area is inferred to occur, on the basis of structural relationships, west of the Treaty Glacier section at Tim Williams Glacier, shown on Map 9-1957 as Late Jurassic-Cretaceous sediments. Abundant, moderately well-preserved, thin-shelled pelecypods and the ammonite *Dactylioceras* sp., collected from the Tim Williams Glacier area and specimens of Hildocerataceae from the Snippaker Creek area, provide paleontological evidence to support this structural interpretation. The correlation between the Tim Williams Glacier section, the Bowser River, Bear River Ridge, and Bear River Pass areas is based on structural and lithological relationships. The strata throughout this general area are similar in aspect and have not been as extensively deformed as at the Snippaker Creek area.

The Tim Williams section includes a fossiliferous, polymictic basal conglomerate intercalated with argillitic siltstones and overlain by a quartzose sandstone conglomerate with minor lithic and crystal tuff bands. The basal conglomerate consists of poorly sorted granodiorite, andesite, and basalt pebbles embedded in crudely layered, blocky, dark grey greywacke. The conglomerate forms beds and lenses from 1 to 3 metres thick. Upward, the pebble conglomerate grades rapidly into gently dipping grey-green greywacke and quartz granule conglomerate which also contains abundant fossil fragments. This bed is conformably overlain by massive green volcanic breccia and agglomerate, comprised of amygdaloidal and porphyritic andesitic fragments, with intercalated thinly banded lithic and lapilli tuffs, grey-green volcanic sandstone, and thinly bedded shale (Fig. 9). The measured thickness of this partly exposed unit is about 120 metres along the margin of the west fork of the glacier.

The Bear River Ridge section has been mapped in detail (Fig. 3, Grove, 1971). The rocks comprising the section have been described by McConnell (1913), Schofield and Hanson (1922), Westgate (1921), Hanson (1929), Buddington (1929), and Hanson (1935), as a thick sequence of shallow west-dipping greenstone, agglomerate, tuff, and/or breccia forming part of the Bear River Formation or Hazelton Group of unknown but probable Jurassic age (*see* Table 1). The internal structural relationships of the various units forming this sequence were not described by any of the early workers.

At Bear River Ridge the upper Unuk River is dominated by green-coloured, interfingering clastic sedimentary units of predominantly volcanic origin. Siltstones and lithic greywackes are intercalated with coarsely layered volcaniclastic rocks. The siltstones and greywackes provide local markers and define structures. The volcanic conglomerates, breccias, and sandstones have been differentiated by macroscopic features as well as structural contacts, but the fine-grained tuffs and cataclasites required microscopic study in order to clarify and discriminate the various rock types.

The geological map shows that the upper Unuk River Formation extends over most of the area, forming the steep valley walls. The formation is overlain with angular unconformity by younger sedimentary and volcanic rocks.

The majority of the country rocks in the Salmon River district, originally termed the Bear River volcanics, have been affected by dynamic metamorphism. In general, sufficient primary structures and textures are preserved to allow the sedimentary character of these rocks to be identified. The least altered and deformed strata lie east of Cascade Creek on the upper slopes of Bear River Ridge where they are unconformably overlain by Salmon River Formation sediments.

With rare exception undeformed Unuk River rocks in the Stewart district exhibit a clastic or fragmental texture and are poorly sorted. The fragments and matrix are generally composed of relatively uniform porphyritic andesitic rocks, angular quartz, and plagioclase. Individual lenses are distinguished by predominant particle size and colour, but few are homogeneous. Breccias, for example, include thin, fine-grained units and commonly grade laterally into conglomerate and sandstone with intercalated siltstone lenses.

A fairly typical volcanic breccia is illustrated in the Mount Dillworth area (Plate IV). The rock is purple breccia; porphyritic purplish cobble and boulder-sized fragments occur in a reddish purple sandstone matrix which forms less than 40 per cent of the rock. A second type, which marks the other extreme, consists of green angular boulders up to 1 metre long in a green sandstone-conglomerate matrix. All variations exist between these two extremes. Significantly, these coarse members stand up as cliffs and form the backbone of Bear River and other ridges.

Volcanic conglomerates and sandstones are present both as minor lenses in the breccias (Fig. 3, map unit H4, Grove, 1971) and as mappable units. Sandstones and conglomerates are prominent along Summit Lake, where they form thick green units with scattered thin siltstone, sandstone, and, rarely, lenticular green pebble conglomerate interlayers.

Volcanic sandstone and tuff are prominent in the upper member, occurring as thin-bedded, well-laminated strata. All the sandstones are relatively thin bedded and greenish with angular grains and poor sorting. Red sandstone lenses occur within green sandstone-conglomerate assemblages but are most prominent as intercalations in massive breccias.

Many of the volcanic sandstones and conglomerates of the upper member contain numerous angular plagioclase and hornblende clasts which, in well-indurated members, give the rock a porphyritic appearance. The hornblende clasts are ubiquitous in the green sandstones and conglomerates, but were not seen in the red beds. Sphene and apatite are common components in almost all the sandstones. Some of these sandstones may be lithic or crystal tuffs.

Few significant differences exist between epiclastic volcanics in the Bear River and those in the Salmon River valley. Exposure is limited by overlying sediments and snow, but there is sufficient continuity to show that the Bear River and the Salmon River valley sequences are part of the same assemblage.

Volcanic epiclastic rocks in the Salmon River district are fairly uniform in texture. Most of the rock clasts are fine-grained porphyritic andesite in which plagioclase is ubiquitous as lath-like phenocrysts. Quartz, plagioclase feldspar, and hornblende are typical mineral clasts. Only quartz, which is present in small amounts, is rounded. Hornblende is common as angular clasts but is generally altered to chlorite and difficult to distinguish from augite. Plagioclase is common to all the Hazelton epiclastic rocks; it has a relatively uniform

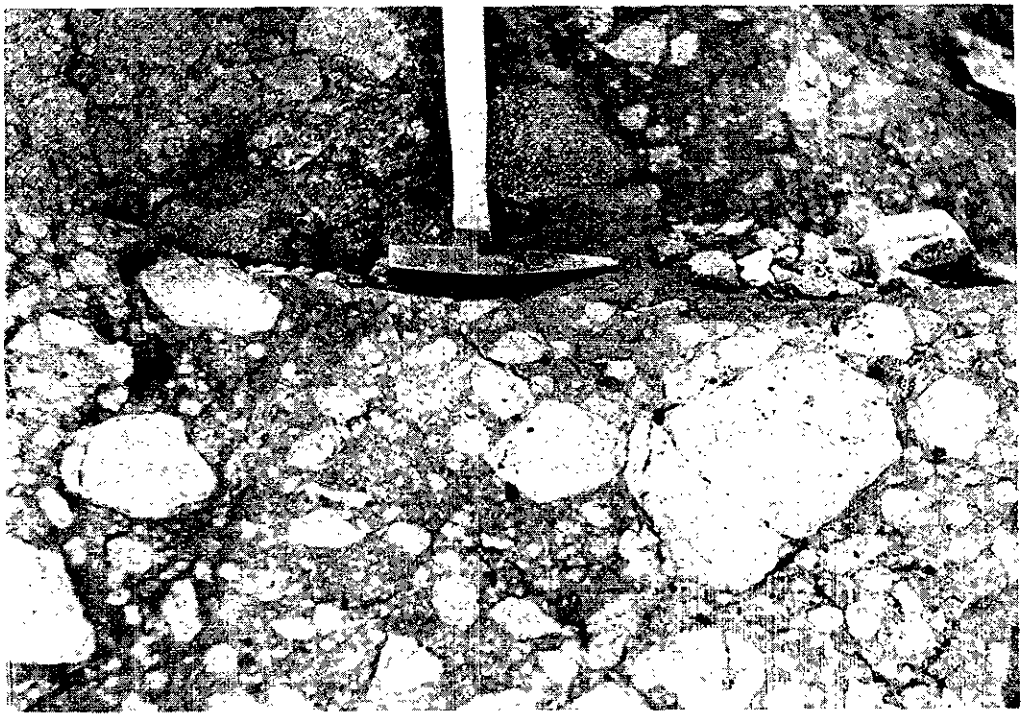


Plate IV. Volcanic breccia, Unuk River strata, Mount Dillworth area.

composition and ranges from An_{27} to An_{35} with the average $An_{32\pm2}$. This composition suggests an andesitic origin. Unlike plagioclases in the local igneous rocks, plagioclase in the epiclastics exhibits normal, not cyclic, zoning. Orthoclase and microcline clasts are rare in most of these rocks, but grains of zircon, apatite, and iron oxide are common. In some of the volcaniclastics the red and purple colour may indicate oxidation during deposition. Iron hydroxides are present in varying amounts in all the purple, red, and green epiclastic members. Although the amount of iron oxide has not been determined chemically, some samples contain up to 40 per cent by volume. Most of the epiclastics are relatively fresh, however, minor sericite, chlorite, and carbonate alteration is common in the clasts.

In the Bear River Pass area the sequence includes pyritic, propylitized, deformed, thick, fine-grained amygdaloidal andesitic volcanic flows that are irregularly intercalated with argillaceous siltstones. Near the top of the volcanic sequence, the thick flows give way to thin lenticular rhyolite, rhyodacite, and dacite flows within a thinly layered siltstone and greywacke sequence which is disconformably overlain by Betty Creek strata (Fig. 9).

Provenance and Depositional Environment: In the Stewart area the upper member of the Unuk River Formation is dominated by volcaniclastic units with lesser volcanic pyroclastic and flow units and minor fine-grained marine sedimentary units. At Bear River Ridge, various epiclastic volcanic units vary along strike from volcanic breccia to conglomerate to sandstone and siltstone. The evidence suggests that andesitic volcanism, marked by extensive thick, volcanic breccias, was concentrated immediately east of Bear River Ridge. Less extensive, thin volcanic flow sequences were recognized in the Tim Williams Glacier, Snippaker Creek, and Anyox areas. Most of the volcaniclastic debris in the upper member can be directly related to a northerly trending belt of extrusive rocks extending along Bear River valley toward Tim Williams Glacier. The southerly extension of the zone passes through the Georgie River and Anyox roof pendants where andesitic volcanic flows were apparently less extensive. Granodiorite pebbles that occur in the basal conglomerate at Tim Williams Glacier suggest that regional uplift and unroofing of the Coast Geanticline took place prior to andesitic volcanic activity. This belt of volcanic rocks roughly coincides with the later axis of regional doming, although the centre of activity appears to have shifted to the south relative to older, early Lower Jurassic volcanism.

Simple planar bedding is the dominant sedimentary structure in the volcaniclastic rocks which form the bulk of the upper member; rare current crossbedding, and occasional mud ball horizons occur in the finely grained units. Metamorphosed coal within the epiclastic material, extensive thick red beds in the upper section, and rhyolite flows suggest deposition in shallow brackish to marine conditions intimately associated with a linear shield-like volcanic highland.

Age: The lowermost part of the upper member of the Unuk River Formation contains abundant fossils that include the Lower Toarcian ammonite *Dactylioceras* sp., poorly preserved Hildocerataceae, and various thin-shelled pelecypods. The Unuk River Formation is unconformably to disconformably overlain by the Early Bajocian Betty Creek Formation, which marks the upper limit of local Lower Jurassic sedimentation and volcanism. The apparent lack of Aalenian fauna in the Stewart Complex as well as the relationship to the younger Betty Creek suggests a period of non-deposition between the Lower and Middle Jurassic epochs. Frebold and Tipper (1970) have not recorded the presence of Aalenian fossils in the Canadian Cordillera, but suggest (*op. cit.*, p. 16) that uplift and erosion could account for the apparent absence of the late Lower Jurassic beds (Table 2).

Discussion: The Lower Jurassic Unuk River Formation includes a thick succession of volcanic, volcaniclastic, and sedimentary rocks that range in age from Hettangian, through Sinemurian and Pliensbachian to Toarcian. The Hettangian lower member of the Unuk River Formation (Fig. 9) is the only well-defined sequence in the Canadian Cordillera that includes volcanic rocks (Frebold and Tipper, *op. cit.*, p. 9). No diagnostic Sinemurian fauna have yet been discovered but the presence of poorly preserved *Weyla* sp. (?) in the upper part of the lower member implies such a zone. Upper Pliensbachian strata, characterized by the presence of the ammonite *Arieticeras* sp. indet., are found west of Twin John Peaks in the lower part of the middle member of the Unuk River Formation. Toarcian rocks recognized at Treaty Glacier are characterized by the ammonite *Dactylioceras* (Frebold and Tipper, *op. cit.*, p. 6), and by poorly preserved specimens of Hildocerataceae.

The evidence presented indicates that Lower Jurassic strata of the Stewart Complex, in part represented by a great thickness and variety of volcanic rocks, were an area of relative stability (Frebold and Tipper, *op. cit.*, p. 18). It follows that the successor Bower Basin, which was initiated at the close of Late Triassic time, received a significant supply of detritus throughout most of the Lower Jurassic epoch from the extensive volcanic highland situated along the Coast geanticline (Figs. 6 and 10).

BETTY CREEK FORMATION (MAP UNITS 13 AND 14)

The Middle Jurassic Betty Creek Formation was first defined and mapped in the Stewart area and later extended throughout the Stewart Complex. Recognition of this unit and its stratigraphic relationship with the underlying Unuk River Formation has provided a key to understanding the tectonic development of the region.

Lithologic members comprising the Betty Creek Formation are shown on the geological map (Fig. 2) and in the stratigraphic column (Fig. 5). Because of excellent exposures and accessibility at Betty Creek it is proposed as a type area for this formation. The formation is characterized by planar bedded, bright red and green volcaniclastics, with sporadic, intercalated, andesitic volcanic flows, pillow lavas, chert, and carbonate lenses.

Distribution: The Betty Creek Formation occurs as structural remnants that unconformably overlie Upper Triassic and Lower Jurassic rocks from Iskut River to Alice Arm.

Plate VII. Pillow breccia, Betty Creek strata, Anyox area.

The pillow sequence may be as thick as 3 000 metres; this is an estimate based on the reconstructed geological sections. Diamond drilling in the Hidden Creek mine area has shown that both the pillow lavas and the overlying siltstones are at least 1 500 metres thick. The lavas are mainly extensively altered, olivine-green andesite and andesitic basalts. Individual pillows are about 1 metre in diameter, and interstices are commonly veined by coarse-grained quartz and epidote. The pillow rims are generally thin, although occasional rims are up to 4 centimetres thick. Radial jointing in pillows is uncommon and concentric joints, which are prominent in the Unuk River pillows, appear to be absent. Most pillows are amygdaloidal and porphyritic; the glassy content has been completely devitrified and largely replaced by alteration products. Plagioclase phenocrysts are generally too altered to determine closely but composition apparently ranges from about An_{40} to An_{60}. Amphibole pseudomorphs suggest the former presence of pyroxene; no olivine was observed. The rock now consists mainly of a very fine-grained, felted mass of acicular actinolite, scattered grains and clumps of epidote and plagioclase remnants, along with minor fresh brown biotite and accessory apatite, pyrite, and leucoxene. Plagioclase phenocrysts are euhedral, are 3 to 8 millimetres long, and comprise from 10 to 20 per cent of the rock. Because of alteration, pillows in the Anyox section show few recognizable vesicles or microvesicles, and may be comparable to Jones' (1969, p. 189) type-2 pillow lava which he suggested represent a final eruptive phase, which consists of degassed lavas extruded along the submerged flanks of emergent volcanoes.

Zones of isolated pillow breccia and broken pillow breccia occur mainly in the upper 600 metres of the sequence. These units are generally a few metres to 30 metres thick and form gradational zones within the closely packed pillow lavas. The transition between the pillow types is lateral along flow margins and between flows rather than a vertical transition as emphasized by Carlisle (1963, p. 55). Toward the top of the pillow sequence pillow flattening is more pronounced, broken pillow breccia more abundant, and tuffaceous lenses are common. Pillows become smaller upsection in certain areas, such as Bonanza Creek (Plate VIII), where the small pillows are immediately overlain by thinly

Plate VIII. Chert transition zone between Betty Creek pillow lava and Salmon River siltstone.

banded chert which in turn is gradational into Salmon River calcareous siltstone and greywacke. Elsewhere this contact is marked by carbonate zones and, locally, by disseminated pyrite-pyrrhotite mineralization. The major massive sulphide orebodies in the Anyox area are concentrated at or near this contact in the underlying cherty calcareous pillow lavas. Other pyrite-pyrrhotite-chalcopyrite mineralization found west of the contact is localized in the broken pillow breccia zones.

Provenance and Depositional Environment: The regional distribution pattern of volcanic flows and volcaniclastic rocks indicates that much of the material comprising the Betty Creek Formation has been extruded, eroded, and deposited locally. The thick piles of lavas appear to extend in a northerly direction through the Anyox pendant, roughly parallel to the axes of the major late Lower Jurassic folds. The depositional sites for the volcaniclastic debris were along the flanks of this eruptive zone and between the major volcanic centres.

The fossil collections from the Betty Creek Formation contain abundant triginoid pelecypods, as well as indeterminate fragments of other thick-shelled pelecypods which indicate a near-shore environment. The presence of scattered, metamorphosed coaly material throughout the clastic section also indicates intermittent shallow, perhaps brackish marine conditions. The configuration suggests isolated emergent shield-like volcanic centres surrounded by erosional debris shed into broad shallow flanking basins. During the late stage eruptive phases pillow lavas were vented locally along the margins from emergent or shallow submarine vents.

Age: The Betty Creek Formation overlies the eroded Toarcian Upper Unuk River Formation and is in turn overlain by the Middle Bajocian Salmon River Formation. Indeterminate pelecypods, belemnoids, gastropods, and deformed ammonoids are distributed through the greywacke strata in the Betty Creek sequence in most of the area north of Stewart. Diagnostic fossil assemblages from the Mitchell Creek section suggest the age of the Betty Creek Formation as either Lower or Middle Bajocian.

Souther (1970b) remapped part of the Spectrum Range and found that part of the extensive volcanic section in the Iskut River sector is Middle Jurassic on the basis of new fossil collections. This sequence, once thought to be Late Triassic in age, was included by Souther and Armstrong (1966) in a northerly trending pillow lava trough of Triassic age that also included the Unuk River and Anyox pillow volcanics. Souther's (*op. cit.*) data lend support to the writer's correlation of the Anyox pillow lavas with the Betty Creek Formation.

SALMON RIVER FORMATION (MAP UNITS 15 AND 16)

The Middle Jurassic Salmon River Formation was originally defined by Schofield and Hanson (1922, pp. 12-15) on the basis of mapping in the Salmon River district. They defined the type area as follows:

> This formation occupies a semicircular area around the southern base of Slate Mountain. The eastern edge of the mass passes under the slate exposed along the shores of Long Lake and on Bear Ridge; the western edge of the area extends northward as a narrow band which passes under the glacier that caps Mount Dilsworth. Another area of these rocks occupies the lower slopes of Big Missouri Ridge below the Fortynine group of mineral claims.

The type area was remapped in detail and the reported 100-metre conglomerate unit does not exist, although there are thin lenticular chert conglomerates lenses within argillaceous siltstones that unconformably overlie the Lower Jurassic volcaniclastic rocks in this section. The term Salmon River Formation is well established in the literature and has been retained by the writer for the complexly folded, thinly bedded, siltstone-greywacke sequence found in the original type area. Locally Schofield and Hanson (*op. cit.*, p. 13) applied the term Nass Formation to this unit apparently assuming it was a correlative of McConnell's (1913, pp. 17, 18) Nass Formation which was originally defined in the Bear River Pass-Meziadin Lake area (Fig. 2B).

The Mount Dillworth section was retained as the type area for the Salmon River Formation because it is adjacent to Betty Creek, and is now accessible from the Granduc road. The Salmon River Formation may be characterized as a thick assemblage of complexly folded, colour-banded, siltstones and lithic wackes, primarily of andesitic provenance (Fig. 5). The lower part of the succession is marked by extensive, thick lenses of grey-weathering greywacke, occasional thick littoral deposits, rhyolite, chert, and carbonate lenses.

Siltstones and sandstones of the Salmon River Formation were described in the earlier literature as the Bitter Creek Formation (McConnell, *op. cit.*, p. 6), the Nass Formation (Hanson, 1922, p. 13), the Salmon River Formation (Schofield and Hanson, 1922, p. 12), the Hazelton Group (Hanson, 1935, pp. 6–13), and the Bowser Group (Duffell and Souther, 1964). The rock package consists of argillite, slate, slaty argillite, shale, greywacke, and sandstone, with conglomerate, limestone, quartzite, tuff, and other minor components.

On the basis of the new interpretation of the Middle Jurassic sequence in the Stewart Complex, the paleogeography of the Bowser Basin has also been revised (Fig. 11).

Distribution: Salmon River strata occur as trough-like structural remnants within the Stewart Complex and overlie early Middle and Lower Jurassic and Triassic country rocks. The formation also extends along the easterly flank of the Stewart Complex where it forms a thick, overlapping apron-like cover on the older rocks (Fig. 2). Within the confines of the Bowser Basin, in the Smithers area, an equivalent unit has been outlined by Tipper (1971). Elsewhere no distinction has been made between the Salmon River Formation and the younger Nass Formation, and the Skeena Group.

Lithology: Conspicuously colour-banded, splintery to blocky weathering siltstones are the most common rocks in the Salmon River Formation. Generally, these rocks have been termed argillites, but under the microscope, clay-sized material appears to be restricted to the matrix and few are true argillites. The siltstones are grey, buff, and black, with dark

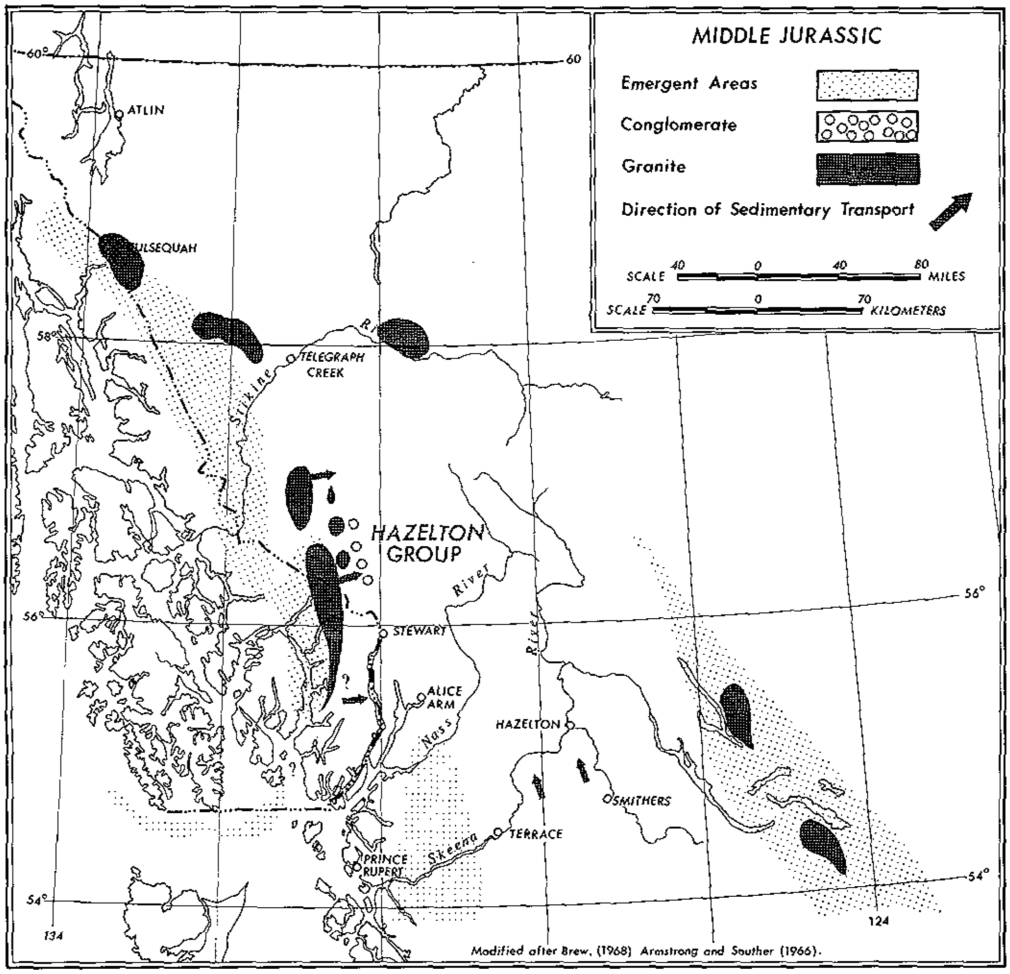


Figure 11. Paleogeographic map, Middle Jurassic, northwestern British Columbia.

greyish black most common. The colour generally changes with the grain size and approximate composition. Black zones are typically carbonaceous with high clay matrix and very fine silt-sized quartz, feldspar, and rock clasts. With an increase in the percentage of rock and mineral fragments and a decrease in clay and organic material, the colour fades from black, through grey to buff. Most are poorly sorted rocks with roughly equal quantities of very fine-grained material and rock fragments but thin lenses of well-sorted calcarenite and quartzite are interspersed within the siltstone sequence. These lenses are most prominent within the lower or basal siltstone member. Black and white chert pebble conglomerates occur within the basal siltstones on the ridge at the northwest end of Long Lake and along the west slope of Mount Dillworth. At Long Lake, these conglomerates form layers about 10 metres thick that are interbedded with banded siltstones. Elsewhere in the area, only thin layers of pebble conglomerate were noted, mostly in the main greywacke member.

In the Mount Dillworth-Divide Lake area, a poorly sorted, fossiliferous zone occurs at the base of the Salmon River Formation. This dark-coloured, poorly bedded, lenticular zone contains a large variety of pebble and cobble-sized sedimentary and vesicular volcanic fragments. This zone, first located by Schofield and Hanson (1922), has been extended north and south of Divide Lake by the writer, and fossils have been found on the west side of Mount Dillworth at the same horizon. The unsorted, irregular nature of this deposit and the abundance of thick-shelled pelecypods suggest deposition in a littoral zone.

Siltstones, minor pebble conglomerates, quartzites, and calcarenites persist over a fairly extensive area in the central part of the Stewart Complex. Without the conglomerate or the equally obvious Monitor Lake rhyolite member it would be difficult to delineate the base of the Salmon River Formation.

Two main areas of greywacke occur within the Mount Dillworth-Bear River Ridge section of the siltstone-sandstone sequence. Both areas flank Mount Dillworth and appear to merge, but continuity is obscured by heavy snow, high cliffs, and complex structure. Both areas of greywacke lie within the siltstone more than 100 metres stratigraphically above its base. These greywackes are predominantly dark grey, are wholly of volcanic derivation, and differ only in grain size from the siltstones. Feldspathic wackes, quartz greywackes, greywackes, and arkosic wackes are included in the sequence. Most of these rocks form fairly massive beds a few metres to a few tens of metres thick, that are interbedded with thin-bedded, striped siltstone. In the Mount Dillworth area greywackes comprise about 40 per cent of the Salmon River sequence. Thinly bedded, graded pebble conglomerates and siltstone breccias are common within the thick wackes. Without exception the greywackes appear to lens out; they are not recognized elsewhere in the Stewart Complex. Buddington (1929, pp. 20, 21) described similar greywacke zones in the Hyder district where they are intercalated with siltstones.

In general, Salmon River rocks in the Stewart area are only weakly indurated and locally phyllitic. Sporadic, fine-grained andalusite developed in thin-bedded argillaceous lenses suggests a regional low amphibolite grade of metamorphism. On Slate Mountain striped siltstones have been weakly metamorphosed to platy phyllites, not slates as the name of the mountain implies. Minor graphitic zones and faults are common but relatively unimportant except in relation to geophysical exploration methods.

Massive rhyolite and rhyolite breccias surrounding Monitor Lake represent the main area of these rocks recognized in the Salmon River Formation (Fig. 2B). Rhyolites noted by Hanson (1929, p. 8) in the Marmot River area are epiclastic volcanic sandstones and crystal tuffs. The rhyolitic rocks lie unconformably on Hazelton epiclastic sandstone and conglomerate and appear to be part of the lowermost Salmon River siltstone-greywacke sequence. The Monitor Lake rhyolite member is conspicuous because of the light, greyish green colour, scattered light buff plagioclase phenocrysts, and numerous pipe vesicles that traverse the rock. For the most part, the vesicles are perpendicular to layering and cross-sections are elliptical in the plane of a very weakly developed schistosity; the volume of the tubes amounts to about 10 per cent of the rock. The tubes average 5 millimetres in diameter and several centimetres in length. The rhyolite is composed of very fine-grained quartz and sodic plagioclase. Minor carbonate, sericite, and scattered chlorite were found in all thin sections studied. A similar rhyolite, about 2 metres thick, occurs in a sequence of finely bedded sandstones and conglomerates, at the northeast end of Divide Lake, also at the base of the Salmon River Formation.

At Monitor Lake the vesicular rhyolites are within a sequence of thin-bedded, fine-grained dolomitic limestone, sandstone, and striped siltstone. The total thickness of the zone is difficult to measure because of folding and the lenticular nature of the members; it is estimated to be about 700 metres (Fig. 5). Flow tops and flow banding suggest that individual flows average 3 to 4 metres in thickness. Several are intercalated with thin lenses of dense grey limestone; plagioclase and quartz clasts as well as rhyolite rock particles form about 1 per cent of the limestone. Under the microscope the limestone is seen to be a thinly laminated clastic rock with scattered dark spheres of probable organic origin that measure 0.2 millimetre in diameter. Judging from the fine silt intercalations and clastic textures, the limestones were deposited by stream action rather than as simple chemical precipitates.

The rhyolite breccia which underlies the thin-bedded rhyolite-limestone sequence is apparently 100 to 150 metres thick, but the very irregular nature of the deposit suggests that thickness varies due to the uneven topography of the underlying Hazelton epiclastic rocks. The breccia, which weathers white, is characterized by irregular, closely packed blocks. In outcrop and thin section rocks forming the breccia and the flows are similar in composition. Minor siltstone lenticles are common in the breccia and between the flows.

A lens, consisting of thinly laminated, tuffaceous, green sandstone and dolomitic limestone 20 to 30 metres thick, is well exposed on the west side of Troy Ridge. It lies between the Betty Creek red sandstone-conglomerate unit and the main Salmon River black siltstones and greywackes in approximately the same stratigraphic position as the Monitor Lake rhyolite-limestone-breccia member. This tuffaceous zone clearly illustrates the sedimentary nature of the sequence. Elsewhere in the region this stratigraphic interval is generally marked by a sharp and pronounced colour contrast, or by a disconformity.

Facies changes in the Salmon River Formation cause the stratigraphic section to vary in detail. In the Sulphurets Creek section, Betty Creek Formation has eroded and the base of the Salmon River is marked by a granodiorite boulder conglomerate which unconformably overlies the Unuk River Formation. At Anyox the thick, folded Salmon River Formation conformably or disconformably overlies the Betty Creek Formation. Apart from variations related to the local depositional environments, the Salmon River Formation appears to represent a broadly uniform, clastic marine sequence.

Provenance and Depositional Environment: The Salmon River Formation has not been subjected to a detailed paleocurrent study. The occurrence of the granodiorite pebbles and cobbles in the basal part of the Sulphurets Creek trough suggests an initial derivation from the nearby Coast Plutonic Complex which was probably unroofed for a short period at the close of Betty Creek volcanism. Crossbedding, slump folds, and bottom markings are observed in parts of the unit, but the section is complexly folded. Slump folds are common in argillaceous members but these are generally difficult to differentiate from tectonic units. In the northerly, marginal part of the Bowser Basin, Souther and Armstrong (1966) suggested that the presence of distinctive sedimentary rock clasts indicated transport of coarse clastics was from the north. Evidence from the Stewart Complex suggests that nearby volcanic highlands were the source areas.

The main Salmon River sequence appears to represent accumulation in a rapidly subsiding marine basin. Local concentrations of near-shore fossils, including fossil logs in the littoral deposits, suggest the presence of marine, brackish, and freshwater units as part of a repeated transitional sequence. The lack of cross-channel scouring of the coarse greywackes, pebble conglomerates, and boulder conglomerates into underlying siltstones and the presence of marked planar bedding of these units indicate deposition in shallow water. These appear to be similar to the floodplain deposits described by McKee, *et al.* (1967) at Bijou Creek, Colorado. Armoured mud balls are common in many of the argillaceous siltstone units overlying the conglomerates, again suggesting shallow marine conditions of deposition. The presence of extensive rhyolite flows at the base of the formation suggests shallow or even emergent extrusion of the rhyolite member with concomitant carbonate deposition and erosion prior to marine sedimentation. Limestone concretions within the basal siltstone sequence appear to be either secondary concretionary structures or early diagenetic features rather than primary carbonate beds.

Age: The Salmon River Formation rests unconformably on the Lower Jurassic Unuk River strata and conformably to disconformably on the Middle Jurassic Betty Creek sequence. Fossil assemblages, which are moderately abundant within the Salmon River strata, suggest an age ranging from Bajocian (or Bathonian) to Upper Callovian or Early Oxfordian (Table 2). Frebold and Tipper (1970) concluded that both the lower and upper parts of the Middle Bajocian are widely distributed in British Columbia and in the Rocky Mountains, where it is represented by the Rock Creek Member of the Fernie Group. They also indicated (Tipper, *op. cit.*, p. 12) that the Upper Callovian had not been found in the Canadian Cordillera. Several fossil collections from the Salmon River Formation have been identified as Early and Late Callovian. In certain conformable sections it appears that the Betty Creek and Salmon River strata represent an almost continuous depositional sequence that began in Early Bajocian and continued through Late Callovian into Late Oxfordian time (Table 2).

NASS FORMATION (MAP UNIT 17)

McConnell (1913, pp. 17, 18) described and defined the Upper Jurassic Nass Formation. It consists largely of weakly deformed dark argillites that are exposed on the mountain summits north and south of Bear River Pass and extend eastward to the Nass River and probably beyond. Hanson (1935) incorporated the formation into his revised Hazelton Group. Later the same rocks became part of the Bowser Group (Map 9-1957; Duffell and Souther, 1964).

McConnell's definition was essentially valid but his Nass Formation also included part of the writer's Salmon River Formation. The two units were originally separated on the basis of a granodiorite cobble conglomerate recognized in the Surprise Creek section (Fig. 2B). H. W. Tipper (personal communication) later indicated 'that the occurrence of this conglomerate below the *Buchia concentrica* zone (*see* Fig. 11) was identical to the occurrence in Taseko Lakes and Mount Waddington, and furthermore was analogous to Crickmay's (1925) stratigraphy in Harrison Lake'. As shown on the accompanying geological maps (Fig. 2), the Nass Formation includes part of the Bowser Group which Rigby (1969) has estimated to include more that 8 000 metres of thin-bedded mudstone and siltstone, thin to thick-bedded greywacke, massive to thick-bedded greywacke pebble to cobble conglomerate, and minor thin limestone, carbonaceous shale, and coal. Rigby (*op. cit.*) compiled his section along the northeastern margin of the Bowser Basin during a field study of the Tertiary Sustut Basin.

In the Stewart area, the Nass Formation unconformably to disconformably overlies the Salmon River Formation and contains Oxfordian to Kimmeridgian fossil assemblages. The top of the Nass Formation is not known in this area but at Skeena Crossing near Terrace, Upper Jurassic equivalents of the Nass Formation are unconformably overlain by rocks of Hauterivian age of the Lower Cretaceous Skeena Group (Tipper, personal communication).

The Nass Formation occurs only within the Bowser Basin; it is the main outcropping unit in the western part of the basin. At Surprise Creek, where an intraformational conglomerate separates the Salmon and Nass Formations, the Nass sequence is complexly folded, but approximately 600 metres of section are exposed. The 6-metre-thick conglomerate unit forming the base includes hornblende granodiorite cobbles and pebbles, chert pebbles, and greywacke and argillite fragments in a grey siltstone matrix. This is overlain by 1 to 3-metre-thick beds of fossiliferous, medium-grained calcareous sandstones within a 250-metre section comprised mainly of thin-banded, splintery weathering siltstones, with thin partings of black shale. The upper 375 metres is mainly thinly bedded grey to black blocky siltstone with occasional thin black shale partings and brachiopod fragments.

Provenance and Depositional Environment: The basal granodiorite conglomerate found along Surprise Creek suggests that the Texas Creek granodiorite, or similar Middle Jurassic plutons localized along the Coast Range geanticline, were unroofed prior to Nass sedimentation. Apart from this apparent easterly transport of material into the Bowser Basin, evidence at Oweegee Dome (Fig. 1) suggests local highland areas within the basin also shed material radially into the Bowser Basin (Fig. 12).

Nass Formation sediments represent deltaic accumulation of materials that are mostly reworked from older volcanic terranes. Local beds with abundant marine fossils are associated with fossil logs in conglomeratic members. The very even sandstone and

TABLE 2. CORRELATION TABLE FOR THE JURASSIC IN THE CANADIAN CORDILLERA

Epoch		Stage	Queen Charlotte and Vancouver Islands		Southern Yukon and British Columbia (North of Latitude 54°)	Southern British Columbia (South of Latitude 54°)	Unuk River—Salmon River—Anyox Area
LATE JURASSIC	TITHONIAN	Upper Tithonian	unknown	Unknown in Queen Charlotte Islands	*Buchia fischeriana* (Yukon)	*Buchia terebratuloides* *Buchia fischeriana*	?
		Portlandian = Lower Volgian	*Buchia blanfordiana* *B.* n. sp. aff. *piochii*		unknown	*Buchia piochii*	?
			Buchia mosquensis			*Buchia blanfordiana* *Buchia* n. sp. aff. *piochii*	?
		Upper Kimmeridgian	unknown			*Buchia mosquensis*	?
		Middle Kimmeridgian			*Buchia mosquensis?*		
		Lower Kimmeridgian Upper Oxfordian	*Buchia concentrica*		*Amoeboceras* *Buchia concentrica* (British Columbia)	*Buchia concentrica*	*Amoeboceras* Hyatt *Plasmatoceras* Buckman *Buchia concentrica*
		Lower Oxfordian	*Cardioceras*		*Cardioceras* (British Columbia)	*Cardioceras*	?
UPPER JURASSIC		Upper Callovian	unknown		?	unknown	*Cylindroteuthis* *Trigonia (Haidaia?)*
		Middle Callovian	*Cadoceras* (Vancouver Island)		*Lilloettia* *Cadoceras* (British Columbia)	*Lilloettia* *Cadoceras*	*Keraiceras* Spath
		Lower Callovian	*Kepplerites* (Queen Charlotte Islands)		*Paracadoceras* *Kepplerites* (British Columbia)	*Paracadoceras* *Kepplerites*	
		Bathonian Upper Bajocian	unknown		unknown	unknown	?
		Middle Bajocian	*Stephanoceras* *Teloceras* *Stemmatoceras* *Zemistephanus* *Chondroceras* (Queen Charlotte Islands) Volcanoes (Vancouver Island)		*Stephanoceras* (Yukon) *Stephanoceras* *Stemmatoceras* *Zemistephanus* *Chondroceras* *Sonninia* (British Columbia)	*Stephanoceras* *Stemmatoceras* *Zemistephanus* *Chondroceras* *Sonninia* *Graphoceras*	*Ctenostreon gikshanensis* McLearn *Sonninia* *Ostrea* *Pleuromya*
		Lower Bajocian	unknown		unknown	*Tmetoceras* *Erycites*	?

LOWER JURASSIC	Aalenian	?	?	?	?
	Upper Toarcian	?	*Grammoceras*	*Phlyseogrammoceras* *Grammoceras*	?
	Middle Toarcian		*Phymatoceras* *Peronoceras* (British Columbia)	?	*Haugia*
	Lower Toarcian	*Harpoceras* *Dactylioceras* (Queen Charlotte Islands)	*Dactylioceras*	*Harpoceras*	*Dactylioceras*
	Upper Pliensbachian	unknown	? - - - - - - - - - *Amaltheus* *Paltarpites* *Arieticeras* *Leptaleoceras*	unknown	?
	Lower Pliensbachian	*Fanninoceras* *Tropidoceras* *Crucilobiceras* *Acanthopleuroceras*	*Prodactylioceras* *Becheiceras* (British Columbia) *Platypleuroceras* (British Columbia)		
	Upper Sinemurian	*Echioceras* *Asteroceras*	unknown	*Echioceras* *Asteroceras*	
	Lower Sinemurian	*Arniotites*	*Paracoroniceras* *Arniotites*	*Coroniceras* *Arnioceras*	*Cardinia* *Weyla*
	Upper Hettangian	unknown	*Psiloceras canadense* (British Columbia)	*Psiloceras canadense*	*Psiloceras canadense* *Weyla* *Pleuromya* *Arieticeras*
	Lower Hettangian		*Psiloceras erugatus* (Yukon)	*Psiloceras* aff. *P.* *Planorbis*	?

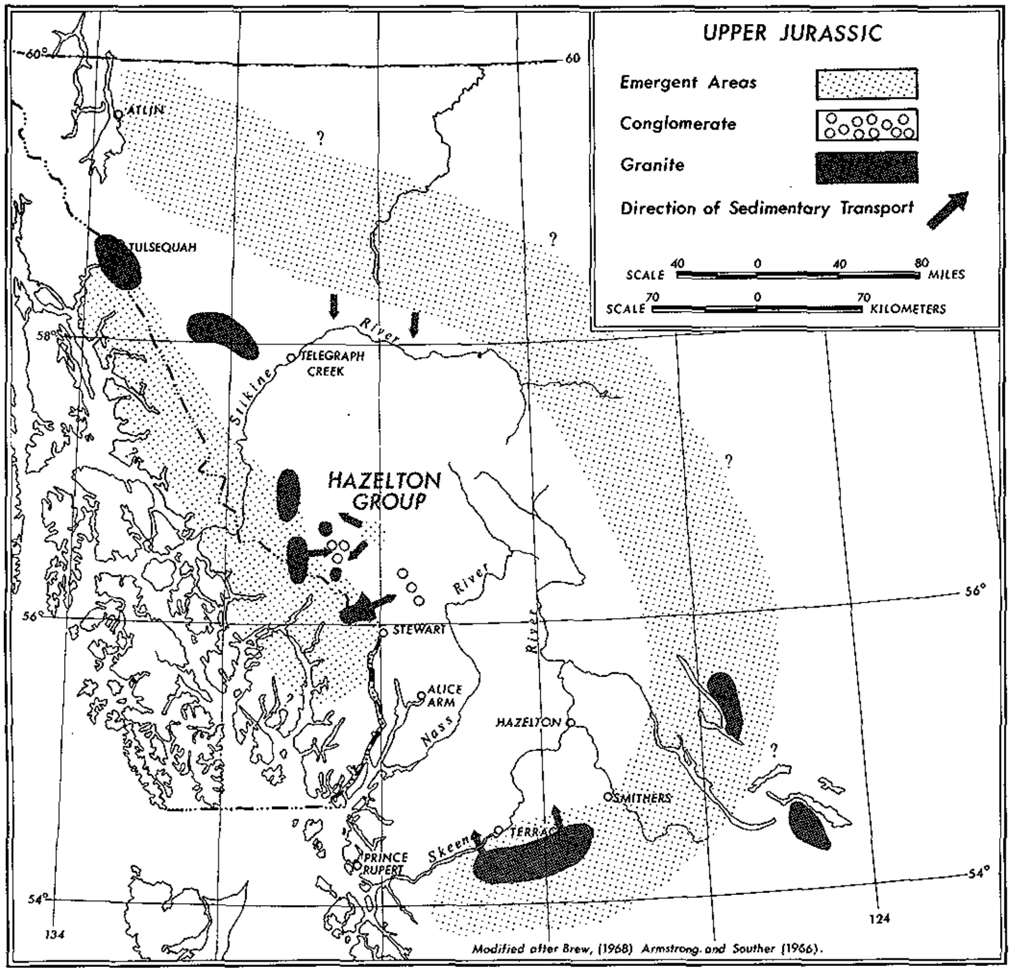


Figure 12. Paleogeographic map, Upper Jurassic, northwestern British Columbia.

conglomerate beds and lack of channeling in the underlying siltstones suggest deposition in relatively shallow water.

Age: The age of the Nass Formation, on the basis of local relationships and fossil assemblages, is Oxfordian to Kimmeridgian. On the basis of the relationships observed by Tipper at Skeena Crossing and in the Smithers area, the Nass Formation is unconformably overlain by the Hauterivian to Albian Skeena Group.

SKEENA GROUP

There are no known members of the Lower Cretaceous Skeena Group within the area of the Stewart Complex, although Fitzgerald (1960) suggested the presence of a thick, possibly correlative, unit along the east flank of the Ritchie anticline (Fig. 1). Tipper (personal communication) has described the Skeena Group as an essentially micaceous shale and sandstone unit, whereas the Nass Formation rocks contain very little mica and the Salmon River Formation rocks have no visible mica. Marine fossils are extremely rare, but the Skeena Group may be definitely identified by the presence of angiosperms. Tipper characterizes the Skeena Group as a monotonous shale-sandstone assemblage exhibiting a micaceous matrix, with no sedimentary structures, and containing significant coal deposits, such as those at Telkwa near Smithers.

QUATERNARY

There are at present no known active volcanoes in the Western Cordillera of British Columbia. In northwestern British Columbia, the abundant Cenozoic volcanics and hot spring deposits had generally been of passing interest until Souther's (1970a, b) detailed study of the Edziza Peak volcanic complex, located immediately southeast of Telegraph Creek. Holland (1964), in his presentation of the distribution of many of the Tertiary and Recent volcanic centres in British Columbia, showed that the main districts are in the Coast Mountains north of Vancouver and in the Stikine Plateau-Coast Mountain region north of Stewart.

The general location, distribution, and extent of Pleistocene and Recent volcanics are shown on Figure 1, with the detailed locations and outlines of the volcanic flows and cones shown on the Unuk River and Anyox map sheets (Figs. 2A and 2C).

Pleistocene and Recent volcanic rocks in the Alice Arm district form a spatially discrete group of basaltic flows and cinder cones that are localized along the southern limit of the Bear River Uplift (Fig. 1). Recent volcanic flows and cinder cones, shown on the Unuk River map sheet (Fig. 2A), form part of an extensive group of Cenozoic volcanic rocks that trends almost due north from Revillagigedo Island in southeastern Alaska along the Unuk River to the Stikine River at Telegraph Creek as far as the Yukon border. The Edziza Peak volcanic complex lies near the central part of this 450-kilometre-long linear cluster.

PLEISTOCENE AND EARLIER (MAP UNIT 18)

Seven areas of flat-lying basaltic lava flows are found east of Alice Arm. They unconformably overlie folded, eroded Nass Formation sediments and are remnants of a more extensive plateau unit which extended for at least 10 kilometres along the high land south of the Illiance River. The largest of these remnants forms Widdzech Mountain, which has an area of about 2.5 square kilometres and presents a steep-sided, mesa-like form, in sharp contrast to the surrounding rounded hills. The flows are flat-lying units of variable green colour, about 7 to 15 metres thick, and marked by prominent columnar joints. Carter (1964, 1968) described these rocks as basalts with trachytic and porphyritic textures with plagioclase (An_{40-60}) phenocrysts, that form up to 25 per cent of the rock, set in a fine-grained matrix of clinopyroxene, olivine, and magnetite. The relationship of the flows to the underlying country rocks is unconformable and well defined in the Clary Creek area where the contact is marked by angular breccia that includes country rock fragments in a scoriaceous matrix.

The age of these flows, determined by the whole rock, K/Ar method (Carter, personal communication), is about 1 000 000 years, or mid-Pleistocene. These basalts are the oldest Quaternary volcanics known in the area. The extensive Aiyansh alkali basalt flow (Figs. 1 and 13 in pocket), described by Sutherland Brown (1969), is of Recent age (220 ± 130 years) and is somewhat larger than the Iskut River flow.

RECENT (MAP UNIT 19)

Recent volcanic flows, cinder cones, hot springs, and ash sheets found within the limits of the study area are restricted to the Iskut River-Unuk River segment at the extreme northwest corner of the area. Several of these flows, including part of the Lava Lake flow (Fig. 2A), were first shown on Map 9-1957. The writer has added the Tom Mackay Lake, Len King Creek, Snippaker Creek, Fewright Creek, and Unuk River flows, cones, ash piles, and volcanic ejectamenta to the above group.

Volcanic Flows: All the Recent volcanic flows shown on the Unuk River map sheet (Fig. 2A) lie west of the prominent South Unuk cataclasite zone, one of the most extensive deformed belts within the Stewart Complex. These flows occupy topographic lows created by stream erosion and modified by Pleistocene and Recent glaciation. Two Recent flows located immediately south of Tom Mackay Lake, too small to be shown on the map, occupy small depressions and have a lateral extent of only a few hundred metres.

Most of the Recent flows appear to be related to single-phase, short-lived events that produced cinder cones with associated flows of blocky olivine basalt. The composition and aspect of the rock forming these flows are generally similar — vesicular, spongy looking, porphyritic black alkali olivine basalt. The uniform composition of the main flows is shown in Table 3 and on Figure 13. The matrix is typically fine grained with felted, acicular plagioclase forming the bulk of the rock. Fine-grained, angular fresh olivine is scattered through the matrix where it forms up to 8 per cent of the rock. Vesicles, which typically make up to 50 per cent of the rock, locally contain calcite and chert fillings. On a larger scale the flows are mainly simple with irregular surfaces, uneven thickness, and variably developed columnar jointing. The Unuk River flow is marked by a prominent steep margin at Border Lake where most of the pile comprises jagged, more or less vesiculated platy slabs and fragments, and compares to rubble lavas described from Sicily (Rittman, 1962) and Paricutin in Mexico.

The extensive Iskut River flows (Fig. 2A) have filled in the old drainage system and represent eruptive activity interspersed by erosion, glaciation, and sedimentation. Like most, the flows comprise blocky alkali olivine basalt. Whole rock age dates suggest the lowermost flows are about 70 000 years B.P. The upper flows and cinder cones are less than 10 000 years old suggesting two periods of activity at least.

The flow extending east from Cinder Mountain into Harrymel Creek is largely covered by a small glacier and its relation to the Cinder Mountain volcanic pile is uncertain. This flow is well exposed at the toe of the glacier. The flow consists of variably vesicular olivine basalt in which blocks of similar composition are visible. The flow surface has an irregular, ropy nature and the unit is marked by well-spaced columnar joints. It overlies a thin, irregular till-like unit which in turn overlies glaciated country rocks. The flow is itself overlain by till and varved clays which are now largely blanketed by the small glacier. Material from the basal till dated by the ^{14}C method suggests this flow sequence to be about 33 000 ± 2 000 years old.

The Cinder Mountain volcanic pile stands out against the ice and snow as a turreted, blunt spire, pocked with a multitude of small caves and holes. It represents a flat-lying accumulation of thin flow, ash, and pyroclastics of more or less uniform composition. Flows at the top of the pile are reddish grey, slightly friable, with calcite-chert amygdules up to 2 centimetres across, and prominent tubules of variable shape and size. In thin section the rock is seen to consist of felted, fine-grained plagioclase laths, irregularly replaced by fine-grained calcite and iron oxides. The amygdules consist entirely of medium to coarse-grained calcite which randomly contains central ovoids of chert. These flows do not contain any recognizable olivine or mafic minerals and appear to be more andesitic than the other Recent flows described (Fig. 13).

The Recent volcanic pile in Len King Creek canyon has a different profile from the Cinder Mountain flow, but relationships suggest a comparable sequence. Here the stream cuts through the edge of the basalt pile exposing part of the section. The creek bottom is overlain in part by varved clays and basal boulder clay about 6 metres thick. These are overlain by a 1-metre-thick, flat-lying, vesicular basalt flow which in turn is overlain by 3 metres of stony, well-banded clays. This basal section is overlain by several hundred metres of steeply piled vesicular basalt blocks, thin flows, and irregular pillow units. Most of these basalts are similar in general aspect and overall composition. The rock is generally black, with up to 50 per cent vesicles which rarely show any filling; the matrix contains fine-grained, lath-like plagioclase (An_{50-60}) and scattered fine-grained olivine. Coarse-grained plagioclase laths form randomly distributed phenocrysts between the ovoid vesicles. The overall features suggest this material was erupted against a glacier contact.

TABLE 3. CHEMICAL ANALYSES, NEOGENE VOLCANIC FLOWS

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
	11282M	11283M	11284M	11285M	11286M	11287M	11288M	11289M	11290M	11291M	11292M	11293M	11294M	11295M	11296M	11297M	11298M
SiO_2	47.3	46.6	46.6	46.1	46.6	47.3	46.8	46.6	48.9	40.9	50.7	50.7	49.1	48.0	49.3	50.0	50.1
Al_2O_3	16.6	15.5	15.1	15.9	15.1	17.8	17.4	17.0	15.9	15.9	16.6	16.3	15.9	15.9	16.7	16.6	16.6
Fe_2O_3	2.37	2.19	1.84	2.66	2.34	2.28	2.04	2.51	2.06	2.31	4.73	3.20	4.75	11.38	1.52	1.28	0.96
FeO	10.32	10.18	10.32	9.75	9.25	10.10	10.38	9.96	8.76	8.54	6.36	7.98	7.06	1.34	9.25	9.47	9.75
MgO	5.81	8.31	8.31	8.31	10.38	6.53	6.37	6.37	6.37	6.78	5.75	5.75	5.95	6.37	7.06	5.95	6.78
CaO	8.05	9.66	9.18	9.66	9.98	8.05	8.05	8.05	8.48	8.31	8.05	8.05	8.58	8.23	8.23	7.74	8.02
Na_2O	3.64	3.03	2.87	2.98	2.62	3.63	3.72	3.60	3.14	3.14	3.63	3.63	3.52	3.14	3.14	3.33	3.33
K_2O	1.07	0.90	0.90	0.87	0.75	0.90	1.07	1.07	1.16	1.02	1.04	1.07	0.87	0.83	0.75	0.90	0.87
H_2O+	0.25	0.51	0.48	0.38	0.25	0.29	0.12	0.03	0.77	0.47	0.31	0.17	0.18	0.62	0.29	0.57	0.25
H_2O-	0.02	0.09	0.44	0.18	0.10	0.11	0.19	0.03	0.33	0.34	0.07	0.03	0.10	0.12	0.02	0.19	0.11
CO_2	0.02	—	—	—	0.02	—	0.02	0.02	0.01	0.01	0.02	0.01	0.01	—	0.02	—	0.02
TiO_2	3.22	3.06	3.02	3.00	2.67	3.08	3.23	3.25	2.72	3.20	2.53	2.66	2.75	2.64	2.41	2.59	2.53
P_2O_5	0.49	0.37	0.32	0.03	0.28	0.39	0.47	0.39	0.62	0.39	0.42	0.34	0.34	0.31	0.29	0.35	0.31
S	0.03	0.02	0.02	0.03	0.01	0.02	0.02	0.02	0.04	0.01	—	—	—	0.01	—	—	—
MnO	0.17	0.18	0.18	0.18	0.18	0.18	0.18	0.18	0.18	0.18	0.18	0.18	0.18	0.18	0.18	0.18	0.18
TOTAL	99.36	100.60	99.58	100.29	100.53	100.74	100.06	99.36	99.44	100.50	100.39	100.07	99.29	99.07	99.26	99.15	99.87
Trace Elements (ppm) — Spectographic Analysis																	
Cu	ND	100	100	100	100	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
V	150	100	100	100	100	ND	100	100	100	100	100	100	100	100	150	150	200
Ni	ND	100	100	100	200	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Zr	250	200	250	200	200	250	200	250	250	200	300	350	200	300	200	200	250
Sr	600	400	500	500	300	600	500	600	500	400	500	400	500	400	400	500	700
B	200	200	200	200	200	200	200	200	400	400	400	400	250	250	250	300	300
Cr	ND	300	300	300	500	ND	ND	ND	200	200	100	100	100	100	150	100	ND

All specimen numbers refer to rock samples in the collection of the British Columbia Ministry of Energy, Mines and Petroleum Resources.

1 — Canyon Creek ash, Lava Fork vent.
2 — Unuk River flow, uper single flow.
3 — Unuk River flow, intermediate single flow.
4 — Unuk River flow, lower intermediate single flow.
5 — Unuk River slow, distal lower flow.
6 — Lava Fork, upper young rubble zone.
7 — Lava Fork, intermediate single flow.
8 — Lava Fork, lower single flow.
9 — King Creek, intermediate single flow.
10 — King Creek, lower single flow.
11 — Cinder Mountain, intermediate single flow.
12 — Cinder Mountain, lower intermediate single flow.
13 — Snippaker Creek, top single flow.
14 — Snippaker Creek, bottom single flow.
15 — Iskut River, bottom single flow.
16 — Iskut River, intermediate single flow.
17 — Iskut River, top single flow.

Analyses 1 to 17 by the Analytical Laboratory, Geological Survey Branch, British Columbia Ministry of Energy, Mines and Petroleum Resources.

The two small flows located due south of Tom Mackay Lake consist almost entirely of basaltic pillow lavas which grade laterally into breccia blocks and reworked marginal material. Both have small craters in which pipe-like breccia cores containing siltstone and sandstone blocks are mixed with the basalt. Both masses have diatreme-like characteristics and compare favourably with shallow-seated diatremes that occur in similar surficial environments (D. P. Gold, personal communication).

Volcanic Ash and Cinder Cones: Volcanic ash and cinder cones are prominent features at the head of Canyon Creek where they stand out against the snow, ice, and granitic country rocks. The glaciers flowing into Canyon Creek carry surficial debris formed by slides and are marked by several ash bands. Glassy basaltic ash was spread by westerly winds across the area and into the Leduc Glacier and Twin John Peaks area. This ash originated from the cinder cone vents along Lava Fork which probably last erupted in 1904. ^{14}C dates on the lower flows in Lava Fork indicated an age of about 130 B.P. making this sequence the youngest eruptives in Canada.

Summary: The evidence gathered from the Stewart Complex and adjacent areas indicates that Quaternary and Recent volcanism in this part of the Western Cordillera has been sporadic and spatially restricted to three main trends. The Alice Arm-Nass River volcanic district appears to represent a northeasterly trending belt, not previously recognized, in which alkali-olivine basalt volcanism has been active periodically during the Pleistocene and Recent epochs. This belt includes the 220-year-old Aiyansh flow, as well as the mid-Pleistocene Widdzech Mountain plateau basalts.

Flows in the Unuk-Iskut River section are mainly alkali olivine basalts of Neogene age. Relations with local glaciers and glacial sediments indicate that several separate pulses of extrusion occurred. Thermal springs at Julian Lake on Snippaker Creek and in the Len King Creek canyon are tepid sodium carbonate-sodium chloride, iron oxide-rich waters which, according to J. Berkosha (personal communication), have been flowing for at least 15 years, but are cooling and show a decreased flow. This group of Quaternary volcanic flows and thermal springs represents the south end of an extensive belt of Quaternary volcanics which extends north to Edziza Peak.

SURFICIAL DEPOSITS

The surficial deposits in the map-area are mainly in the river valleys, deltas, and along ice margins. Deposits on the hillsides are normally thin and deposits on the glaciers are scattered. Above timberline the glacial veneer is limited to rock rubble and erratics.

Marine silts, clays, and sands that are located in the Salmon and Bear River valleys and have been described by McConnell (1913, p. 22), Hanson (1929, p. 16), and Buddington (1929, p. 39) indicate that the Portland Canal district has undergone post-glacial uplift of at least 150 metres.

COAST PLUTONIC COMPLEX

The Coast Plutonic Complex presents the most extensive exposure of plutonic rock in the Canadian Cordillera and represents one of the largest post-Precambrian plutonic complexes in the world. This unit extends 1 800 kilometres from the southwest Yukon, through southeast Alaska and British Columbia, into Washington State. In width the complex ranges from 80 kilometres to a maximum of about 200 kilometres opposite the north end of Vancouver Island (Fig. 5). The complex has an area of approximately 150 000 square kilometres, of which an area of 110 000 square kilometres lies entirely in British Columbia. Physiographically, the complex is expressed as the Coast Mountains. The Coast Mountain system has been subdivided by Holland (1964) into the northern Boundary Ranges, central Kitimat Ranges, and southern Pacific Ranges. The central Kitimat Ranges present considerably lower summit elevations than the Boundary and Pacific Ranges and are conspicuous by the lack of large icefields.

In Buddington's (1959) review of granite emplacement he summarized his own work in southeastern Alaska with reference to the Coast Range batholith. He suggested (*op. cit.*, p. 702) that the intrusions in the northern Coast Range batholith were characteristic of bodies emplaced in the mesozone, that the southeastern part of the batholith and country rocks exhibit characteristics of the catazone, and that the northeastern part appears to belong to either the upper part of the mesozone or the lower part of the epizone. He also suggested that the Texas Creek granodiorite pluton at Hyder on the east side of the batholith (Portland Canal) is representative of the transitional epizonal-mesozonal type. Kerr (1948), who mapped the eastern margin of the Coast Range batholith in the vicinity of the Skeena and Iskut Rivers, suggested at least six to ten distinctive intrusive phases ranging in age from Triassic to Cretaceous. Buddington (*op. cit.*, p. 712) interpreted Kerr's youngest discordant phase as epizonal, the dome-shaped masses as mesozonal, and the Triassic hornblende diorite as catazonal intrusions.

Fieldwork between Observatory Inlet and the Iskut River (*see* Fig. 1) has delimited this portion of the Coast Plutonic Complex and defined the general composition and internal relations of the plutons, the presence of a previously unrecognized gneiss-migmatite complex, and the external relationships of the Coast Plutonic Complex with the country rocks. The overall relationships between the major elements of the geology are displayed on Figures 1 and 13 and on the geological maps.

Maps and reports by Hanson (1929, 1935), Schofield and Hanson (1922), and McConnell (1913) dealt briefly with plutonic rocks in the Portland Canal district at Hyder. Buddington (1929) recognized and described several phases and facies of the plutons and the relationships to country rocks; most significantly, he suggested a spatial relationship between one of the plutons and extensive mineralization in the adjacent Salmon River valley.

The writer has subdivided the eastern margin of the Coast Plutonic Complex into a number of intrusive phases. These include: the Texas Creek pluton of probable Middle Jurassic age; the Hyder pluton and related bodies of Tertiary age; and an undivided group comprising part of the Central Gneiss Complex. The contact zone of the marginal Texas Creek and Hyder intrusive phases with the Mesozoic country rocks has been mapped in detail but the limits of the Central Gneiss Complex, as well as its overall composition and structure, have only been examined on reconnaissance scale.

TEXAS CREEK PLUTON (MAP UNIT 6)

The Texas Creek phase of the Coast Plutonic Complex and related dyke rocks was first recognized and mapped as a distinct older intrusive phase by Buddington (1929), who separated it from the surrounding younger granitic intrusives on the basis of structural relationships. The pluton lies along and west of the Salmon River between Hyder and Summit Lake; the maximum westerly extent is near the terminus of the Chickamin Glacier, where the Frankmackie Icefield limits observation. The exposed area of the Texas Creek is about 200 square kilometres and is therefore intermediate in size when compared to the plutons in the Prince Rupert area (Hutchison, 1970). Buddington's map as well as his observations show that the contact of the Texas Creek granodiorite with intruded Hazelton Group country rocks is sharp and sinuous. The southerly igneous contact is similar but along Salmon Glacier the contact is extremely irregular and gradational (Grove, 1971).

The Texas Creek pluton is particularly well exposed along the steep hillsides above Salmon Glacier; the contact on the west slope of Bear River Ridge in the Silbak Premier mine area is well exposed along the Granduc road. The importance of the Texas Creek mass and its relationship to mineral deposits was pointed out by Buddington (*op. cit.*, pp. 22, 23), who also first recognized the significance of these plutonic rocks near the Premier orebodies:

'It is probable that the porphyries with which the Premier orebodies in British Columbia are associated are outlying stocks genetically associated with the Texas Creek batholith.'

The core of the main Texas Creek pluton is a foliated, medium-grained, porphyritic granodiorite. Rocks in the core zone are typically massive and mottled grey to greenish grey in colour; orthoclase phenocrysts up to 3 centimetres long comprise up to 15 per cent of the rock. Mafics make up 12 to 15 per cent of the core; dark green altered hornblende dominates but fine-grained brown biotite comprises up to 5 per cent. Accessory magnetite and sphene form about 1 per cent of the rock. In summary, the most noticeable characteristics of the core of the Texas Creek pluton are coarse pink orthoclase phenocrysts and coarse-grained dark brown hornblende crystals embedded in a generally grey, andesine plagioclase matrix. The mineral content is not uniform and macro-variations are commonly sharp (*see* Smith, 1977, for details).

Border Phase of the Texas Creek Pluton: Rocks referred to as Border phase are found along the margins of the Salmon Glacier. The contact zone is irregular and variable in both nature and composition, consisting not only of intrusive Texas Creek rocks but also of altered country rock inclusions and gradational, altered country rock equivalents. In this restricted area the general limits of the complex border zone lie between the lower slope of Big Missouri Ridge on the east and Cantu-Mount Bayard Ridge on the west. On the Alaska side, south of the Salmon Glacier, this contact zone is not as irregular or as complicated. In his paragraph on contact metamorphism, Buddington (*op. cit.*, p. 37) noted:

'One of the most amazing features of the geology of this district is the almost complete failure of the Texas Creek intrusives to produce any observable contact metamorphism in the country rock. This is more striking when contrasted with the contact-metamorphic effects which the Boundary granodiorite, the Hyder quartz monzonite, and their associated porphyry dykes have produced in the same kind of country rock and in the Texas Creek granodiorite itself.'

West of and along the Salmon Glacier, the border phase of the Texas Creek pluton has a generally green or muddy green, spotted appearance with irregular slashes of orange-red, representing zones of altered country rock inclusions. At the south end of Cantu Mountain, near the Mineral Hill inclusion zone, the granodiorite is fine to medium-grained, grey hornblende biotite granodiorite, similar in appearance to the core rocks. Away from the inclusions this phase grades rapidly into the green porphyritic hornblende granodiorite-quartz diorite border phase which extends north along the Salmon Glacier. The spotted or blotchy appearance is caused by the distribution of dark brown hornblende and pink-grey orthoclase phenocrysts. Quartz blebs up to 1 centimetre in diameter are common, but recognizable biotite is rare. Where weathered, the rock takes on a spotted light grey to almost white appearance, except in pyritic fractured zones where oxide coats the surface.

East of Salmon Glacier and Salmon River, the same mottled green Texas Creek border phase grades perceptibly into green Hazelton volcanic conglomerates. The outcrops are generally clean below the glacier trimline and the distinction between intrusive and country rocks is fairly clear. This is also true along the road section where the rock cuts are deep and exposure is almost continuous.

The essential distinctions between the core and marginal phases of the Texas Creek granodiorite are composition and colour. The grain size, porphyritic texture, and general structure are similar suggesting derivation from a simple intrusive mass. The border phase is distinguished by the green colour, the lower content of potash-feldspar phenocrysts, and the near absence of biotite. Buddington's (1929, p. 26) petrographic work suggested a deficiency of quartz in the contact facies when compared to the core of the pluton. Inspection of 25 thin sections from the core zone showed an average of about 20 per cent quartz, whereas the quartz content in 15 fairly fresh specimens from the Salmon Glacier border zone varied from about 10 per cent to 15 per cent. Late quartz as veins, veinlets, and interstitial blebs is a typical feature of the granodiorite along the contact and this, along with other alteration, has limited the usefulness of petrographic studies in this zone.

Generally, the border phase of the Texas Creek pluton possesses an overall uniformity of texture, grain size, mineral composition, and general mineral relationships. However, intense alteration of all the plagioclase to an intimate mixture of very fine-grained sericite and epidote with minor chlorite, carbonate, and biotite causes striking colour variations. Most of the perthitic orthoclase grains in the border phase are rimmed and veined by albite. Where the plagioclase is only partly altered, it has the composition about An_{40}. Within the gradational zone between plutonic material and recognizable Hazelton Group volcanic conglomerates, the plagioclase porphyroblasts are in the range An_{30-34}. As noted in the description of the epiclastic volcanic rocks in this area, the average plagioclase composition in these rocks was also about An_{32}.

In the Texas Creek-Salmon River area, the pluton is discordant with the steeply inclined northerly trending members of the Lower Jurassic Unuk River Formation. The steep contact zone, marked by limited induration and minor deformation developed in the country rocks, suggests a broad, westerly dipping, fairly flat roof. In his summary of granite emplacement, Buddington (1959) cited the Texas Creek granodiorite as representative of the transitional epizonal-mesozonal type of batholith. He cites (*op. cit.*, p. 694) the main reasons for this transitional classification are steeply discordant contacts and flat roofs, common aplite and pegmatite dykes in the contact zone only, and the presence of other associated aphanitic and porphyritic dykes, which are all indicative of epizonal plutonism. Observations that the Texas Creek mass is foliated and has intruded 'closely folded' country rocks were used as his criteria for a mesozonal character. Indeed, the easterly contact along Salmon River valley appears to fit his mesozonal classification more closely than he was aware, as is indicated by the complex emplacement-replacement relationships, extensive assimilation, and flaring walls.

Age of the Texas Creek Pluton: The age of the Texas Creek pluton cannot be determined closely from its external relationships with the sedimentary and volcanic contact rocks. The intrusion, deformation, and replacement of Lower Jurassic Unuk River Formation members suggest a maximum age of about 170 Ma, while the presence of equivalent granodiorite pebbles and cobbles in Lower Oxfordian Nass Formation members indicates a minimum age of about 145 Ma. Potassium-argon determinations on biotite from fresh Texas Creek granodiorite gave an age of 106 Ma; K/Ar determinations on hornblende from the same samples gave an age of 206 Ma (Table 3; Smith, personal communication). The best fit from the available information suggests that the age of the Texas Creek pluton is about 160 Ma, or Middle Jurassic. The Texas Creek pluton is probably genetically related to widespread Early to Middle Jurassic volcanism which, as previously outlined, includes extensive andesite-basalt pillow lava at Anyox and in the Bowser River-Treaty Creek section, as well as rhyolite at Monitor Lake and rhyolite flows in the Bear River Pass section. The evidence strongly suggests that emplacement of the Texas Creek pluton took place over a large period of time.

In the Sulphurets Creek section (Fig. 2A), the writer has described extensive biotite granodiorite pebble and cobble conglomerates in basal members of the Lower Middle Jurassic Salmon River Formation structural remnant. This granitic material is uniform and is unlike the Texas Creek rocks. This evidence suggests the presence of nearby Middle Jurassic (or older) plutons within the Coast Plutonic Complex other than the Texas Creek pluton.

The evidence presented here shows that the eastern margin of the Coast Plutonic Complex includes dykes, stocks, and batholiths of probable Lower and Middle Jurassic age. These plutons are generally granodiorite in composition with gradational phases of quartz diorite and are commonly similar in general aspect to the more extensive Tertiary plutons.

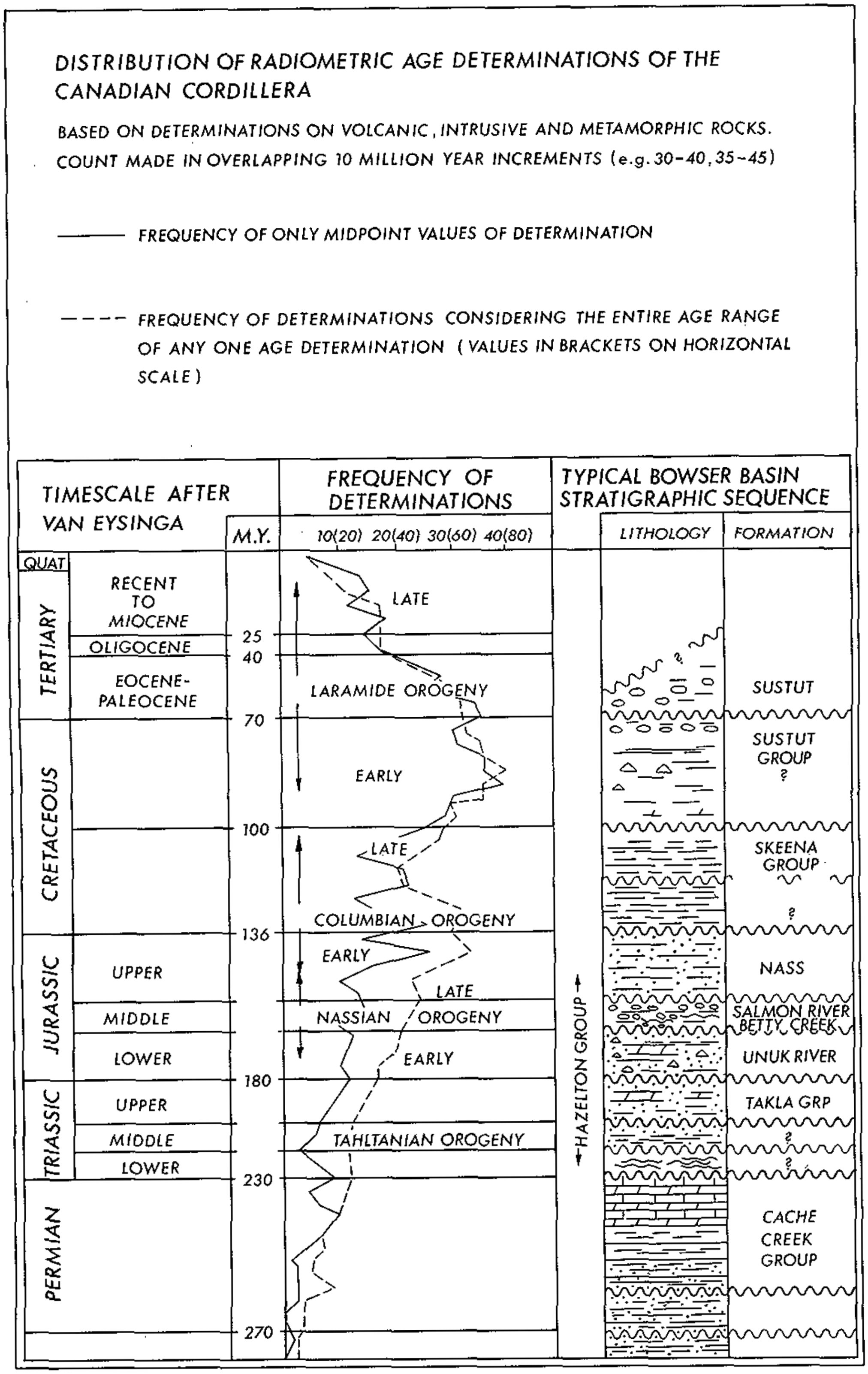


Figure 14. Distribution of radiometric age determinations in the Canadian Cordillera.

Pebbles and cobbles of granodiorite are localized at the contact between the Middle Jurassic Salmon River Formation and the Upper Jurassic Nass Formation (Fig. 12). This has been interpreted as an extensive erosional event affecting a large part of the Western Cordillera and has been generally referred to as the Nassian Orogeny (White, 1959). The writer suggests that Middle Jurassic plutons, represented by intrusive phases such as the Texas Creek granodiorite, are more widespread in the Coast Plutonic Complex than generally recognized (Fig. 14). It is also apparent that Middle Jurassic volcanism, represented by extensive pillow lavas at Anyox and Treaty Creek and by widespread andesites and rhyolites in the Stewart Complex, is more important than is generally understood.

HYDER PLUTON (MAP UNIT 7)

The Hyder pluton comprises part of the Coast Plutonic Complex and has been described by Hanson (1929, pp. 13–15) and Buddington (1929, pp. 29–32). At Hyder and Stewart the pluton is very well exposed in road cuts, and along the Salmon River, Bear River, and Portland Canal. Elsewhere the Hyder phase plutonic rocks are best exposed along tidal zones, canyons, and ridge crests. Access is only by helicopter or small boat to most of the outcrop area, and the tendency of the plutonic rocks to form rather steep, smooth valley walls greatly limits access. The Hyder pluton is extensive but is not known to contain any significant mineral deposits except in the Stewart, Hyder, and Anyox sections, therefore it has not been examined in detail. Overall the pluton is fairly uniform, although mapping at Stewart and Anyox has shown rapid mineral variations and gradations within small areas.

The Hyder pluton includes the zone of quartz monzonite and granodiorite that extends along the east margin of the plutonic complex from the Unuk River area, southeast along the Alaska border through the head of Portland Canal to Observatory Inlet and Alice Arm. The overall length of this zone is about 175 kilometres and the width of the zone, which varies from 12 to 32 kilometres, averages about 16 kilometres. The main bulk of the exposed Hyder pluton is limited on the west by the central gneiss-migmatite belt and on the east by Mesozoic country rocks. Similar rocks extend southerly into the Terrace area (Carter and Grove, 1972) and northerly into the Stikine River area (Kerr, 1948; Map 9-1957), where they are described as mainly quartz monzonite, granodiorite, and granite. The general limits of the main Hyder pluton are shown on Figure 13; this figure also shows an extensive swarm of satellitic plutonic masses located east of the main plutonic margin within the Stewart Complex. The satellite dykes, stocks, and plugs, some of which are correlatives of the Hyder pluton, will be described in a following section.

The Hyder pluton is distinguished from the older Texas Creek granodiorite on the basis of mineral composition and colour. The Hyder pluton is medium grained, porphyritic, and light pink to light grey, speckled with fine-grained black biotite or hornblende, or both. A predominantly biotitic phase lies north and west of Marmot Bay, while a hornblende-rich phase lies to the south and along the Marmot River. Buddington (1929, p. 30) also noted zoning west of the Salmon River, where the quartz monzonite grades into granodiorite that forms the interior of the Coast Plutonic Complex in this area.

The plagioclase, which forms from 20 to 55 per cent of the rock, is typically euhedral with strong oscillatory zoning; it is variably altered to very fine-grained sericite. The general composition of the plagioclase is about An_{36-38} but it ranges from An_{20} to An_{46} between the leucocratic to melanocratic phases. Potash feldspars, which commonly form large phenocrysts, generally consist of microcline and perthitic orthoclase; they form 25 to 55 per cent of the rock. The potash feldspar content varies from 65 per cent in leucocratic phases to 10 per cent in melanocratic phases.

Together, fine-grained biotite and fine to medium-grained hornblende comprise from 2 to 10 per cent of the rock; they are seldom extensively altered. In the fine, even-grained quartz monzonite near Hyder, the biotite is black and fine grained, whereas in the strongly porphyritic rock at Stewart, the brownish black biotite is medium to coarse grained. The gradation from porphyritic biotite quartz monzonite to hornblende granodiorite is readily apparent in the excellent rock exposures between Stewart and the Marmot River. The transition here from biotite to hornblende granodiorite is fairly sharp, and these phases of the Hyder pluton are distinct in aspect and composition from the Texas Creek pluton.

Accessory minerals common to the Hyder granodiorite quartz monzonite are apatite, magnetite, and sphene. Molybdenite has been noted as a frequent constituent, particularly in the quartz-rich, biotitic zones. The molybdenite commonly occurs as discrete flakes with quartz on joint surfaces, as discrete interstitial flakes with rosettes in quartz veins, and as veinlets criss-crossing small areas of the pluton. To date, with the exception of the few molybdenite occurrences just south of Anyox, there has been little interest in the Hyder pluton as an economic source of molybdenite.

The small, ovoid pluton which intrudes the Texas Creek pluton just west of the Salmon Glacier (Fig. 13 and Grove, 1971, Fig. 3) was originally mapped and named the Boundary granodiorite by Buddington (1929, pp. 32–38). He described the Boundary pluton as a massive, light-coloured rock predominantly composed of white plagioclase with scattered grains of pink orthoclase, glassy quartz, black biotite, and hornblende. Both the biotite and hornblende are euhedral, each forming 6 to 7 per cent of the rock and are partly replaced by the feldspars and quartz. The plagioclase is typically complexly zoned and has average composition of andesine. Alteration is widespread although weak and includes fine-grained chlorite, magnetite, and sericite. Buddington (*op. cit.*, p. 32) suggested that this unit represented a less advanced stage of differentiation than the Hyder pluton.

From Mount Bayard, near the contact of the Texas Creek and Boundary plutons, the Hyder pluton trends northwesterly in a sinuous manner. This trend leads into the Frankmackie Icefield, and the rocks in this extensive area are known only from scattered nunataks and ice margin exposures. Granitic rocks in this section are massive, white-weathering, pink, porphyritic biotite-hornblende granodiorites very comparable in aspect and composition to the Boundary granodiorite. Grey-white plagioclase, which forms about 45 to 50 per cent of the rock, is strongly zoned and ranges in composition from andesine to oligoclase. Pink orthoclase, which forms conspicuous phenocrysts and constitutes about 15 to 20 per cent of the rock, appears to be less abundant at country rock contacts where it is also finer grained. Glassy, interstitial quartz forms about 25 per cent of the rock. Biotite and hornblende together generally amount to 10 per cent or less, with hornblende commonly more prominent near the contact with the country rocks. The overall composition of the exposed Hyder pluton in this large area is probably granodiorite.

Age of the Hyder Pluton: Lithologic relationships between the Hyder pluton and country rocks indicate only that the batholith has intruded late Upper Jurassic sediments. However, absolute age determinations on samples taken from the Hyder phase in both the Stewart and Anyox-Alice Arm districts indicate Tertiary emplacement. Near Stewart age determinations by the United States Geological Survey using K/Ar methods gave dates from 47 to 51 Ma ($\pm$2-3 Ma) (Table 4). Regarding the Hyder pluton, Smith (personal communication) stated:

'Potassium argon determinations by the United States Geological Survey on five samples of granitic rocks from the Hyder area indicate two intrusive episodes. The younger episode took place 45–50 million years ago. The numbers for the Hyder and Boundary rocks are firm, but all we can say at this point about the Texas Creek is that the Texas Creek is older than the other Coast Mountain intrusions and its K/Ar clocks were affected by the 45–50 m.y. intrusions.'

In the Alice Arm district, Carter (1981) has made several age determinations on the Hyder plutonic phase using K/Ar equipment at The University of British Columbia. His results indicate a range of 48–51 Ma for the crystallization of the pluton.

TABLE 4. RADIOMETRIC AGE DATES, MIDDLE JURASSIC AND TERTIARY PLUTONS

Sample No.	Mineral	Age*(Ma)	Location and Unit
68ASj-52	Bio	49.2	United States-Canada border on Hyder-Stewart road; Hyder quartz monzonite.
68ASj-163	Bio	49.2	Small nunatack in Chickamin Glacier, about 1.5 kilometres north-northwest of Mount Jefferson Coolidge; Hyder quartz monzonite.
68ASj-163	Hbl	48.7	
68ADn-75	Bio	50.9	Ridge between Boundary Glacier and Texas Glacier; Boundary granodiorite.
68ADn-75	Hbl	43.7	
68ASj-196A	Bio	43.7	Porphyritic quartz monzonite, a separate intrusive from the Hyder quartz monzonite; mouth of Davis River.
68ASj-196A	Hbl	52.5	
68ASj-160	Bio	106.0	Texas Creek granodiorite; east side of Ferguson Glacier.
68ASj-160	Hbl	206.0	

* All analytical results ± 3 per cent.

DISCUSSION

Both the concept that the Coast Plutonic Complex includes mainly Upper Cretaceous and Eocene plutons (Roddick, 1966) and the older concept that the Coast Range batholith was a mainly Upper Jurassic-Lower Cretaceous event require modification. It is apparent that the Coast Plutonic Complex includes plutons ranging in age from Ordovician (?) to Tertiary. It is also apparent that unlike the Late Triassic to Late Cretaceous Sierra Nevada batholith (Kistler, *et al.*, 1971), which was emplaced along divergent linear trends, the Coast Plutonic Complex has evolved within a single, narrow belt. Kistler (*op. cit.*, 1971) suggested that the present positions of loci of age groups of batholithic rocks can be explained by the drift of the North American continent across a linear zone of high heat flow or by a heat source and continent moving relative to each other, and that magmatic events in the mantle instigated the massive introduction of granitic rock that form the Sierra Nevada batholith. Kuno (1959, 1966) and Dickinson (1968) related magma production to underthrusting of oceanic lithosphere. Hutchison (1970) suggested that the absence of ultrabasic rocks in the Coast Plutonic Complex indicates that there has been no appreciable direct contribution from the mantle. It therefore appears that the Coast Plutonic Complex has no direct similarity to the Sierra Nevada batholith and the question of its ultimate origin, as Hutchison (*op. cit.*) has stated, must await more detailed studies.

It is now generally presumed that the large composite batholiths of orogenic belts are emplaced in the upper crust beneath a cover of their own volcanic ejecta (Hamilton and Myers, 1967; Hamilton, 1969; Dickinson, 1970). This hypothesis assumes that the emplacement of plutonic rocks and the extrusion of volcanic rocks are roughly contemporaneous events, and that the parent magmas are cogenetic. Hutchison (1970) has supported this concept and suggested that the plutons of the Coast Mountains represent the roots of volcanoes. In the Stewart Complex, the Texas Creek pluton and the various Middle Jurassic volcanics appear to be very closely related in time and space, supporting the above hypothesis. James (1971) has also indicated that evidence from the volcanic-plutonic complexes of the Andes supports the theory of consanguineous intrusive and extrusive rocks. It is a reasonable conclusion that the thick andesitic volcaniclastic and volcanic Triassic and Jurassic assemblages found in the Stewart Complex are generally related to relatively shallow magmas.

CENTRAL GNEISS COMPLEX

Metamorphic rocks are concentrated in three areas: at the margin of the Stewart Complex, along the east contact of the Tertiary Hyder pluton, and west of the complex in the relatively unknown Alaska section. The bulk of the metamorphic rocks, which are in association with the Tertiary plutons, constitute the eastern margin of the Coast Plutonic Complex. Within

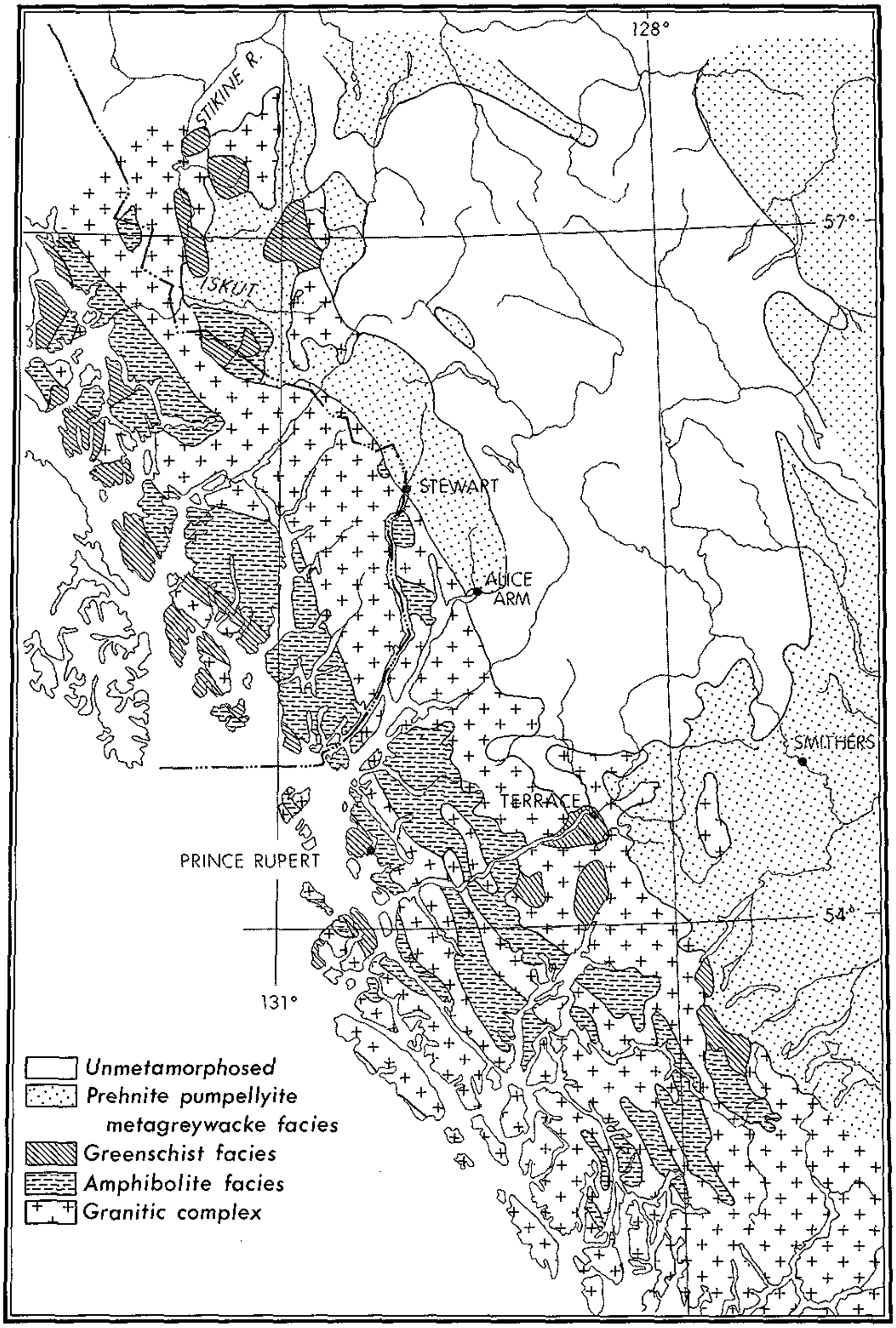


Figure 15. Metamorphic belts of northwestern British Columbia.

the complex the metamorphic rocks include mixed, banded gneiss, migmatite, and minor gneissic plutonic rocks.

The metamorphic map of the Canadian Cordillera compiled by Monger and Hutchinson (1971) illustrates the general northwesterly trend of metamorphic belts in the Coast Ranges of British Columbia. A simplified metamorphic map of part of the Western Cordillera (Fig. 15) has been included with this study to show the relative position of the Stewart Complex within the regional metamorphic environment.

Portland Canal Area: The Central Gneiss Complex extends to the contact with the Hyder pluton, this is, to within about 16 kilometres of the east margin of the Coast Plutonic Complex. The Portland Canal district includes a variety of gneisses, generally of a granodioritic to quartz monzonitic composition, marked by well-developed foliation, abundant microcline, and extensive quartz-rich zones.

The granitoid gneisses are mainly coarse-grained, equigranular, pinkish to grey, moderately well-foliated rocks that occur in northerly trending lenses; they are commonly gradational between augen gneiss and banded gneiss. The granitoid gneisses average 30 per cent quartz, 18 per cent microcline, 38 per cent plagioclase, and about 11 per cent biotite, with minor hornblende, apatite, sphene, and opaques. Quartz is generally interstitial and shows moderate undulatory extinction near contacts with augen gneisses, but is otherwise clear and undeformed. The plagioclase is euhedral, is rarely zoned, and shows considerable variation in the amount of sericitic alteration. The composition of the plagioclase is about An_{28}. Microcline typically shows grid twinning and generally replaces plagioclase along grain rims and cleavage planes. The microcline is variably porphyroblastic and 2V determinations with the universal stage give values between 84 degrees and 88 degrees. Biotite, in part moderately altered to chlorite, is dark brown to pale green in colour. The composition of these gneisses is usually that of granodiorite, although considerable variation toward quartz monzonite and more mafic-rich phases occurs.

Augen gneisses occur as gradational phases within the coarse-grained granitic gneisses and as lenses between grey gneisses and banded gneisses. The zones are generally difficult to trace, but excellent exposures are found at Hattie Island where it is reported that the augen gneiss was once quarried for headstones. The augen gneisses are generally pinkish, are very coarse grained, and occur as northerly trending lenses or bands. They are typically moderately foliated and concordant with the grey and banded gneisses; mineral lineation is rare. These contacts are commonly marked by local faulting. The augen gneiss, contains about 25 to 30 per cent quartz, 35 to 55 per cent microcline, 20 to 30 per cent plagioclase, 5 to 10 per cent biotite, and minor amounts of apatite, sphene, epidote, and opaques. The gneissic texture relates to the parallel development of the biotite folia, quartz stringers, and fine-grained aggregates of plagioclase and microcline. Microcline generally occurs as euhedral single crystal porphyroblasts, but variations and gradations to porphyroblastic aggregates are common. The microcline, which exhibits crosshatched twinning, generally appears to be the latest mineral to crystallize and form veinlets cutting plagioclase. Several 2V measurements on microcline gave results between 84 degrees and 86 degrees. The plagioclase is generally euhedral, weakly zoned, and altered; it has composition An_{28}. Biotite in these rocks is brown to light brown and commonly chloritized. The augen gneisses are principally leucocratic quartz monzonites although, like all granitic rocks in the area, they show rapid variations within short distances in both femic and mafic constituents.

Migmatites are well exposed along Portland Canal where they comprise up to 40 per cent of the gneiss complex. There may be two generations or more in this belt related to periodic anatexis and plutonism, but only one recognizable stage is conspicuous within the main zone. The Georgie River pendant (Fig. 2C) is cut by the Tertiary Hyder quartz monzonite and the margins of the pluton are enveloped by a 150-metre-wide agmatitic zone in which rotated blocks of indurated, hornfelsed country rocks are veined by a reticulate stockwork of quartzofeldspathic material. Within the main gneiss complex, the amount of migmatite appears to increase toward the southwest where, at the boundaries of the study area, broad zones of mixed mafic and granitic gneisses grade into rheomorphic breccia and agmatite complexes. Foliation in these gneissic zones swings rapidly and suggests gently dipping to flat-lying structures.

The most spectacular development of migmatite in the study area is found along Tauw Creek, near the southeast corner of the Anyox pendant, where a quartz-rich granitic stock penetrates the axial zone of the Hidden Creek syncline. The migmatite is exposed on the vertical canyon walls and consists of concentric shells; the outermost is indurated, generally biotitic siltstone; the inner shells are of quartz feldspathic gneiss, biotite schist, and coarse-grained quartz-microcline pegmatite.

Banded gneisses are prominent in the Belle Bay area, where they are intercalated with augen gneiss, grey gneiss, and migmatite. In these zones the dark-banded gneisses consist principally of medium-grained black biotite with variable quartz, plagioclase, and minor microcline. The leucocratic bands are fine grained and generally have a granodioritic composition.

Unuk River Area The small area of northerly trending gneisses shown on the Unuk River geology map (Unit 1, Fig. 2A) are the oldest rocks known in the study area. The gneisses are overlain by late Upper Triassic and Lower Jurassic country rocks with apparent fault relationships. Clasts of gneiss occur in the Hettangian member of the Unuk River Formation; these indicate the presence of a pre-Lower Jurassic metamorphic complex to the west. The adjoining area in southeastern Alaska has extensive snow and ice cover and has not yet been mapped. In the Unuk River-Leduc area, opposite Granduc Mountain, the metamorphic zone includes banded gneisses, transitional zones of augen gneiss, pegmatites, and swarms of dykes. Tertiary granitic plutons transect the gneisses and have narrow contact metamorphic aureoles. To the east, the gneisses are bounded by the South Unuk cataclasite zone, but the contact is hidden beneath the North and South Leduc Glaciers.

The gneisses are thinly layered, fine-grained, light and dark-coloured hornblende biotite gneisses. The mafic-rich gneisses are interbanded with coarse-grained, thick-layered granitoid gneiss and augen gneiss; they are cut by irregular tourmaline-bearing, quartz-rich pegmatites. The hornblende gneisses are fine grained and dark coloured, with mafic layers generally about 1 centimetre wide. The quartz content ranges from 5 to 35 per cent; plagioclase, which is typically unzoned with composition about An_{26} to An_{28}, comprises 25 to 40 per cent; hornblende is dark brown to bluish green, commonly altered to biotite, chlorite, and epidote, and forms up to 45 per cent of the melanocratic layers. In leucocratic layers, brown biotite ranges from 5 to 15 per cent and hornblende forms up to 10 per cent, although much has been altered to epidote, chlorite, and magnetite. In granitoid bands, biotite is the dominant mafic mineral and microcline forms from 30 to 50 per cent of the weakly foliated layers. Plagioclase in these units, which has a composition of about An_{28}, is typically fresh and unzoned. The augen gneisses are marked by clump porphyroblasts of microcline and are quartz rich; medium-grained biotite and plagioclase comprise the matrix. The gneisses vary considerably in mineral content, but most are granodiorite gneisses.

Discussion: Hutchison (1970) concluded that the pattern of metamorphism in the Coast Plutonic Complex is typical of progressive regional metamorphism and, from west to east, ranges from greenschist facies through to amphibolite facies. The eastern limit of the highest grade, sillimanite-cordierite zone, extends roughly from Ransden Point (where Portland Canal joins Observatory Inlet), southeasterly to the Skeena River (Fig. 15). The gneisses east of this line along Portland Canal and Observeratory Inlet contain mineral assemblages, including biotite and K-feldspar, that represent amphibolite facies regional metamorphism (Miyashiro, 1967, p. 278). Sporadic andalusite in the Middle Jurassic siltstone at Anyox, which is related to pre-Tertiary regional metamorphism, also indicates amphibolite facies of regional metamorphism (Miyashiro, 1961, p. 279; Turner, 1968).

If, as Hutchison (1970) has suggested, these regional metamorphic mineral assemblages are all part of one facies series, then the assemblages lie within the Barrovian facies series of Hietanen (1967). If andalusite found at Anyox is a regional metamorphic mineral, then local assemblages lie in the slightly lower pressure Idahoan facies series (Miyashiro, 1967, pp. 284, 285). As Hutchison (*op. cit.*) pointed out, this long, narrow complex belt has probably evolved through several regional metamorphic cycles, repeated plutonism and sequential block uplift.

The gneisses in the Unuk River and Portland Canal areas are similar. The two areas are now completely separated by the Hyder pluton, but may formerly have been joined. If this interpretation is correct, then gneisses west of Anyox along the Portland Canal are at least pre-Early Jurassic in age, and may, like the Unuk River zone, be Middle Triassic or older.

Souther and Armstrong (1966) and Souther (1971) suggested a Middle Triassic or older age for regionally metamorphosed strata in the Tulsequah area. Evidence of a probable pre-Devonian crystalline complex in the northern Cascades (Misch, 1966) and the pre-Devonian metamorphic complex in southeastern Alaska (Brew, *et al.*, 1966) gives an approximate age for the beginning of evolution of the Coast Plutonic Complex. The evidence previously cited, indicating at least two younger periods of regional metamorphism, suggests a continuous evolution within the gneiss complex that is related to polyphase plutonism.

SATELLITE PLUTONS

An extensive concentration of satellite plutons occurs at the eastern margin of the Coast Plutonic Complex in the map-area. The location of these bodies and their relation to major tectonic elements are shown on Figures 1 and 13. This concentration of such diverse plutons was found to be spatially restricted to the Stewart Complex, and confined to a belt bounded on the west by the Coast Plutonic Complex and on the east by the Meziadin Hinge.

The length of the satellite pluton belt between Alice Arm and the Iskut River is about 175 kilometres and the width, which varies from 16 to 40 kilometres, has its maximum in the Unuk River area and its minimum at Alice Arm. The belt parallels the margin of the north-northwesterly trending Coast Plutonic Complex and transects the northerly grain of the country rocks. Many of the individual plutons are semi-concordant, whereas major dyke swarms trend northwesterly and northeasterly and are strongly discordant with the local fabric. The plutons, which range in age from Late Triassic to Late Tertiary, have a wide range of rock compositions, from gabbro to syenite, diorite, quartz diorite, granodiorite, and quartz monzonite. Many of these satellite plutons have related metallic sulphide mineralization and one, the Lime Creek pluton near Alice Arm, has been mined. Because of their large number, the satellite plutons will be described according to groups.

UPPER TRIASSIC (MAP UNIT 4)

The McQuillan Ridge pluton is an elongate, irregular, northerly trending mass which is fairly well exposed along the north end of McQuillan Ridge, above Cebuck Creek, and on the high cliffs above the Unuk River. It has a length of about 10 kilometres and a width from 1 to 2 kilometres. The pluton exhibits gradational zoning from massive, coarse-grained, white-weathering quartz diorite in the centre to medium-grained hornblende diorite at its south end. Although the northern part is poorly exposed and has been cataclastically deformed, it is thought to be principally melanocratic granodiorite. In the field the contact between the country rocks and the pluton is locally sharp but, along the southeastern margin, the pluton grades into altered, stratified, volcanic conglomerates over a distance of several hundred metres. Adjacent to the pluton the country rock is hornfelsed in a generally narrow zone with conspicuous euhedral brown hornblende. Near the contact the hornblende crystals in the pluton are from 1 to 3 centimetres long; 15 metres from the contact they are only 1 to 2 millimitres long.

The McQuillan Ridge pluton is inferred to be Upper Triassic from stratigraphic relationships. Country rocks intruded by the pluton contain *Halobia* sp. and are of Karnian age. Pebbles, cobbles, and boulders of hornblende granodiorite, identical with material forming the pluton, are found in a thick Lower Jurassic conglomerate near Twin John Peaks (Fig. 2A). The presence of other Triassic plutons along the eastern margin of the Coast Plutonic Complex also lends support to the Late Triassic age assigned to the McQuillan Ridge pluton.

A large massive magnetite-chalcopyrite skarn deposit lies above Cebuck Creek immediately adjacent to the McQuillan Ridge pluton where limestone member localized mineralization. The pluton, mineral zone, and country rocks are deformed, but the spatial relationships of the intrusive and skarn zone have generally been assumed to represent a contact metamorphic association.

LOWER JURASSIC (MAP UNIT 5)

Several small plutons that are apparently of an Early Jurassic age have been mapped in the western part of the Unuk River map sheet (Figs. 2A, 13). These include deformed hornblende diorites along the South Unuk River, small syenite masses at Sawyer Glacier, a syenodiorite complex at Mitchell and Sulphurets Creeks, hornblende gabbro plutons at Twin John Peaks and Len King Creek, and a small pipe-like gabbro pluton at Nickel Mountain.

The Nickel Mountain pluton and the syenodiorite complex at Mitchell and Sulphurets Creeks have undergone extensive exploration by mining companies because of associated mineralization. The altered nickeliferous gabbro pluton at Nickel Mountain has been studied by Jeffrey (1966) and the Michell-Sulphurets syenodiorite complex has been studied by Kirkham (1968). Other plutons in this group were originally mapped by various mining companies during the course of detailed mineral exploration studies. This group of plutons has been called the Unuk River Intrusions by Norman (personal communication) who directed mineral exploration for the Granduc company during 1959 and 1960.

The hornblende diorite plutons just north of Granduc Mountain intruded Early Jurassic and older country rocks and lie along the South Unuk cataclasite zone. These plutons are entirely discordant and characterized by well-developed gneissic banding and mineral differentiation. The mineral components include crushed brown hornblende, plagioclase (An^{45-60}) with minor quartz, and accessory apatite, sphene, and magnetite. There are no known mineral occurrences related to these intrusions.

The two syenite stocks at Sawyer Glacier lie within the South Unuk cataclasite zone and are highly deformed. These rocks consist almost entirely of red, perthitic microcline which exhibits grid twinning and is triclinic maximum microcline. The rock is weakly sericitic, but principally appears to have suffered intense cataclasis. Fragments within the finely crushed matrix include stretched microcline and ribbon grains up to 20 centimetres long. Both plutons cut across mixed Lower Jurassic sediments and volcanics with no apparent metasomatism or contact metamorphism. Copper and molybdenum mineralization is present in the country rocks, but is not directly related to the syenites.

The syenodiorite complex in the Mitchell-Sulphurets area is a zoned intrusion grading transitionally from diorite at the south end through monzonite, syenite, and quartz monzonite to alaskite granite at the north end (Kirkham, *op. cit.*). The elongate, dyke-like pluton is surrounded by a broad alteration halo, characterized by coarse-grained porphyroblastic orthoclase, quartz, sericite, talc, and pyrite. The alteration zone, which is developed in Lower Jurassic epiclastic volcanics and tuffaceous sandstones, includes disseminated copper, vein-type molybdenite, and gold-silver mineralization (Grove, 1968).

The age of the Unuk River Intrusions has been inferred on the basis of stratigraphic relationships. The hornblende diorite and syenite plutons intrude Lower Jurassic sediments and volcanics but have been affected by late Lower Jurassic deformation. The gabbroic plutons have intruded Lower Jurassic country rocks. The syenodiorite pluton, which intruded the middle member of the Unuk River Formation, was partly eroded, then covered by Middle Jurassic strata. The general relationships between these plutons and the country rocks indicate that intrusion was completed before the onset of late Lower Jurassic-pre-Middle Jurassic erosion.

TERTIARY OR OLDER (MAP UNIT 8)

Kitsault Intrusions: This group includes five small plutons that occur along a narrow, northwesterly trending belt between Alice Arm and Teigen Creek. They are irregular in shape and are discordant with the country rocks. The plutons are cut by numerous lamprophyre and diorite dykes. They are characterized by a porphyritic texture and extensive alteration, and they are generally accompanied by minor mineralization. The rock varies considerably in texture and apparent composition. Where relatively fresh, the rock is greenish grey, with medium-grained plagioclase phenocrysts set in a matrix crowded with fine-grained plagioclase crystals of 1 to 2-millimetre size, which are about An_{30}, altered biotite, and fine-grained quartz. Generally pervasive carbonate-sericite alteration produced a greenish pyritic rock. These rocks are texturally and compositionally similar to the Premier dykes which are described in a later section.

Mineralization associated with these plutons includes disseminated and replacement chalcopyrite-pyrite in the adjacent country rocks, as well as minor quartz-sulphide fissure veins within the plutons. No major mineral deposits have been found with the Kitsault Intrusions.

The age of these plutons is difficult to determine. They intrude Middle Jurassic Salmon River strata and are cut by Oligocene dyke swarms. At the present they are considered to be Tertiary but like the Glacier Creek plutons may represent Cretaceous plutonism.

Glacier Creek Intrusions (Map Unit 8): Porphyritic augite diorite stocks are found at Glacier Creek, at Long Lake, and at the entrance to Bear River Pass. The distribution of this rock type is shown on Figures 2 and 13.

In appearance these augite diorites are distinguishable from the nearby Texas Creek and Hyder batholithic masses, as well as from the many satellite plutons found within the marginal belt. The rock is massive, dark brownish green, and spotted by coarse euhedral crystals of dark brown altered augite, which commonly forms 15 to 25 per cent of the mass. The matrix is generally fine to medium grained and dark green. Apart from the augite phenocrysts the mineral content of the rock is difficult to determine macroscopically; its uniform appearance from area to area is impressive.

Thin-section studies of these dark green rocks reveal that most of the component minerals are altered. Generally, augite is partly replaced by chlorite and sheaf-like bundles of fine-grained quartz. The matrix commonly consists of a very fine-grained felted mass of secondary sericite, black oxides, epidote, and plagioclase. The rock is cut by hairline veinlets of quartz and calcite. Pyrite is disseminated throughout both the matrix and phenocrysts. Preserved pyroxene and plagioclase have been determined as augite and calcic andesine (Grove, 1971; Plate XIVA). Primary quartz and alkali feldspar were not recognized although Hanson (*op. cit.*, p. 13) refers to orthoclase as a primary constituent and terms the rock on Glacier Creek augite syenite. Although the Glacier Creek plutons have been called augite diorite for the sake of simplicity, both monzonitic and syenitic phases occur.

These plutons are fairly small in outcrop areas but, in the Glacier Creek section just northeast of Stewart, outliers and bleached, indurated siltstones in deep cuts and gulches imply a larger mass at shallow depth. Contacts with stratified country rocks are apparently concordant but close observation of the contact zones shows many sill-like and even dyke-like apophyses.

The Glacier Creek plutons intruded Middle Jurassic Salmon River Formation rocks and, in turn, were intruded by numerous Tertiary granitic and lamprophyre dykes. Until other evidence is collected, these plutons are therefore assigned an Early Tertiary age.

These plutons are cut by *en echelon* groups of coarse, milky white vuggy quartz veins with local sulphide pods and shoots. Many of these veins have been extensively explored, but no major deposits have been found to date. A number of vein-like, transitional replacement, quartz-sulphide deposits have also been discovered in the country rocks immediately adjacent to the Glacier Creek stock.

TERTIARY

Large satellitic Tertiary plutons and extensive Tertiary dyke swarms are similar in composition to the Hyder pluton. These include the Lee Brant Creek stock, Summit Lake stock, Bitter Creek stock, and Strohn Creek stock (Figs. 2, 13). Each has an elongate, ameboid form and sharp, steep, discordant contacts with narrow biotite or hornblende hornfels zones. The hornfels is cut by numerous offshoot dykes and sills. For purposes of description these four plutons are grouped as the Divelbliss Creek Intrusions, largely because of similarity in size, spatial relationships, and apparent lack of known significant mineralization.

The Alice Arm Intrusions comprise at least 20 small stocks and plug-like intrusives south of the Divelbliss Creek group of stocks. The intrusions are similar in size and composition and often have significant associated molybdenite mineralization. They are quartz monzonites, with sharp, steep, intrusive contacts and narrow biotite hornfels contact zones; most are less than 1 kilometre in diameter. The best known of this group is the Lime Creek stock which has been mined for molybdenite.

Divelbliss Creek Intrusions — LEE BRANT PLUTON: This pluton or stock is the largest of the group, with a length of 12 kilometres and an average width of 3 kilometres. It lies east of the South Unuk River and is partly cut by Lee Brant and Divelbliss Creeks where the rock is moderately well exposed. The west edge of the Frankmackie Icefield and several small glaciers overlap the main body leaving only small parts accessible for study.

The rock is a massive, coarse to medium-grained, grey-weathering, pinkish quartz monzonite; it is closely jointed and sheds large slabs into the small valleys. The colour index of the rock is generally less than 10, and coarse-grained fresh biotite predominates. Hornblende, which is usually present, is medium grained; locally it is the dominant mafic constituent near intrusive margins. The plagioclase is weakly altered, shows strong reversed oscillatory zoning, and occasionally exhibits resorbed grain boundaries. Perthitic orthoclase is preserved as large phenocrysts and, with quartz, forms the interstitial matrix partly replacing plagioclase. The biotite is reddish brown, fresh, and present as randomly oriented euhedral crystals. The accessory minerals are pyrite, magnetite, apatite, and angular sphene as crystals and clumps up to 3 millimetres long.

The stock sharply cuts surrounding country rocks; contacts are digitating and narrow hornfelsic zones developed in adjoining Unuk River and Salmon River Formations. At Lee Brant Creek hornfelsed epiclastic volcanic conglomerates, sandstones, and siltstones form a zone 1 kilometre wide that is marked by a general induration and erratic development of fine-grained brown hornblende. At Divelbliss Creek the country rocks are crossed by numerous medium-grained hornblende diorite dykes that are offshoots of the pluton. The east marginal contact is weakly sheared, with some pyrite, pyrrhotite, and minor chalcopyrite mineralization exposed in a small re-entrant south of Unuk Finger Mountain. Along the southeast margin of the pluton the contacts are sharp, there are extensive dykes, and the country rock is little altered or deformed. Like the major plutons in the area the Lee Brant pluton contact relationships suggest passive emplacement in an epizonal environment.

Summit Lake Pluton: The Summit Lake granodiorite pluton has been included with the Divelbliss Creek intrusions mainly because it has similar size, contact relationships, general aspect, and composition (Figs. 2B, 13). However, it has some differences. The Summit Lake pluton is about 6 kilometres long and 2 kilometres wide; the long axis is oriented easterly, approximately at right angles to the trend of the country rock and the orientation of virtually all the other satellitic stocks. It differs also from the Divelbliss and Alice Arm Intrusions in that the predominant mafic constituent is coarse-grained hornblende, and biotite is a minor constituent (Grove, 1971, Plate XIVB).

The pluton is well exposed near Summit Lake; access from the Granduc road and from the Granduc tunnel at elevation 754 metres is good (Fig. 3). Approximately 6 kilometres of the stock is exposed in the tunnel and this section was sampled at 150-metre intervals. This stock is therefore one of the most thoroughly studied plutons in the area. In the tunnel section, almost continuous gradations and variations in colour and quartz content occurred over distances of only a few metres; no particular mineral trend was apparent. Only one small sulphide-bearing quartz vein was intersected in the tunnel. Small, generally hand-sized, inclusions of fine-grained, indurated country rock appear to form about 25 per cent of the stock in the tunnel section. Joint sets are variably oriented and generally widely spaced.

Alteration of the plagioclase, hornblende, and biotite is extensive. Plagioclase in less altered zones is andesine. The euhedral hornblende is almost entirely altered to a spotted, fuzzy aggregate of chlorite, calcite, quartz, and occasional epidote. The biotite is altered to chlorite, quartz, and iron oxides but retains its characteristic book-like form. Together, the altered hornblende and biotite form from 5 to 35 per cent of the rock; hornblende comprises 2 to 25 per cent. The grain size of both the hornblende and biotite varies continuously from about 5 to 15 millimetres, with the coarse material localized in the western part of the stock. As noted, the quartz content is variable, ranging from 15 to 35 per cent. Unlike most of the plutons described in this study, accessory minerals are rare.

The contact of this pluton with Hazelton Group country rocks is clearly intrusive and is marked by a narrow pyritic, indurated zone at its west end and an irregular broad alteration zone at the north end of Summit Lake. In the latter, brown hornblende crystals up to 10 centimetres long developed in epiclastic volcanic conglomerates at the contact; fine-grained secondary hornblende occurs in sediments up to 1 kilometre east of the contact.

The Summit Lake pluton intruded Middle Jurassic Salmon River Formation rocks, and in turn was cut by a variety of Late Tertiary dykes and quartz veins. Although grouped with the Divelbliss Creek intrusions, it could be an outlier of the Middle Jurassic Texas Creek, or one of the younger Cretaceous-Tertiary plutons. No mineral deposits are known to be directly related to this pluton.

Bitter Creek Pluton: The Bitter Creek pluton and related granitic dykes that form the extensive Portland Canal dyke swarms (Fig. 13) have been exposed by deep erosion along the Bear River valley. Rock exposures in road cuts are excellent and there is a small quarry on the road near the south margin of the pluton.

The Bitter Creek pluton is marked by impressive variations in texture and apparent composition. At the quarry site the rock is a uniform grey to mottled pinkish grey granite speckled with black biotite; it is generally coarse grained and invariably porphyritic along the contacts. In this zone the rock is fresh, typically hypidiomorphic, with perthite forming up to 65 per cent by volume, plagioclase (An_{20-22}) about 51 per cent, quartz about 20 per cent, slightly chloritic biotite about 1 per cent, and sphene, apatite, and black opaque minerals present in only minor amounts. Molybdenite is mainly in quartz veinlets filling hairline fractures and has not been found in commercial quantities.

Northward, toward the central portion of the stock, the texture changes gradually from coarse-grained granitic to fine-grained porphyritic quartz monzonite. Only quartz blebs up to 3 millimetres and fine-grained greenish biotite are recognizable in hand specimens of the porphyry. Microscopically, the porphyry consists mainly of quartz and microcline-perthite as phenocrysts in a very fine-grained quartz, alkali feldspar, and plagioclase (An_{28}) matrix. Chloritic, fine-grained biotite and black opaque minerals form less than 2 per cent of the rock. The alkali feldspar content is about 40 per cent.

The narrow northeast margin of the Bitter Creek stock is unlike the main central zone quartz porphyry and the coarse-grained, porphyritic southern edge. This phase is greenish grey with medium-grained buff feldspar and brown biotite as phenocrysts in a fine-grained matrix. In thin section the buff phenocrysts, which form about 35 per cent of the rock, are strongly zoned plagioclase with a composition of about An_{32}. The matrix is predominantly a similar plagioclase, some orthoclase, 15 to 20 per cent fine-grained interstitial quartz, 3 to 5 per cent biotite, about 1 per cent black opaque minerals, and minor apatite. This phase can be termed porphyritic quartz diorite, but because of the highly variable alkali feldspar content the average composition is difficult to determine.

In summary, the Bitter Creek pluton consists primarily of medium to coarse-grained biotite quartz monzonite which is gradational into very coarse pink granite on the southwest, through pink quartz porphyry into a fine-grained grey-green quartz diorite on the northeast. Outward and upward from the main mass, the stock has sent out innumerable dykes which form the main belt of dykes in the Portland Canal area.

Strohn Creek Pluton: The Strohn Creek pluton was recognized by McConnell (1913). The stock lies about 6.5 kilometres west of Meziadin Lake and is well exposed in road cuts in Bear River Pass (Figs. 2, 13). It has an exposed area of about 13 square kilometres; the long axis of the pluton trends northerly. Aeromagnetic surveys (Fitzgerald, 1960) indicate that the stock has a shallow easterly dipping contact and has a considerably greater subsurface extent.

The rock is a pinkish, massive, coarse-grained quartz monzonite. The colour index is less than 10 and biotite is the most abundant mafic constituent. Potash feldspar commonly forms large phenocrysts. Molybdenite is visible in the rock along the road where fresh rock surfaces are accessible.

In thin section the rock is fresh with a hypidiomorphic granular texture. The plagioclase (An_{22-28}) is subhedral with reversed zoning and complex twinning; it shows only minor saussuritization. Clear quartz and perthitic microcline form the groundmass and partly replace the plagioclase. Biotite and minor hornblende form small anhedral crystals with random orientation. The common accessory minerals are apatite, zircon, and magnetite. Molybdenite was seen only on fracture or joint surfaces with quartz.

The pluton intruded along the east-dipping contact between siltstones and underlying epiclastic volcanic conglomerates without producing significant deformation. The contact is sharply defined; there are no related dykes and sills. Mineral deposits occur in the area but are not known to be directly associated with this intrusive.

The Strohn Creek pluton has not been dated by K/Ar methods but, like the Alice Arm Intrusions which it resembles, has intruded the Middle Jurassic Salmon River Formation; it was probably emplaced in Tertiary time.

Alice Arm Intrusions: All plutons included within the group of Alice Arm Intrusions lie within the southern half of the map-area. These plutons are quartz monzonite stocks that contain significant molybdenite, in some places in commercial amounts. The intrusives are typically ovoid, are less than 1.5 kilometres in diameter, and usually show several strongly contrasting phases (Fig. 13). The contacts with country rocks are sharply defined; a narrow biotitic hornfels zone is typically developed where the stocks have intruded siltstones and greywacke units. The plutons form a narrow belt that extends south from the central Bear River Pass area through the Cambria Icefield, to the Alice Arm district where eight stocks are clustered near the margin of the Coast Plutonic Complex. The belt extends south of the map-area to include a small cluster of plugs localized along the Nass River valley, as well as other scattered, small bodies localized near the margin of the plutonic complex in the Terrace area (Carter and Grove, 1972).

The best known and most extensively explored (Fig. 13) of these plutons are the eight in the Alice Arm district where one, the Lime Creek stock, has been a major molybdenite producer. These plutons were not shown on Hanson's Portland Canal map, but he did mention (1935, p. 37) the presence of molybdenite at both Lime Creek and the Tidewater property, and the apparent relationship of this mineralization to small granitic bodies. In recent years these stocks have received considerable attention from the mining industry and the detailed geology of the stocks in the Alice Arm district has been described by Carter (1964, 1968, 1981) and Woodcock, *et al.* (1966).

The McAdam Point pluton was first recognized in 1965, after it was exposed by glacial ablation (Grove, 1965b, pp. 52–55). At first it was exposed only at the margins of part of the Bromley Glacier, but continued ablation has exposed more of the pluton at the ice margin below the ice fall. It appears to be an ovoid mass, like most of the Alice Arm Intrusions, with a diameter of about 750 metres. There is a central area of coarse-grained quartz monzonite that grades through granodiorite to a quartz diorite phase on the east side under the ice fall. The quartz monzonite is uniformly pink and porphyritic, with potash feldspar phenocrysts up to 12 millimetres long distributed through the coarse-grained matrix. It consists of 10 to 15 per cent quartz, 35 to 40 per cent plagioclase (An_{26}), 30 to 35 per cent perthitic orthoclase, and 3 to 5 per cent fine-grained black biotite. Molybdenite is a minor constituent and occurs as rosettes and as plates along grain boundaries. Quartz-molybdenite veins cut the quartz monzonite phase as well as filling hairline fractures in indurated country rock near the contact. The stock intrudes Lower Jurassic Hazelton Group metaquartzites and greywackes.

The Lime Creek stock is concentrically zoned with a central section of porphyritic quartz monzonite grading outward into quartz diorite at the contacts (Fig. 16). Molybdenite mineralization is localized in the north-central half of the stock where the quartz monzonite has been extensively replaced by potash feldspar, veined by quartz, and cut by alaskite and lamprophyre dykes. The relatively unaltered quartz monzonite at the south side of the stock is leucocratic, medium grained, and relatively massive. Normally zoned plagioclase (oligoclase-andesine), potash feldspar, and interstitial quartz are the dominant constituents. Biotite and hornblende are pervasively altered to chlorite and fine-grained brown biotite.

Contacts of the stock with the Upper Jurassic Nass Formation siltstones and greywackes are sharp and crosscutting. A 60 to 150-metre-wide biotite hornfels zone developed.

Other Alice Arm Intrusions intrude Upper Jurassic Hazelton Group rocks. These stocks are cut by numerous Late Tertiary dykes. Potassium-argon age determinations at The University of British Columbia indicate that these plutons were intruded 50–53 million years ago (White, *et al.*, 1968).

DYKE ROCKS

The Stewart Complex contains an extensive array of dykes and dyke swarms. To review them, the dykes have been grouped on the basis of comparable composition, texture, and relative age. Some of the mappable dykes and dyke swarms are shown on the geological maps (Fig. 2; Grove, 1971, Fig. 3); the major swarms are illustrated on Figure 13 to show

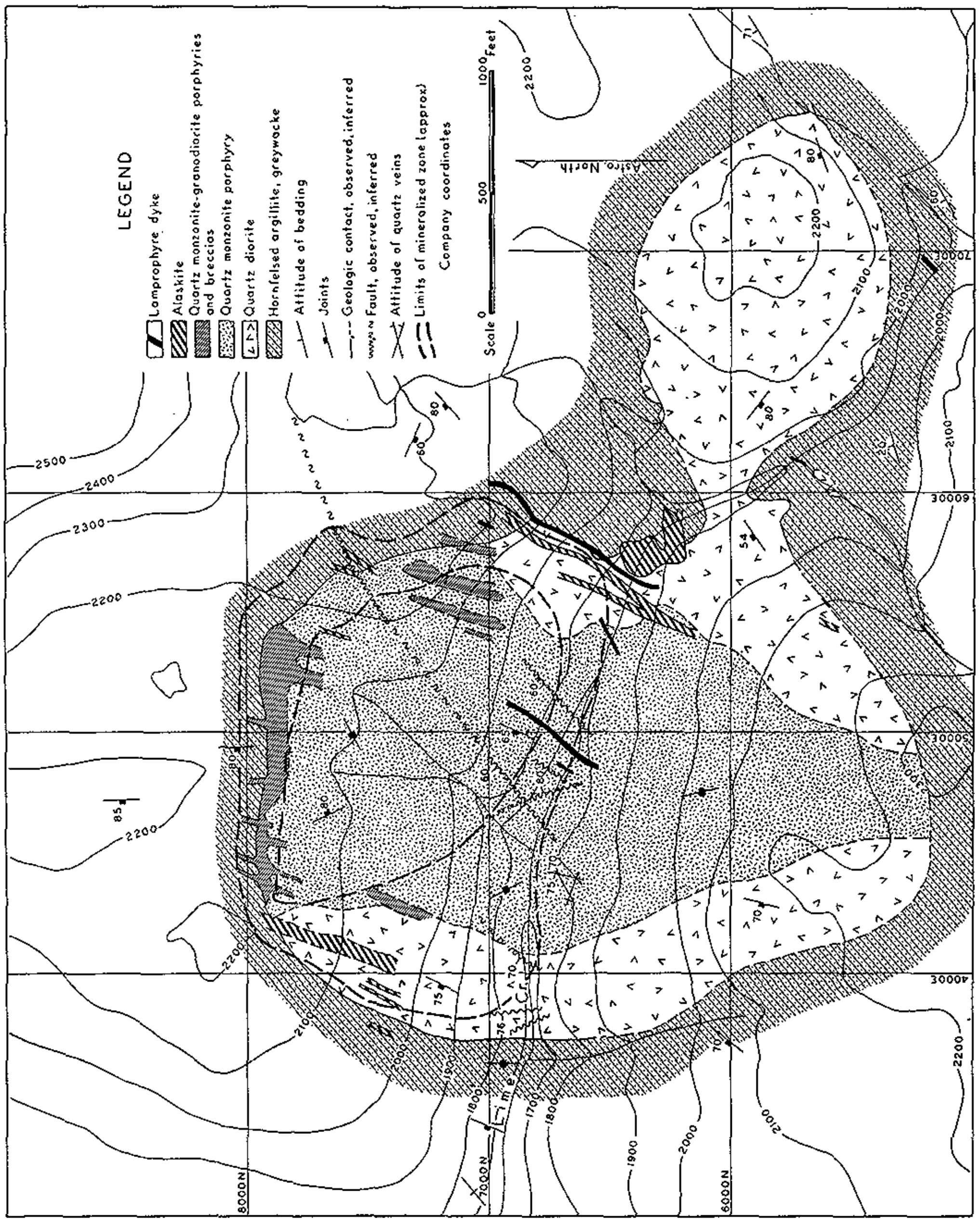


Figure 16. Geology of the Lime Creek pluton.

their spatial and temporal relationships. The dominant trends of individual dykes and swarms are northwesterly and northeasterly; several of the groups follow both directions. The dykes probably form up to 10 per cent of the rock in the area. Of more importance are the localization of dyke swarms in mineralized areas and the presence of mineral deposits in dykes.

Portland Canal Dyke Swarm: The location and extent of the Portland Canal dyke swarm have been outlined by Grove (*op. cit.*) and are shown on Figure 13. Both McConnell (1913) and Hanson (1935) showed the Portland Canal swarm as a single unit extending from Mount Dickie, east of Stewart, across the Bear River valley and across Bear River Ridge.

Hanson extended the western limit to the lower slopes of Mount Bayard where the swarm is beautifully exposed (Grove, *op. cit.*, Plates XXVIA and B). The Portland Canal dyke swarm is one of several *en echelon* swarms that are spatially related to the margin of the Coast Plutonic Complex. The Portland Canal swarm is the most extensive of these and has been traced in detail from Mount Bayard to Mount Dickie, and extended another 5 kilometres to Mount Trevor, located in the centre of the Cambria Icefield. Southeast from Mount Trevor outcrop is poor, but similar dyke material has been traced into the west Kitsault Glacier area. The known length of the Portland Canal dyke swarm is 42 kilometres and the inferred length about 56 kilometres.

On the east side of Bear River Ridge, the country rock, thick-bedded volcanic conglomerates and breccias show stratification, but within the swarm primary features are destroyed and hundreds of dykes form up to 90 per cent of the total rock mass. Toward the valley bottom in the Bitter Creek section this myriad of tentacle-like dykes coalesce at the Bitter Creek pluton. Southeastward, the dyke swarm again spreads from the stock into the country rock and extends for many kilometres to the southeast.

The attitude of the dykes and dyke swarms is strongly influenced by the structure and competence of the country rocks. Where the country rocks are siltstones and greywackes the Portland Canal swarm curves arc-like between Bear River Ridge and Salmon Glacier. The most prominent curve, a sharp northward bulge between Long Lake and Union Lake on the south slope of Mount Dillworth, marks the area where dykes were injected into fairly flat-lying, thin-bedded sedimentary rocks in the axial zone of the Dillworth syncline. Both east and west of this syncline dykes cut massive epiclastic volcanics and are nearly vertical and have a constant trend. In the flat-lying sediments intrusion was dominantly along bedding planes to produce a layer-cake effect.

The larger dykes are up to 140 metres thick and extend for thousands of metres in length and depth. Some probably extend down into an underlying larger mass like the Bitter Creek pluton. The multitude of smaller dykes included in the swarm, which measure from a few to 60 metres in thickness, appears to form a complex, almost reticulated network which encompasses the pluton core. Toward the main pluton dykes are closer together and more numerous.

Within the Portland Canal swarm, individual dykes vary both in texture and composition. Most are granite, quartz monzonite, granodiorite, and quartz diorite. Changes or variations in the texture and composition also occur within the dykes.

West of Mount Welker similar granodiorite and quartz monzonite dykes form a small swarm that lies west of the main Portland Canal swarm. Dykes in this zone appear to be apophyses of the Hyder pluton; like the Portland Canal dykes, they cut the Texas Creek pluton. Other small dyke swarms correlated with the Portland Canal group occur along the east slope of American Creek, in central Bear River Pass, at Mount Dolly, in the Georgie River area, and in the Anyox pendant.

In the Stewart district the Portland Canal dyke swarm was a locus for late quartz sulphide mineralization. Many dykes in the swarm have been fractured and faulted and the openings filled with pods and lenses of quartz and silver-bearing sulphides. None of these deposits has been a large producer but the dykes have attracted exploration for many years.

Although none of the Portland Canal dykes have been radiometrically dated, the field evidence supports a relationship with the Late Tertiary Hyder pluton.

Premier Dyke Swarm: A swarm of northwest-trending dykes lies along the international border between Cantu Mountain and Mount Welker. It has been called the Premier dyke swarm because the Premier orebodies are within it. Dykes of this swarm are not 'Premier Porphyry' and 'Premier Sills' referred to in the older literature. The term 'Premier Sills' was used by Schofield and Hanson (1922, pp. 21, 22) to describe a variety of rocks in the

Premier mine area that was characterized by pink alkali feldspar phenocrysts. The Premier sills are localized in the international border area between Premier mine and Indian Lake.

The Portland Canal dyke and Premier dyke swarms have the same general northwesterly trend, and both are complicated by crosscutting dyke swarms. The Premier swarm has been selected for study because of its economic significance. Several dykes of the Premier swarm are exposed along the Silbak Premier mine road, the Granduc road, and in the canyon of Cascade Creek (Fig. 22).

In general, Premier dykes are up to 45 metres thick. They are distinguished by their porphyritic texture and colour from other swarms. Pinkish to buff plagioclase ($An_{40\pm2}$) phenocrysts, 3 to 6 millimetres long, form up to 45 per cent of the rock. The greenish grey to dark grey matrix generally consists of fine-grained plagioclase and quartz, and accessory apatite, sphene, zircon, and black opaque minerals, largely magnetite. Other phenocrysts include quartz, hornblende, and orthoclase, but except in good fresh outcrop these are relatively inconspicuous. Blebby quartz averages about 10 to 15 per cent, acicular hornblende 5 to 15 per cent, and myrmekitic orthoclase 15 to 20 per cent. Secondary alteration is variable and is indicated in outcrop by shades of green. Most of the dykes are quartz diorite but minor monzonite phases are present. Although the dyke rock is generally fairly uniform in grain size, some coarse-grained phases marked by large orthoclase phenocrysts occur; these resemble marginal phases of the Texas Creek pluton.

Like the Portland Canal dyke swarm, the trends of the Premier swarm and of individual dykes within it reflect changes in competency in the country rock. In the Cascade Creek section sharp curves in trend occur where the dykes cross from massive epiclastic volcanics to cataclasites or massive altered country rock. Branching of the dykes illustrates the presence of persistent local fracture patterns with northwesterly, easterly, and northerly components.

Only one other dyke swarm with comparable texture and composition has been recognized within the Stewart Complex. This small swarm is found in the cirque at the head of the South Leduc Glacier where the light-coloured dykes stand out against the dark volcanic rocks which form Scotty Dog Mountain. These dykes are not very accessible, but excellent fresh samples occur in the medial moraines on the glacier.

The Premier dykes transect the margin of the Texas Creek batholith and Early Jurassic strata. In turn they are cut by Late Tertiary lamprophyre dykes, and are probably Tertiary in age. Absolute age determinations have not been made on the Premier dykes.

Bear River Pass Dyke Swarm: An extensive northerly trending swarm of these fine-grained diorite dykes are well exposed in the Bear River Pass canyon. Other large diorite dyke swarms have been mapped at Granduc Mountain, north of Frank Mackie Glacier, at the northwest end of Summit Lake, south of Premier, along the Kitsault River valley, west of Alice Arm, and in the Maple Bay-Anyox areas.

Some of the Bear River Pass dykes are diorite; others are quartz diorite. They are generally similar in size and composition to the Premier dykes, but differ markedly in texture. The Bonanza ore deposit, located at Bonanza Creek south of Anyox, is cut by many dark diorite dykes which are part of an extensive swarm visible along the walls of Bonanza Creek canyon.

The dykes show considerable local textural variations from fine-grained equigranular to porphyritic types, with plagioclase (An_{50}) phenocrysts forming from 10 to 55 per cent of the rocks. Hornblende and pyroxene, which vary in amount, are generally altered to chlorite and secondary biotite.

In individual size, the Bear River Pass dykes range from a few metres wide to a maximum of about 30 metres. In places, as in the Anyox area individual dykes have been traced for up to 5 kilometres. These dykes may be seen in large numbers along the shoreline in Alice Arm and Observatory Inlet. They generally show narrow chilled margins against hornfelsed country rocks. Where the country rock is siltstone, tremolite is typically developed. Known contact metamorphic mineralization related to these dykes includes auriferous pyrite, nickeliferous pyrrhotite, molybdenite, and pyrite-chalcopyrite, as well as ubiquitous magnetite.

In the Anyox area, Bear River Pass dykes cut the Hyder pluton and related dykes, and appear to be more or less contemporaneous with lamprophyre dyke swarms of the area.

Lamprophyre Dyke Swarms: Lamprophyre dykes are fine-grained dark green to dark grey spessartites which cut all the competent rock units in the map-area except relatively minor basaltic dykes. The lamprophyres are common throughout the area, but local zones of concentration are outlined on Figure 13 to indicate their relationship to the Portland Canal and Premier swarms. They are distinguished from the country rock by rusty weathering, spotted grey colour, and blocky jointing.

Microscopically they are characterized by fine-grained lath-like andesine plagioclase, brown hornblende, and minor augite set in a felted matrix of very fine-grained andesine and hornblende with accessory apatite, sphene, and magnetite. Both phenocrysts and matrix are typically altered to sericite, chlorite, epidote, calcite, and quartz; original quartz in the matrix is difficult to distinguish from secondary quartz.

The lamprophyres have three distinct trends: northwesterly, northeasterly, and northerly.

Unlike the Portland Canal and Premier swarms, which have a single prominent northwest trend, lamprophyres appear to be more or less evenly distributed in all three orientations, except in the central Stewart district where most trend northerly.

Lamprophyre dyke swarms are also prominent in southeastern Alaska. Smith (personal communication) suggested that the strong northeasterly fracture trend, which appears to have controlled fjord development, also controlled regional emplacement of lamprophyre dyke swarms. Portland Canal is an exception to the general northeasterly trend; in this section northerly trending lamprophyre swarms (Bear River Pass area) are more common than northeasterly dykes.

Lamprophyre dykes and dyke swarms are prominent in virtually every known mineralized area. They are, however, ubiquitous and would not, of themselves, provide a unique clue to mineral deposit location.

Carter (personal communication) has made age determinations by the K/Ar method on a number of lamprophyre dykes in the Alice Arm and Anyox areas. The results indicate that the lamprophyre dyke swarms (and diorite) were emplaced during Oligocene time, about 32 to 34 Ma.

CATACLASITES AND SCHISTS

Four major cataclasite zones have been mapped in the Stewart Complex (Fig. 13). These include the South Unuk, Cascade Creek, Bear River, and Maple Bay zones. All trend northerly across Lower Jurassic country rocks; they are partially obscured by overlying Middle Jurassic strata and partially dismembered by Tertiary intrusions. All include significant mineral deposits and are important to the understanding of tectonics and metallogenesis in the Stewart Complex.

Cataclasite: The South Unuk cataclasite zone, which is the most extensive zone, includes the large Granduc sulphide ore deposit and several lesser mineralized zones. The South Unuk zone has been partly outlined by Norman (1962) during a detailed mineral exploration program conducted during 1959 and 1960 along the South Unuk River. The

Granduc Mountain section was first mapped by Bacon (1956) during early exploration at the mine. He outlined the general geology of the section between Summit Lake and the Alaska border, 5 kilometres west of Granduc Mountain.

The geology of the section from the Alaska border north through Granduc Mountain and along the South Unuk-Harrymel lineament to the Iskut River is shown on Figures 2A and 2B. The northerly trending cataclasite zone essentially parallels structures in the sedimentary, volcanic, and plutonic rocks that comprise the middle member of the Unuk River Formation (Fig. 9). The stratigraphy of the Unuk River Formation has been previously described in this chapter, and the structural relationships of the major South Unuk zone to the country rocks and within the local tectonic framework are described in Chapter 4. The following description generally deals with the Granduc Mountain portion of the cataclasite zone; it is the widest and most accessible section.

The zone at Granduc Mountain is about 2 kilometres wide and extends from the North Leduc Glacier, east to about the centre of the mountain. From west to east the zone includes broad areas of calc-silicate cataclasites, mylonites, and mixed mylonite-phyllonites. Most of the rocks are marked by more or less vertical, northerly trending layering or banding that is best developed in the central mylonite zone and includes most of the known Granduc ore zones. These rocks, and the ore, have been cut by dykes of several ages which have in turn been offset by several graphitic fault zones.

The cataclasite zone includes a broad section essentially composed of weakly to moderately recrystallized, deep green, skarn-like material, generally too fine-grained in hand specimen to determine the mineralogy. The mylonites, including boudinaged limestone lenses, breccia, and ultramylonite, are generally marked by knife edge, dark and light green bands a few millimetres to several centimetres thick which can be traced for tens of metres. The lenses of fine-grained limestone which are usually blue to buff-white are marked by thin colour bands and are generally only a few metres thick. However, they have been traced underground for hundreds of metres in the west side of the ore zone. The ultramylonites are weakly foliated, cherty looking, grey-white lenses. They are localized in the ore section where they comprise distinct layers a few to 10 metres thick, and have been traced for several hundred metres within the workings. The phyllonites are dark brown to black, minutely banded units marked by very fine-grained biotite, and common ribbons and augen of glossy white quartz. Breccia and fine breccia lenses or pods are scattered throughout the mylonite-phyllonite sequence in sizes ranging from small fragments to large blocks. These units, which are generally black to purplish black, are marked by undeformed remnants a few millimetres to several centimetres in diameter, and generally lack any directional texture. They are generally thought to represent deformed diorite dykes (Norman and McCue, 1966).

In the past, most rocks in the South Unuk zone have been identified as various sediments or bedded volcanics because of the well-developed banding and because of the very fine-grained nature of the units. In thin section, medium to light green calc-silicate rocks are seen to consist of alternating bands and lenses up to several millimetres wide of fresh clastic green diopside and epidote, with scattered lenses and clumps of recrystallized calcite, apatite, very fine-grained magnetite, and clastic sphene. The grain size of the coarse material is generally 1 millimetre and the fine matrix is much less than 0.1 millimetre. Scattered plagioclase clasts and clumps generally form less than 5 per cent of the rock, and quartz, which commonly occurs as clear grains, typically exhibits ribbon texture (Plate XI).

Strongly boudinaged carbonate lenses along the west margin of the cataclasite zone are very fine grained, dense, and completely recrystallized. Calcite forms most of these units with minor rounded quartz beads, scattered garnet crystals, and occasional lenses of epidote and magnetite. The grain size is generally about 0.1 to 0.2 millimetre, although considerably coarser material usually envelopes the inclusions in the carbonate (Plate X).

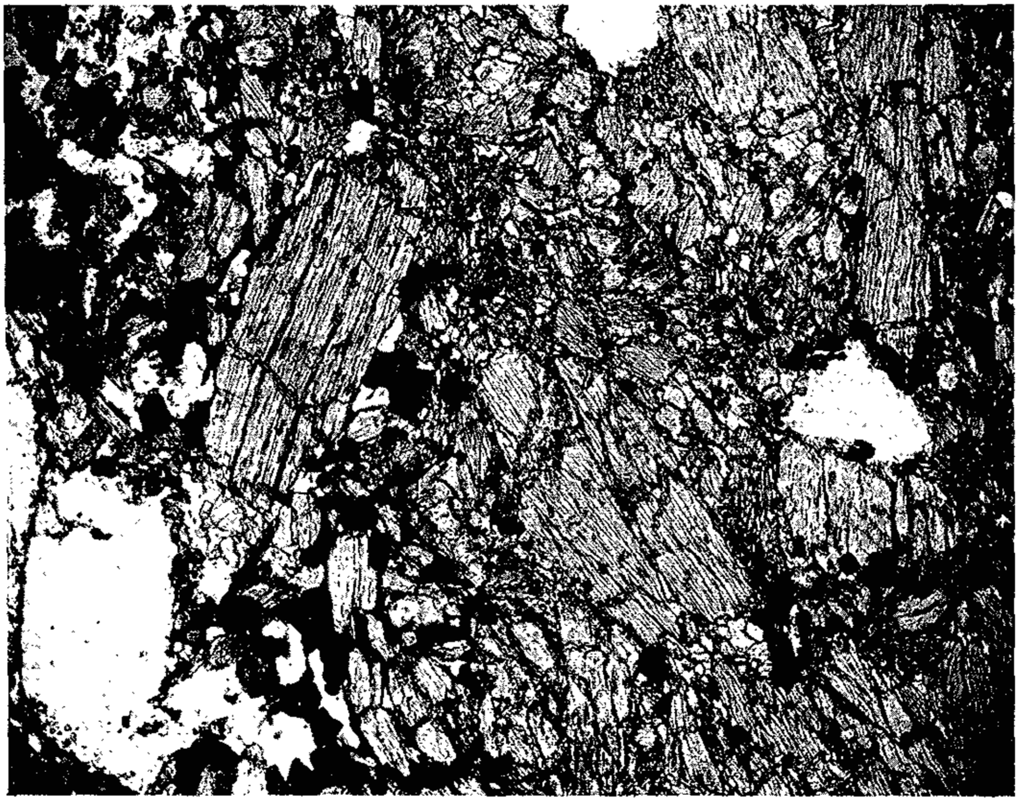


Plate IX. Photomicrograph of cataclasite, South Unuk cataclasite zone, Granduc Mountain area.


Plate X. Deformed limestone strata, South Unuk cataclasite zone, east side of North Leduc Glacier.

The mylonite zone includes a variety of rocks separated on the basis of microscopic textures. These include mylonite, blastomylonite, hartschiefer, layered mylonite, and ultramylonite. These units are finely crystalline to cryptocrystalline, are usually well foliated, and exhibit various degrees and gradations of recrystallization. Blastomylonites exhibiting weakly foliated, clear recrystallized ribbon quartz and quartzose matrix are typically thick banded and are interbanded within millimetre-scale layered mylonite, phyllonite, layered mylonite, and epidote-diopside cataclasite laminae. The layered mylonites generally include clastic hornblende or epidote-diopside-rich lamellae interlayered with weakly to moderately recrystallized quartz and minor feldspar layers (Plate XI). Simple mylonites consisting of feldspar, tourmaline, epidote, or diopside clasts appear to be moderately graphitic and well laminated. In hand specimen these simple mylonites are usually an even grey-green colour and weakly pyritic. Plagioclase clasts are angular and fresh, show little or no banding or twin lamellae, and are generally about 0.5 millimetre in size; the matrix is usually cryptocrystalline. The ultramylonites are cryptocrystalline, lack significant component clasts, and lack good foliation. Phyllonite-mylonite and phyllonite are typically graphitic, finely crystalline to cryptocrystalline and commonly contain tourmaline, epidote, or diopside clasts (Plate XII). The finely crystalline biotite is brown and fresh; it forms 15 to 20 per cent of individual layers. Finely crystalline apatite, calcite, and magnetite are variable components throughout the sequence, although the most extensive zones appear to lie within the mixed carbonate, calc-silicate members near the west limit of the cataclasite zone and west of the ore-bearing mylonite-phyllonite section. The apatite, calcite, and magnetite-rich layers are folded on both outcrop (Plate XIII) and thin section scale (Plate XIV).

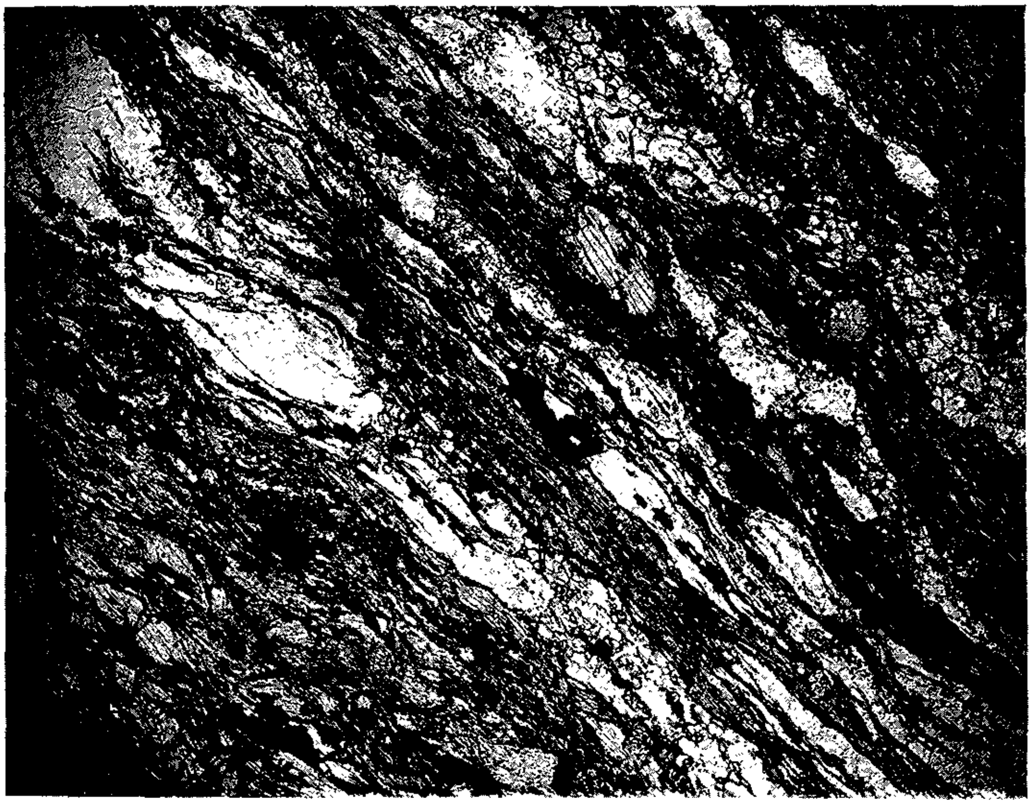


Plate XI. Photomicrograph of mylonite with epidote-diopside and quartz-feldspar layers, South Unuk cataclasite zone, Granduc Mountain area.

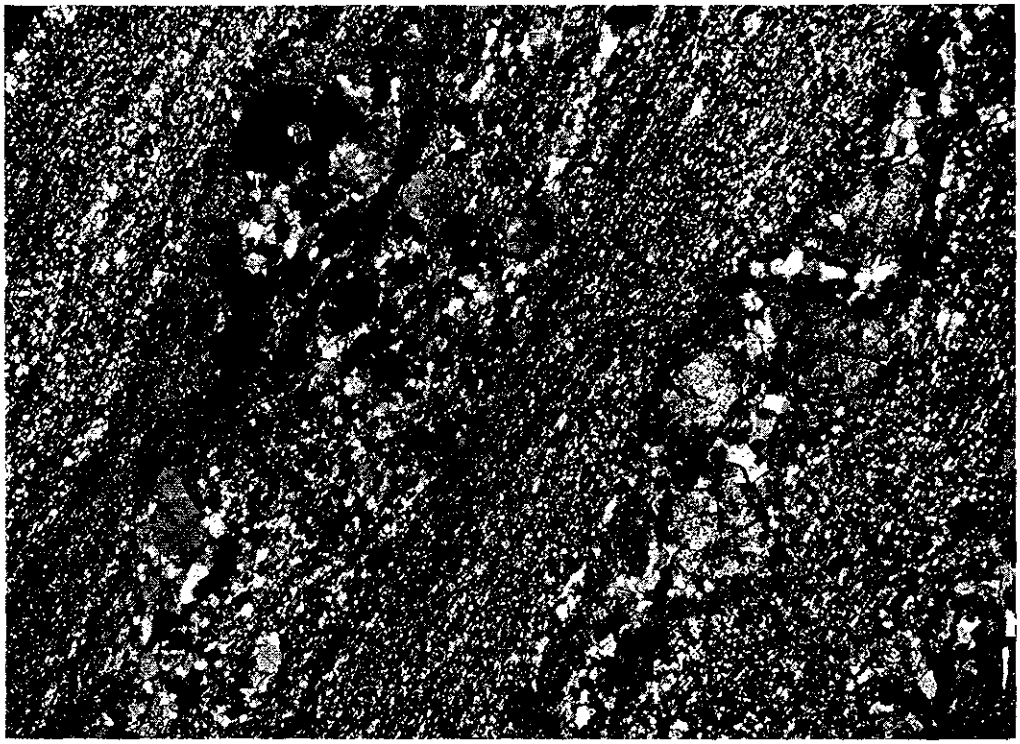


Plate XII. Photomicrograph of phyllonite showing tourmaline as clasts, South Unuk cataclasite zone, Granduc Mountain area.

Plate XIII. Banded mylonite, South Unuk cataclasite zone.

The various members of the complex cataclasite zone show considerable variation in the degree of recrystallization, but the grain size of the crushed and neo-minerals shows general constancy. Secondary alteration of the mineral components is rare even in the surface exposures. The degree of metamorphic differentiation in these rocks is expressed by layering of epidote, diopside, hornblende, apatite, magnetite, and quartz. Compared to mylonites developed from andesitic, volcaniclastic rocks in the Cascade Creek zone and the Maple Bay zone, there is a high degree of mechanical differentiation and layering

Plate XIV. Photomicrograph of mylonite, showing apatite-magnetite laminae, *South Unuk cataclasite zone.*

developed. Few clasts in the Unuk River mylonites show evidence of post-tectonic deformation although the zone has been extensively faulted with the production of wide graphitic shears. Ovoid to flattened, recrystallized chert or quartz pebbles in the mylonite-phyllonite section are common in the phyllonite members (Plate XV). They are parallel to the foliation and apparently parallel to primary structures. Spry (1969, p. 211) suggested that a simple flattening related to tectonic movement which produces an orthorhombic fabric indicates nonrotational movement.

The mineral assemblages of the South Unuk cataclasite zone formed at a low temperature. Country rocks, plutons, dykes, and sulphide lenses have been deformed under high pressure and low temperature conditions to produce a relatively uniform sequence of rocks, once thought to comprise a simple siltstone-sandstone succession.

Cascade Creek Cataclasite Zone: The Cascade Creek zone extends northerly from southeastern Alaska through Premier and along the east slope above Salmon Glacier to Mount Dillworth, where Middle Jurassic strata cover the zone. Rocks in this zone were originally called volcanics by Schofield and Hanson (1922) and Hanson (1929, 1935). The original country rocks along the zone, and partially preserved within it, are Lower Jurassic Hazelton Group epiclastic volcanic conglomerates, sandstones, breccias, and lithic tuffs. In the cataclasite zone, particularly in the altered mineralized zones at the Silbak Premier mine, deformation, alteration, and quartz replacement have combined to obscure most of the primary rock structures and textures.

Cataclasites are the most significant rock units in the Salmon River district. All of the major ore deposits, including the Silbak Premier, have been found in altered cataclasites derived from green volcanic conglomerates and sandstones.

These deformed rocks are largely derived from thick-bedded, fine to medium-grained volcanic conglomerates or breccias, with thin intercalated sandstones. The cataclasites include mylonites, phyllonites and kakirites, as well as schists; all occur as nondiscrete zones crosscutting mappable lithologic strata. The cataclasites include rocks which are shades of green, black, red, and purple, whereas the associated schists are buff or light green.

The coarse cataclasites consist of a heterogenous accumulation of angular to subangular fragments of andesitic composition embedded in a clastic volcanic sandstone matrix, generally also of andesitic composition. Some of these coarse cataclasites retain the original sedimentary colours. The fine-grained cataclasites are commonly marked by centimetre-scale layering which resembles primary bedding. Because of feldspar clasts, these have been described as tuffaceous or porphyritic volcanics. In the Premier area these rocks are commonly marked by prominent bands of feldspar clasts, the larger of which resemble phenocrysts. The metamorphic banding generally trends northerly, dips at a low angle to the west, and may be misconstrued to be relict bedding. Lenses with coarse feldspar clasts within finely layered bands have the appearance of porphyritic sills injected into a predominantly volcanic assemblage.

All these cataclasites are foliated and submetallic greyish to greenish in colour. The foliation is variably developed depending on proximity to intrusive contacts and zones of shearing. Areas of schist on the geological map form discrete lenticular zones such as may be seen at Summit Lake or in the area between Big Missouri and Premier. On the Alaskan side of the border, as noted by both Westgate (1922) and Buddington (1929), these cataclasites are apparently featureless in outcrop. At Premier, however, deformation was not pervasive and primary rock textures are commonly visible.

The true texture, composition, and alteration of the Salmon River cataclasites are revealed in thin sections. In the great majority, the parent material is still recognizable. These are kakirites (Knopf, 1931) or more generally cataclasites. A few are extremely granulated and are mylonites.

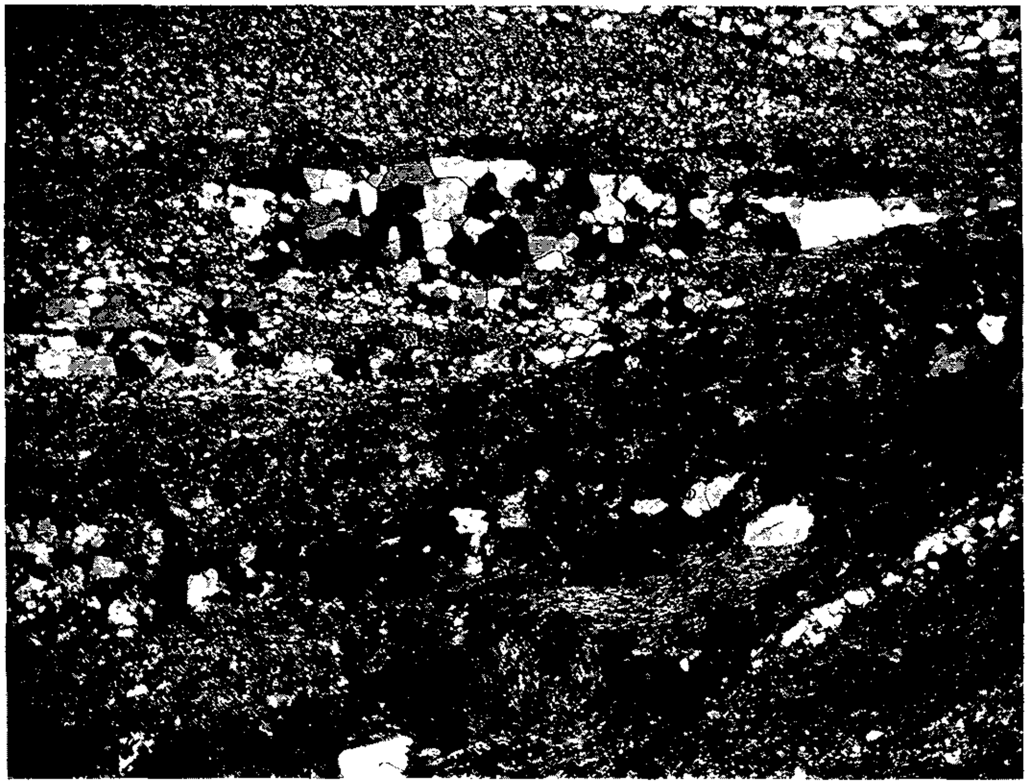


Plate XV. Photomicrograph of mylonite-phyllonite, showing flattened quartz pebbles.

Macroscopically the mylonites are variably black, red, or purple. They have a dense, fine-grained pseudoporphyritic texture. The relict crystals are either plagioclase or quartz, one of which predominates, comprising from 8 to 50 per cent of the rock. The plagioclase clasts all fall within the composition range An_{28-32}, most are An_{30-32}. They are typically angular, show marginal strain effects, and are enclosed in a very fine-grained granulated matrix composed of quartz, feldspar, sericite or chlorite, and iron oxide 'dust' which imparts either black, red, or purple tones to the rock. Quartz occurs as eyes with clear sharp outlines; they seldom exhibit marginal strain effects but commonly contain undulatory extinction bands (Plate XVI).

A few samples, taken from purple lenses south of Hog Lake, have relict rock fragment augen and are kakirites. The augen consist of plagioclase (An_{30}) porphyry fragments; they are embedded in a finely granulated feldspathic matrix containing abundant iron oxide which envelopes each fragment and imparts a black colour to the rock.

Relict hornblende grains have been recognized either as partially altered fragments or as ghosts in several of the black mylonites which occur as lenses within the extensive schist zone west of Silver Lake. The parent material is not preserved, but it was probably a medium to coarse-grained hornblende quartz diorite related to the nearby Texas Creek granodiorite.

Alteration has preferentially affected the matrices of the mylonites which are commonly traversed by very fine-grained replacement quartz, carbonate, or epidote. Sericite and chlorite are common minor constituents and introduce a weak laminar fabric to these rocks.

Alteration: Alteration is a prominent feature of the deformed parts of the Hazelton succession. Quartz, potash feldspar, pyrite, and hornblende are common as alteration

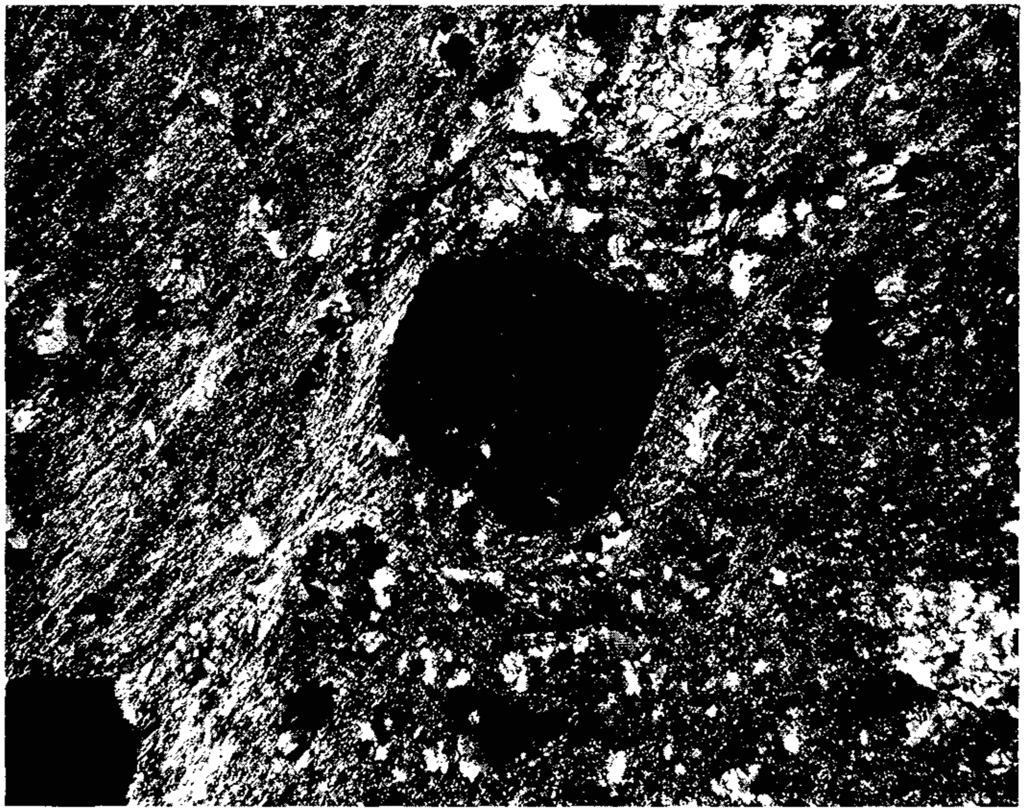


Plate XVI. Photomicrograph of cataclasite, Cascade Creek zone, Premier area.

products in the cataclasites. Cataclasis merely caused crushing and distortion of the volcanic sediments. Metasomatism related to intrusion of the Coast Plutonic Complex has variably altered some of these cataclasites, producing either silicification and pyritization or a variety of minerals. Only in the well-developed schists in the Noname Lake area, however, the metasomatism has obscured the true character of the country rocks. The dark green foliated rocks are generally chloritic, whereas the very light green rocks are usually sericitic or siliceous.

Schists: Mappable schist areas are outlined on Figure 2; they are most prominent east of Summit Lake. The schists represent shear zones in the Hazelton country rocks and commonly include minor lenses of mylonite and cataclasite. These shear zones are small but economically important because of the mineral deposits which lie within them.

The schists can usually be distinguished from associated cataclasites by colour and texture. True schists are rare and the term 'semischist' is probably a more accurate description. Schistosity or foliation, however, is well developed and readily measured. A few scattered relict plagioclase clasts up to 5 millimetres in size are discernible in most schists. They all contain 5 to 10 per cent fine to medium-grained pyrite cubes as well as varying small amounts of fine magnetite. Carbonate is ubiquitous as scattered grains or as veinlets with quartz which cut the schistosity. At surface these schist zones form extensive bright red and orange gossans and shallow depressions, particularly on open slopes above the Salmon Glacier. In hand specimen, the schists are commonly friable and marked by vug-like pores where sulphide and carbonate grains have been leached.

In thin section the schists consist of aggregates of muscovite, plagioclase, chlorite, quartz, and carbonate as well as accessory pyrite and black oxide. Sericitic muscovite generally makes up 25 to 40 per cent of the matrix; the other components vary widely. A few small remnants of parent volcanic sandstones and conglomerates are commonly visible and indicate the low grade of the dislocation metamorphism. Residual plagioclase clasts, although extensively altered, have an approximate composition of An^{28-32} similar to that in the surrounding cataclasites. Quartz and calcite are common alteration minerals which together comprise from 10 to 70 per cent of the schists. Where abundant these impart a faint greenish white colour and lessen fissility in the schists.

The schists are quartz plagioclase sericite with accessory pyrite, magnetite, and carbonate. It is concluded that these schists have been produced from Lower Jurassic rocks by metasomatism. The intercalation of kakirite and mylonite with schist suggests that the kinetic process was selective, favouring volcanic conglomerate and breccia, while the alteration process aided the development of muscovite, chlorite, and other minerals in the more homogeneous sandstones.

Origin of the Deformed Rocks: In the foregoing descriptions it has been emphasized that the cataclasites, mylonites, and schists were largely derived from pre-existing sedimentary and volcanic country rocks. Abundant relict textures are still evident in spite of dynamothermal metamorphism, leaving little doubt as to the source rocks. Surface weathering and limited recrystallization locally obscured diagnostic features and have led, in the past, to various identifications which stressed a simple sedimentary or volcanic origin and disregarded metamorphism.

The differential movements that produced the cataclasite zones appear to have been related to a single pre or early Middle Jurassic tectonic event. Temporal and spatial relationships between the Cascade Creek zone and the Middle Jurassic (or older) Texas Creek pluton, as well as the marked northerly alignment of pre-Middle Jurassic satellite plutons, suggest that deformation preceded extensive plutonism. Textures and mineral relationships in the cataclasites suggest high pressures, low temperatures, and essentially dry conditions. Textures in the schists indicate that recrystallization outlasted the deformation event.

4

STRUCTURAL GEOLOGY

TECTONIC FRAMEWORK

The relative position of the idealized tectonic elements of the region is illustrated on Figure 1. From west to east these elements include the Wrangell-Revillagigedo Metamorphic Belt, the Coast Plutonic Complex, and the Bowser Basin. The Bear River Uplift involves part of the Whitehorse Trough as well as part of the Bowser Basin and includes minor elements like Stewart Complex, Oweegee Dome, and Ritchie anticline. The terms Bear River Uplift, Stewart Complex, and Meziadin Hinge have been introduced in order to describe these structural elements within the regional framework.

Bowser Basin: The Bowser Basin evolved from the parent subtrough through geologic time as the result of the interplay of tectonic, volcanic, sedimentary, and igneous events which have produced a northwest-trending sedimentary basin about 150 kilometres wide and up to 500 kilometres long. The area of the basin is about 75 000 square kilometres, which in terms of basin size is considered moderate; the depth, based on unit thicknesses proposed by various workers in the area, appears to be variable. The basin is situated in a tectonically active zone; there are repeated periods of deposition, plutonism, uplift, and erosion revealed in the geologic sequence (Fig. 14).

Presumably the present Bowser Básin was initiated by Late Triassic time. Rocks exposed along the periphery include Middle Mississippian, Pennsylvanian, and Permian rocks which in part unconformably overlie an older complex (Fig. 7). Upper Jurassic Nass Formation marine sediments now cover a large part of the original basin. In the eastern Bowser Basin these sediments are generally overlain by nonmarine Cretaceous and early Upper Tertiary sediments which include some coal members. During the evolution of the Bowser Basin, the margins were marked by intrusive activity in Paleozoic, Triassic, Jurassic-Cretaceous, and Tertiary time (Grove, 1968a).

Discussion: The Bowser Basin is infilled by a thick succession of marine, brackish, and freshwater shales, greywackes, and conglomerates. These comprise the Bowser assemblage of latest Late Jurassic and Early Cretaceous age (Souther and Armstrong, 1966). Douglas (1970, p. 438) suggested that following the Nassian orogeny (Fig. 14) in the Western Cordillera, three discrete depositional basins, including the Bowser Basin, were developed. Fitzgerald (1960) stated:

'Superficially, the Bowser Basin is characterized by intensely folded sedimentary rocks ranging in age from Lower Jurassic to Lower Cretaceous'.

In the Smithers area Tipper (personal communication) re-examined the stratigraphic sequence. There a mainly sedimentary unit overlies tuffs and breccias that range in age from Middle Jurassic to early Late Jurassic. In the northern part of the Smithers area, Tipper also identified marine and nonmarine late Early Cretaceous (Albian) Skeena Group sediments that overlie the Late Jurassic rocks either unconformably or disconfor-

mably. This interpretation of the Mesozoic stratigraphy renders earlier published concepts of the age and extent of the Bowser Basin invalid.

Bear River Uplift: The term Bear River Uplift has been introduced for a physiographic-geologic unit that is bounded by the granitic coastal Boundary Ranges of British Columbia and Alaska on the west and the sedimentary Skeena Mountains on the east. The northern limit of this uplift is represented by the Iskut River valley and the southern margin by a low divide between Alice Arm and the Nass River. This physiographic unit includes minor mountain ranges which are higher than the adjacent coastal Boundary Ranges and Skeena Mountains and have extensive icefields. The Bear River Uplift is defined as a structurally controlled feature that has been uplifted and eroded at a faster rate than immediately adjacent basin sections. Lower to Middle Jurassic and older sedimentary, volcanic, and metamorphic country rocks occur within the limits of the Bear River Uplift. Blankets of mainly Upper Jurassic marine sediments deposited during the late phase of *development, have been largely eroded, but trough-like sections of them are preserved as* structural remnants within the uplift. The western portion of the Bear River Uplift has been named the Stewart Complex.

Stewart Complex: The Stewart Complex lies along the contact between the Coast Plutonic Complex on the west, the Bowser Basin on the east, Alice Arm on the south, and the Iskut River on the north (Fig. 1). A complex, as defined by the American Commission *on Nomenclature (1961, p. 651), is composed of diverse rock types of many classes and is* characterized by complicated structure. The Stewart Complex contains abundant diverse metallic sulphide mineralization.

The west boundary of the Stewart Complex is the contact with the Coast Plutonic Complex. The Leduc River sections expose old structures which have been truncated. The intrusive contact is generally steep, but satellite Tertiary plutons suggest that the Coast Plutonic Complex underlies part of the Stewart Complex at depth. It is suggested that the Anyox and Georgie River pendants represent an intrusive level comparable to the projected deep contact between the Stewart Complex and underlying intrusives in the Unuk-Leduc section.

The northern boundary of the Stewart Complex lies approximately along the Iskut River. Extensive deformation along the easterly trending Iskut River valley defines a major structural zone involving thrust faulting of Paleozoic strata south across Middle Jurassic and older units and younger tear faulting which has offset the northerly trending Forrest Kerr-Harrymel Creek fault. The junction of the easterly Iskut River zone, the Forrest Kerr-Harrymel zone, and the north-northeasterly Iskut River zone marks the vent of the Quaternary Iskut River lava flow. The southern limit of the Stewart Complex is marked by a line of Quaternary volcanic flows that occur just south of the east-northeasterly trending Alice Arm-Illiance River lineament.

The Meziadin Hinge marks the eastern limit of the Stewart Complex from the Nass to the Iskut River, and also partly represents the physiographic boundary between the Nass Basin and the Boundary Range mountains (Fig. 1). It also roughly marks the easterly limit of the extensive lower Middle Jurassic Betty Creek Formation. It is possible that the major Fraser-Yalakom fault extends along the eastern margin of the Coast Plutonic Complex from southern British Columbia through Terrace to Tulsequah (Campbell, personal communication). Thus, the Meziadin Hinge may represent a 225-kilometre-long segment of this fault and may be related to the Denalai fault system of Alaska and the Yukon.

In summary, the Stewart Complex is bounded on the west by the intrusive margin of the Coast Plutonic Complex and on the south, east, and north by high-angle normal faults which are major tectonic features. It appears that the the Stewart Complex has been essentially frozen to the east margin of the Coast Plutonic Complex and has been involved in uplift along with the Coast Geanticline, whereas the adjacent basin is separated by *normal faults and exhibits a relative depression.*

STRUCTURAL RELATIONS BETWEEN FORMATIONS

Late Triassic and Older: The oldest fossiliferous rocks identified in the study area range from Karnian to Norian age and are found west of the Unuk River at McQuillan Ridge and west of Harrymel Creek. The McQuillan Ridge member is tightly folded in detail, but the major structure appears to represent an open, northeasterly trending anticlinal fold. At Gracey Creek northerly trending amphibolite-grade gneiss is overlain unconformably by comparatively fresh, well-bedded, northeast-trending Karnian sediments and basalt flows. Crushed equivalents of these Karnian rocks are found along parts of the west side of Gracey Creek immediately above the gneisses. The creek appears to follow a deformed 30-metre-wide breccia zone which probably represents a major fault. The attitude of the fault zone is difficult to determine, but lineations in the Triassic rocks plunge northerly at about 18 degrees, suggesting a low-angle fault plane that is roughly coincident with the east slope of Gracey Creek. The fault may be a thrust, which would be in keeping with compressional conditions in Oweegee Dome to the east. Both the gneiss zone and the Late Triassic rocks are truncated on the west by a salient of the Hyder pluton; there is little attendant deformation and a narrow contact metamorphic zone.

With the exception of the 3-kilometre-wide section between the south Unuk River and Gracey Creek and at Shirley Mountain, the contact between the Triassic rocks and the overlying Lower Jurassic Unuk River Formation is marked by an extensive cataclasite zone. In Gracey Creek area thick-bedded Lower Jurassic strata form northerly plunging slabs that overlie both the gneiss and Triassic sediments with fault relationships. At Shirley Mountain metamorphosed Triassic or older rocks are unconformably overlain by Lower Jurassic sediments and pillowed volcanics. The relationships between the Late Triassic and Jurassic rocks along the west limit of the Unuk River sheet are obscured by the Frankmackie Icefield, Quaternary volcanic flows, and the effects of deformation and plutonism.

Relations between Late Triassic rocks and the older gneisses imply that simple compressional folds were developed before the Karnian rocks were thrust over the gneisses. Lower Jurassic Unuk River Formation rocks are generally in fault contact with the Late Triassic and older rocks, as, for example, at Gracey Creek where the contact is a normal fault. Later cataclastic deformation along the Leduc-South Unuk-Harrymel lineament obscured contact relationships between the Triassic and Jurassic rocks along most of the zone.

Souther (1971) named the mid-Triassic uplift, folding, metamorphism, and plutonism, which affected the northwestern Cordillera, the Tahltanian Orogeny (Fig. 14). It is roughly equivalent to White's (1959) Cassiar Orogeny, which marked the close of mid-Triassic volcanism and preceded Late Triassic volcanism and sedimentation. Formation of the gneiss belt along the margin of the Coast Plutonic Complex between Leduc River and Gracey Creek may be correlated with the Tahltanian orogeny, although Hutchison (1970) also indicates a pre-Permian age for part of the Central Gneiss Complex.

Jurassic: Relationships between various formations comprising the Jurassic Hazelton Group are generally simple; extensive Tertiary erosion has exposed the contacts. Within the Lower Jurassic Unuk River Formation interruptions in sedimentation and volcanism are marked by unconformities with conglomerate units such as are seen at Twin John Peaks, on Mount Shorty Stevenson on Bear River Ridge, and on Mount Rainey east of Stewart. The Unuk River Formation is folded, deformed, and separated from the early Middle Jurassic Betty Creek Formation by a regional angular unconformity, first recognized north of Stewart at Betty Creek. The Salmon River sequence was deposited on the Unuk River and Betty Creek Formations following limited deformation and during graben and half-graben development which produced an uneven surface. The Upper Jurassic Nass River Formation, which includes a basal, granodiorite-bearing cobble conglomerate, was deposited unconformably across the underlying Salmon River Formation; the contact is best displayed along the Meziadin Hinge. Extensive, narrow trough-like accumulations of Salmon River and Nass River formation sedimentary rocks, marked by gravity slide features, illustrate almost continuous graben tectonics during these periods of marine sedimentation.

In the Stewart Complex the Lower Jurassic strata were deformed and intruded prior to lower Middle Jurassic sedimentation. Because of this relationship and the fact that the Middle Jurassic strata are relatively undeformed, it is suggested that Early Nassian Orogeny (Fig. 14) was mainly responsible.

The absence of Cretaceous and Tertiary strata in the Stewart Complex and in large parts of the western Bowser Basin reflects the extensive uplift and erosion that accompanied Late Laramide Orogeny.

Quaternary: Excluding glacial deposits and unconsolidated recent sediments, basalts in the Unuk River and Alice Arm districts are the only known Quaternary deposits in the general area. These are unconformable on all older rocks and appear to be related to tensional volcanic belts localized along graben-like features that originated in Tertiary time (Fig. 1).

Summary: There have been several distinct periods of metamorphism, plutonism, volcanism, and sedimentation in the area. The intensity of deformation has apparently decreased after the mid-Triassic Tahltanian Orogeny, but plutonism increased and climaxed in Tertiary time.

MAJOR STRUCTURES IN THE STEWART COMPLEX

Unuk River Folds: The well-bedded mixed volcanic-sedimentary sequence exposed along the east wall of the South Unuk River valley extends northwesterly from the Tertiary intrusive contact at the South Leduc Glacier on the south to the vicinity of Twin John Peaks. At that point the sequence swings northeasterly toward Star Lake, then sharply southeast into the Treaty Glacier area. The main belt of exposed Unuk River Formation and scattered windows in the Frankmackie Icefield, form a major, north-northwesterly trending domical structure that extends from the Bowser River through Brucejack Lake toward the head of Storie Creek. Structural cross-sections (Fig. 3) illustrate subparallel, asymmetric north-northwesterly trending warps within the dome. Along the western flank of the dome major folds are mainly homomorphic (Belloussov, 1960) similar folds inclined to the west. At Gracey Creek, there is a deformed, upright slab of Unuk River Formation; comparable strata along Harrymel Creek dip easterly and are preserved segments of an eroded, deformed syncline. In the Mitchell-Sulphurets Creek window, the major structure is a simple antiform or warp lying parallel to the axis of the major dome, which has been fragmented by plutons and faults.

American Creek Anticline: The American Creek anticline is one of many regional warps that have involved rocks of the Lower Jurassic Unuk River Formation. The fold is open and slightly inclined (Grove, 1971, Fig. 4). The northern axial section of the anticline is well exposed in American Creek and in Bear River Pass. North of Stewart, at Mount Mitre, it plunges about 15 degrees northwest under younger sediments. Southeast of Stewart the structure is partly exposed in the Bromley Glacier area where overlying Salmon River Formation rocks have been eroded.

Bear River Pass Folds: The general structure, based on observations at Bear River Pass (Fig. 2B) and in valleys north and south of the pass, defines a uniformly gentle, east-dipping sequence that is marked by gentle warps. The Mount Pattullo and Willoughby Creek sections, which lie along the eastern limits of the Stewart Complex, have not been studied in detail, but are apparently a warped easterly dipping essentially homoclinal succession, like that at the Bear River Pass and Alice Arm sections.

Georgie River and Maple Bay Folds: The Georgie River pendant includes a more or less uniform sequence of westerly to northwesterly trending epiclastic volcanic and sedimentary rocks that dip steeply to the south. No major folds were recognized but margins of the pendant are hornfelsed and the sequence has been extensively deformed and faulted.

At Maple Bay the Lower Jurassic pillow lava sandstone-carbonate sequence forms an open, northerly trending syncline. Deformation and normal faulting have reduced the syncline to parallel, northerly trending, fault-bounded segments. Many Tertiary plutons transect the older folds; these leave the structure essentially undisturbed.

Alice Arm Folds: Hanson (1935, p. 24) suggested that the entire Alice Arm district appeared to be a northerly trending anticline. Mapping by Carter (personal communication) disclosed northerly trending major folds in the rocks that underlie most of the area.

Mount Rainey Syncline: The Mount Rainey syncline represents a structural remnant that is underlain by intrusives, unconformably overlain by deformed Middle Jurassic Salmon River strata. Along Portland Canal, an apparent continuous homoclinal succession of green volcanic conglomerates dip easterly at a moderate angle. Thin-bedded members intercalated with these rocks were traced into the Marmot Glacier area where steep north dips prevail; they outline as a northeasterly trending asymmetrical fold overturned to the east and plunging northeasterly at about 60 degrees. Dragfolds and lineations mapped in thin-bedded sandstones in the Marmot River section show a steep northerly plunge.

Mount Bunting Syncline: The Mount Bunting syncline has been partially exposed on the upper east slope of Mount Bunting by recent ablation of ice and snow. The rocks forming the synclinal remnant consist of well-bedded red and green Hazelton volcanic sandstones and conglomerates, and minor breccias. Strata forming the west limb trend north-northwest with steep to vertical dips; beds along the east limb dip north at 30 degrees to 70 degrees. The axial plane of the syncline trends north-northeast and minor structures show that the fold plunges northeasterly at about 80 degrees. At the head of Donahue Creek the strata forming this minor fold trough unconformably overlie part of the lower Unuk River succession.

Summit Lake Folds: Westerly trending folds, that form a second set of minor structures, occur in Hazelton epiclastic volcanics along the west side of Summit Lake and in the Big Missouri Ridge section. Most of the epiclastics west of Summit Lake are thick-bedded conglomerates. Thin-bedded siltstones within the succession are well exposed north of August Mountain Glacier, where minor folds plunge at about 60 degrees west. Other west-plunging minor folds were mapped in fine-grained, thin-bedded, tuffaceous volcanic sandstone on Big Missouri Ridge, west of Fetter Lake, where quartz sulphide lenses similar to Big Missouri-type mineralization have been explored. The mineralization appears to be localized along axial planar fractures in the sandstones.

STRUCTURES IN HAZELTON ROCKS: Members of the Hazelton Group in the Stewart Complex form elongated, lenticular masses. In the third dimension as well they are apparently lenticular and illustrate what can be termed grossly a maceral structure in which each lens overlaps the others. Weak foliation, minor folds, and some lineations are variably developed in all the members of the assemblage. The degree of deformation depends on rock particle size and competency.

Foliation: Foliation, which includes all secondary planar structures, has developed in a number of ways with varying degrees of complexity. Least deformed cataclasites of shiny green, grey, or purplish laminations that transect primary features have been caused by smearing of the matrix. In mylonites, foliation laminae are more pronounced and accentuated by fine mineral layers. Semi-schists and schists developed in the Salmon River valley area exhibit planar structure resulting from the development of metamorphic minerals.

Well-foliated gneisses are rare, but alternating feldspar-hornblende laminations may occur along the margins of the plutons. Foliated rocks are largely in the contact zones of plutons or dykes. The large cataclastic zones developed in certain Hazelton members pre-date plutonism.

Minor Folds: Small open folds characterize the fine-grained strata, whereas major folds formed in the thick, coarse-grained beds. As a result, small-scale folds are most abundant in areas, such as Big Missouri Ridge and Summit Lake, where fine-grained members are prominent. Minor folds in medium-grained Hazelton strata west of Bear River Ridge have upright axial planes and plunge steeply west. East of American Creek, where the rocks are uniform sandstones, minor folds are open undulations plunging easterly at a moderate angle. South and east of Bear River the rocks are generally coarse grained and massive except in the Marmot River area where minor folds in thin-bedded, fine-grained sediments plunge steeply north.

Lineation: Outside the main cataclasite zones, lineation is not a conspicuous structural element in the area. Linear elements in the deformed volcaniclastics are largely elongate rock and mineral clasts, and grooves in the foliation planes, which reflect lenticular mineral clumps. In the Unuk River and Cascade Creek areas lineations are more variable than elsewhere, but are crudely subparallel to minor fold axes.

Summary: The heterogeneous nature of strata of the Unuk River Formation resulted in variable responses to deformation. Except for local schist development, mineral re-crystallization has not been a major feature of the overall deformation. Uniform structural features, combined with the evidence for limited recrystallization, suggest that deformation was related to a regional tectonic event, the uplift of the Coast geanticline, and related plutonism during the early phase of Nassian Orogeny.

BETTY CREEK STRATA: Folds in Betty Creek rocks are mainly large open flexures related to erosional troughs formed in Lower Jurassic and older country rocks. Thin wedges of fossiliferous Betty Creek conglomerate blanket the eastern flank of the Bruce-jack Dome; these form remnant, northeasterly plunging, synclinal sheets that are overlapped by younger formations at Treaty Creek. The bulk of the Betty Creek Formation, which extends from Treaty Glacier to the Bowser River at Mount Jancowski, is an open, basin-like syncline that plunges at a shallow angle to the southeast. From Mount Jancowski south to the top of Bear River Ridge opposite Bitter Creek, the Betty Creek Formation is a tighter syncline. The Jancowski syncline has its strongest development along the 3 000-metre-high Mount Jancowski-Mitre Mountain massif; the Betty Creek Formation thins rapidly to the south, roughly along the axis of the Divide-Long Lake valley. The Jancowski syncline is asymmetric and overturned slightly to the east; from the top of Bear River Ridge at Mount Shorty Stevenson, the canoe-shaped syncline plunges northerly toward the Bowser River at a shallow angle. At Bowser River it is transected by a series of south-side-down normal faults. The total length of the syncline, from Treaty Glacier to the top of Bear River Ridge, is 60 kilometres; it is one of the largest features in the area.

In the Bear River Pass section Betty Creek strata blanket the Lower Jurassic sequence, filling in the old erosional surface, and as a result, Betty Creek rocks have been left as irregular, slightly warped erosional remnants.

In the Alice Arm district, correlatives of the Betty Creek strata blanket part of the easterly flank of the Lower Jurassic rocks much as they do in the Bear River pass section.

At Anyox, the volcanic flow and pillow lava sequence defines northerly trending open asymmetric folds that are moderately overturned to the east, like the Jancowski syncline. Parallel folds in the pillow volcanic sequence at Anyox have an important bearing on the present location of ore deposits. A major fold that involves overlying Salmon River Formation rocks has been called the Bonanza syncline (Fig. 2C).

Summary: Rocks comprising the Betty Creek Formation were deposited as a thick blanket on the folded, faulted, and eroded Lower Jurassic Unuk River Formation. Normal faulting and pre-late Middle Jurassic uplift and erosion have left irregular remnants of Betty Creek strata in the area. Major folds in the Betty Creek Formation are restricted to a northerly trending belt along the central part of the Stewart Complex, where extensive northerly trending faults also are localized. Minor folds, lineations, and foliations are rare.

SALMON RIVER STRATA: Bajocian Salmon River strata comprise the northerly, easterly, and southerly limits of the study area; like Betty Creek strata, rocks of this unit are found as erosional remnants on the older rocks from Iskut River south to Alice Arm.

Large outliers of Salmon River Formation are shown on the geological maps at Sulphurets Creek, Bowser River, Bear River Ridge, Bitter Creek, and in the Anyox and Alice Arm districts. These remnants are all synclinal marking fault-controlled trough-like basins of deposition in underlying Betty Creek and Unuk River strata. These depositional basins generally trend northerly to northwesterly and, where best exposed, usually contain upright, canoe-like folds. They have all been subjected to variable amounts of plutonism, metamorphism, deformation, and alteration.

Along the northern limits of the Stewart Complex the edge of the overlying Salmon River Formation has been mapped in some detail (Fig. 2A). The finger-like extensions of these rocks across the older strata are localized along fault or shear zones where erosion in the Betty Creek and underlying Unuk River rocks was more extensive. Salmon River rocks and younger Nass strata in this area display a disharmonic, nonplanar, noncylindrical fold pattern (Badgley, 1965, pp. 50–94). The Dillworth Syncline typifies structures in the Salmon River strata.

Mount Dillworth Syncline: The Mount Dillworth syncline lies in a parallel structural trough astride the westerly limb of the American Creek anticline. The fold is open, slightly inclined, and exhibits fold disharmony typical of structures involving strata of variable competency and thickness. Overall, the fold has a canoe-like shape with the ends resting on the south shoulder of Mount Mitre and on Bear River Ridge at Mount Shorty Stevenson. From the northerly apex of the fold on Mount Mitre, the structure plunges south into Betty Creek at about 40 degrees. The keel section has a maximum thickness of about 1 800 metres in the Mount Dillworth section. The plunge of the syncline north from Mount Shorty Stevenson is about 25 degrees. The contact between Salmon River and older rocks outlines the Dillworth syncline (Grove, 1971, Fig. 3), and displays several complex digitations.

Salmon River siltstones and greywackes overlying competent Hazelton epiclastic volcanics illustrate fold attenuation at the south end of Summit Lake, whereas the smooth, apparently conformable zone along the west side of American Creek represents a contact between physically similar rock types. Minor folds are visible on all scales and many are disharmonic. In these rocks the minor folds are difficult to trace because of the general lack of marker horizons. Complex folds mapped west of Little John Lake on Troy Ridge are perhaps the best examples of disharmonic folds in the sequence (Grove, *op. cit.*, Plate XI).

Minor Structures: Salmon River strata are preserved as structural remnants lying in contorted trough-like or canoe-shaped depressions in the underlying Hazelton. These troughs are largely tectonic, but they partly reflect Middle Jurassic erosion. The sediments deposited in these depressions were thick and because of subsequent deformation have been preserved from erosion.

Cleavage: Cleavage is a conspicuous feature in the thinly laminated argillaceous siltstones of the Salmon River assemblage. Phyllites are prominent at Slate Mountain, where the siltstones unconformably overlie Hazelton epiclastics and cataclasites. At the south end of Slate Mountain cleavage is generally horizontal, cutting across the steep axial planes of minor folds. Cleavage is also apparent as a thin phyllitic zone developed below and parallel to the unconformity in underlying Unuk River Formation strata. To the north cleavage patterns show no direct relationship to the minor folds. Well-developed cleavage south of the Long Lake dam and along the west side of Slate Mountain cuts across all visible minor fold axes parallel to a small, steep, northerly trending fault (Grove, *op. cit.*, Fig. 3). Phyllitic siltstones are well developed along this section, and the fault-related cleavage has been superimposed on an undulating, contact-controlled cleavage. The foliations are related to thrust faulting and to sliding of Salmon River strata across the old surface with the production of slip cleavage.

Minor Folds: Folds of different styles are visible at various scales in almost all the Salmon River rocks. In size, the minor folds range from centimetre scale, complex folds to simple troughs up to 8 kilometres long. The multitude of structures precludes using a simple nomenclature such as was used for folds in the older Hazelton rocks. Instead, generalized groups of folds are named and described with examples in the following paragraphs.

Small-scale ripple-like structures occur in thinly striped grey to buff argillaceous siltstones such as are exposed at the south end of Slate Mountain; the amplitude seldom exceeds 1 to 2 centimetres. In all the laminae examined the peaked crests indicated stratigraphic tops. Where completely exposed these structures exhibit separate peaks rather than the elongate ripple wave form. In foliated laminae, the ripple-like structures are asymmetric and disharmonic.

Folds larger than centimetre scale but less than 25 metres in amplitude are found in all Salmon River Formation siltstones. These vary in form from simple, open, upright flexures to complex, tight recumbent folds. These structures are generally restricted to thin-bedded siltstones intercalated in sandstones. The small-scale isoclinal folds are typically found where the containing sandstone members are strongly flexed, such as in the crest of a fold. Flexure folds are common on Mount Dillworth in siltstones within the sandstone unit.

Complex isoclinal fold zones are most common in thick siltstone units in which there are faults and igneous intrusions. The Glacier Creek-Maude Gulch section exemplifies such a zone, and complex, large amplitude isoclinal folds abound.

Folds with amplitudes greater than 25 metres are common in siltstone members within the Dillworth syncline. These can be mapped by using marker horizons and are also traceable on air photographs. Grove (*op. cit.*, Fig. 2) shows the most prominent of these minor folds. Along the west side of the main trough these folds are generally asymmetric with Z and box-like geometry. At Long Lake folds plunge northerly; on the north slope of Mount Dillworth they plunge southerly into the trough. To the east, toward Bear River Ridge, the folds become upright. The folds show both concentric and similar styles. Canoe-folds at outcrop and larger scales are common in the Divide Lake area.

Hidden Creek Syncline: The Hidden Creek syncline at Anyox represents one of the smaller Salmon River structural remnants, but economically is the most important yet found. All major known massive sulphide deposits in the Anyox pendant lie at, or near, the contact between the pillow volcanics and the overlying siltstones. At the Hidden Creek mine (Hanson, 1935, p. 9) suggested that the argillites (Salmon River Formation) dip easterly at surface, then westerly to a depth of 600 metres. Nelson (1948) concluded that these sediments, although folded, dipped westerly under the 'amphibolites' which intruded the sedimentary sequence.

The supposed 'intrusive amphibolite' at Anyox is a thick pillow volcanic sequence that is in part conformably overlain by a thick calcareous siltstone and greywacke sequence. The major northerly trending 'Anyox' syncline includes both the pillow volcanics and the overlying siltstones. The restricted, highly folded, northerly trending belt of Salmon River siltstones lying along the west side of Hastings Arm comprises the Bonanza syncline (Fig. 2C).

The Bonanza syncline is a shallow plunging structure, and, like the Dillworth syncline, is overturned to the east. Minor folds in the rocks are disharmonic, nonplanar, noncylindrical folds with noncylindrical axial surfaces. The axial plane area of the fold between Cascade and Bonanza Creeks has been penetrated by Tertiary plutons; these deform an already complexly folded section. Contacts show a variety of small-scale features developed in both the underlying pillow volcanics and the overlying sediments. In the axial zone at Bonanza Creek the pillow lava sequence is gradational through banded cherts into the overlying calcareous siltstones. On the east limb of the syncline, pillows are sharply flattened parallel to the fold axis; pillows along the upright to overturned west limb are less flattened. Minor folds are variably developed south of Hidden Creek and foliation and lineation are virtually absent in the broad open fold to the north.

Summary: Fold structures in Salmon River strata are related to plutonic emplacement and gravity tectonics. Plutonism was most significant at the margins of the plutons and in the dyke swarms. The maximum observed width of a deformation halo around an intrusion is about 1 500 metres along the margin of the Texas Creek pluton. At Anyox, deformation related to the plutons is minor and apparently restricted to the axial zone of part of the Hidden Creek syncline.

Gravity tectonics played a major role in the development of fold structures in the Salmon River strata and produced numerous slump features and minor fold structures within the stratigraphic sequence. These structures, which are found throughout the Salmon River sequence, indicate a close relationship between deformation and basin subsidence.

CATACLASITE ZONES

Several major cataclasite zones have been mapped in the Stewart Complex (Figs. 2 and 13). These zones were not recognized by earlier workers and they were important in localizing certain mineral deposits. It is significant that none of the cataclasite zones mapped extend into strata of the Betty Creek or Salmon River Formations. Also, as shown on Figure 2, the cataclasites were largely, if not exclusively, confined to a sequence consisting of acid lava, mixed conglomerate, sandstone, and limestone.

South Unuk Zone: The South Unuk cataclasite zone has been traced from the South Leduc Glacier, where it is cut by Tertiary granite, north along the west slope of Granduc Mountain to the west slope of Mount George Pearson, where it lies between the thick pillow volcanic unit and the hornblende diorite stock. It then continues northwesterly toward the lower east slope of the South Unuk River and past the Unuk River junction to join the narrow Harrymel Creek fault zone, which appears to die out toward the Iskut River. In this 45-kilometre length, the zone of deformation includes, or follows, the carbonate-rich sequence of the Unuk River Formation, has a steep to vertical dip, and strikes northerly to northwesterly, essentially parallel to attitudes of the involved members. At Granduc Mountain, the zone is bounded on the west by north-trending, steep-dipping gneisses and on the east by faulted massive pillow volcanics and foliated thick volcanic conglomerates. In this 2-kilometre-wide section the zone includes a diverse group of metamorphic rocks consisting of calc-silicate cataclasites and mylonites, pelitic mylonites, ultramylonites, blastomylonites, boudinaged carbonate lenses, and phyllonites, as well as the extensive sulphide lenses that constitute the Granduc ore deposit. The zone has been intruded by northwesterly trending Tertiary Hyder phase dykes and cut by northerly trending graphitic fault zones that offset these dykes and the orebodies. At Sawyer Glacier, the zone includes two deformed syenite stocks as well as the mixed sedimentary-volcanic sequence consisting of limestone lenses, tuffaceous sandstones, cherts, andesitic volcanic flows, and quartz boulder and cobble conglomerates. Toward Unuk River, where the amount of limestone and fine-grained sediments decreases, the cataclasite zone narrows rapidly; at Harrymel Creek it is a narrow, vertical, chloritic schist zone.

At Granduc Mountain dark and light mineral segregations produce a well-developed colour banding in the cataclasite zone. This banding typifies most of the length of the zone and extensive underground mine workings provide outstanding examples of metamorphic differentiation by mechanical deformation (Plate XIII). Although Prinz and Poldervaart (1964) suggested that distinctly layered mylonites are rare, the Unuk River, Cascade Creek, and Maple Bay cataclasite zones are characteristically so well layered that they have generally been described as volcanic tuffs, sediments, and schists in the older literature (Norman, 1962). Most of the limestone lenses or bands within the deformed zone are boudinaged and tightly folded, as illustrated on the geological maps (Figs. 2A and 2B). Some of these lenses have been deformed, producing simple tight folds with crests thickened up to 10 times the thickness of the stretched limbs; extensive 6-metre-thick lenses have been partly balled up to form 120-metre-thick piles. Other large features in the zone include crushed syenite stocks, now seen as lumps of broken coarse red microcline crystals in a mylonitic feldspar matrix. Diorite dykes and stocks in the zone are boudinaged and crushed to an extent that they are now kakirites. Rhyolite, chert, and quartz cobble and pebble conglomerate lenses traced from the Sawyer Glacier area into the Granduc Mountain section are represented by the weakly foliated, thick ultramylonite lenses in the sulphide ore zone. Definite relationships have not been established between all the primary and deformed units. Sulphide and oxide bodies within the zone are also deformed; they are preserved as overlapping, pancake-like lenses within the mylonite-phyllonite-ultramylonite sequence.

Mineral aggregate lineations and dragfolds provide dispersed patterns which are probably related to the inhomogeneous deformation character of the movement. The presence of strained microcline and quartz clasts in the mylonite confirms that stress was nonuniform during deformation (Theodore, 1970). At the Granduc mine rolls and warps along the mylonite zone correspond to thick sulphide sections that are mantled by ultramylonite sheets. Neither the amount nor the sense of movement within the Unuk River cataclasite zone are presently known in detail but minor structures in many of the folded limestone lenses indicate a component of horizontal movement. Norman and McCue (1966) suggested that the dragfolds, developed in what they termed recrystallized argillites, siltstones, and tuffs, form one of the major ore controls at the mine and record internal rotational movement caused by relative south and upward movement of the west side of the Granduc ore section.

Layering, colour striping, and banding of rocks in the South Unuk cataclasite zone reflect the mineral differentiation effected by the deformation. Unaltered, broken, or rolled layers of brown hornblende form the darker bands, broken angular diopside and epidote form green layers, and quartz, feldspar, and recrystallized calcite form light-coloured layers. Recrystallization appears to be restricted to calcite, quartz, apatite, and magnetite (excluding sulphide minerals) with very fine-grained fresh brown biotite prominent as discrete folia in the phyllonite layers. Lenses and streaks of recrystallized quartz are characteristic of the phyllonites; these were originally constituents of pebble conglomerates (Plate XV).

Discussion: Knopf (1931) and Theodore (*op. cit.*) suggested that the physical conditions that existed during mylonitization can be determined by a study of phase petrology and textural relations of the mineral components. The minerals in the pelitic and calc-silicate mylonites forming a large part of the South Unuk cataclasite zone remained stable, whereas minerals in the carbonate lenses underwent complete recrystallization. Limestone samples from the cataclasite zone contain about 0.23 per cent MgO; using Theodore's (*op. cit.*, p. 444) temperature calibrations for Mg content of calcite in dolomitic marble, this indicates that deformation in the Unuk River zone took place at temperatures less than 300 degrees Celsius. Epidote remained stable throughout the zone, and only biotite in the phyllonites indicates minor recrystallization of hydrous phases. The evidence suggests that much of the rock in the zone deformed by shear at low temperature rather than by plastic flow in the presence of an aqueous fluid phase where rock strengths are negligible.

The zone cuts Lower Jurassic rocks but, at the head of Harrymel Creek, it is overlain by Middle Jurassic sediments. It is suggested that the cataclasite zone developed as a result of local tectonic overpressures related to Middle Jurassic or earlier plutonism, represented near Stewart by the Texas Creek intrusion and evidenced in the Unuk area by granodiorite boulder conglomerates at the base of the Middle Jurassic Salmon River Formation.

Cascade Creek Zone: The Cascade Creek zone extends 12 kilometres along the lower west slope of Bear River Ridge between Mount Dolly and Mount Dillworth. The maximum width of the zone is 2 kilometres along the Cascade Creek section immediately north of the Alaska border.

The Cascade Creek unit includes cataclasites, mylonites, minor kakirites, semischists, and panels of country rock. The zone trends northerly and is convex to the east; minor structures in the zone indicate an overall moderate to steep westerly dip. Foliations vary widely, but lineations show a consistent westerly plunge.

Petrography (*see* Chapter 3) indicates that the parent materials were derived by sedimentary processes from a pre-existing sequence of epiclastic volcanics; abundant relict textures survived the dynamothermal metamorphism. Surface weathering and limited recrystallization locally obscure the primary features; these have led, in the past, to the conclusion that the rocks are volcanic extrusives, and disregarded the effects of metamorphism.

The dynamothermal metamorphic zone is narrow and lies along the margin of the Texas Creek granodiorite and Hyder quartz monzonite intrusives. The event was low grade, as indicated by the relict structures and textures, but involved a complex interplay of cataclastic and crystalloblastic processes that produced the various mylonites, cataclasites, and low-grade schists which now comprise most of the Unuk River strata in this zone. Textures in the schists suggest that recrystallization outlasted the deformational events. Undeformed micas are aligned in planes of schistosity produced during cataclasis and recrystallized quartz and plagioclase grains show no sign of strain or granulation.

Field relationships indicate that the Cascade Creek cataclasite zone is overlain by Middle Jurassic sediments in the Mount Dillworth section and is truncated by Tertiary Hyder phase plutons. The zone developed prior to Texas Creek plutonism and associated metasomatism, but was closely related in time to that plutonism.

Maple Bay Zone: A mylonite-cataclasite zone 3 kilometres wide and 11 kilometres long is preserved at Maple Bay within the Anyox pendant. A narrow mylonite zone in the Georgie River pendant, which is on strike with the Maple Bay zone, may have been a northerly extension prior to the intrusion of Tertiary plutons.

The Maple Bay cataclasite zone includes a broad area of cherty looking, weakly foliated ultramylonites bounded on the west by chloritic biotite schists and on the east by phyllonites. Foliation in these rocks is essentially vertical and northerly trending. In the central ultramylonite zone, where irregular blocks of weakly crushed hornblendite are crudely aligned in a northerly direction, the zone has been closely faulted and extensively veined by quartz sulphide lenses. The deformed zone and quartz veins are cut by Tertiary intrusives forming the north and south boundaries of the Anyox pendant.

Summary: The Unuk River, Cascade Creek, and Maple Bay cataclasite zones are all steep, northerly trending structures developed within Lower Jurassic sedimentary and volcanic rocks, dykes, and small plutons. The mylonites were developed largely in response to intense differential deformation accompanied by some metamorphic recrystallizaton. The temperature at which this mylonitization occurred in the Unuk River zone, as indicated by MgO content in limestone, is below 300 degrees celsius. The apparent lack of chemical degradation of the finely comminuted plagioclase phyllonites suggests a generally dry environment during mylonitization.

The high-pressure, dry, low-temperature deformational events recorded here appear to be comparable to reported small-scale or restricted zones found in many parts of the world. Similar zones are rare in Western Cordilleran literature. The general lack of recognition of cataclasite zones in the Western Cordillera can be partly attributed to an extensive cover of glacial debris, and partly to the tendency to map banded, fine-grained greenish rocks as volcanic tuffs (Schofield and Hanson, 1922; Hanson, 1929, 1935, etc.) and zones as fault lineaments.

FAULTS, LINEAMENTS, AND FRACTURES

Many of the major topographic features in this area were controlled by extensive fault and fracture systems, along which apparent movement has been limited but is of local importance. The abrupt direction changes of erosional features, such as the fjords and glacier and river valleys, are attributed to these zones of limited movement.

Four fault systems can be deduced from the geologic map; these comprise northwesterly, northerly, northeasterly, and easterly sets. However, in any attempted stress analysis, the time factor would show that each set has been reactivated several times. Later faults, which affect the majority of the rocks in the area, mainly represent simple displacement features where rock competency has played a role in determining the attitude and the degree of development of the faults. Both strike-slip and thrust faults are prominent in Salmon River and Nass Formation rocks, but strike-slip faults are more extensive, involve the underlying Hazelton rocks, and include most of the faults shown on Figure 2.

Faults are common features in all the mines and mineral deposits in the Stewart Complex. They have generally small movements and played a minor role in controlling sulphide mineralization.

Simple rock fractures have not been subjected to any rigorous treatment but they have been considered significant in the study of mineral deposits. Fractures were found useful as a means of discriminating between dyke rocks, various plutonic rocks, and other country rocks. At the Silbak Premier mine, for example, it was found that rock fracture sets could be used to differentiate between similar-looking altered country rock and the Premier porphyry.

TECTONIC EVOLUTION OF THE STEWART COMPLEX

The Stewart Complex lies along the west margin of the Bowser Basin where, because of essentially continuous tectonic activity, an important part of the evolution of the Bowser Basin and the adjoining Coast Plutonic Complex has been revealed. Evidence for the pre-Permian history of the Coast Plutonic Complex has been mainly derived from southeastern Alaska or from more remote points. Scattered evidence from Alaska, Washington, and California suggests that Precambrian crust underlies considerably more of the Western Canadian Cordillera than is generally accepted. In southeastern Alaska, Buddington and Chapin (1929) presented the first evidence for Early Paleozoic granite emplacement, as shown by the presence of granite cobbles in Silurian-Devonian sediments.

Radiometric age dates (Lamphere, *et al.*, 1965) indicate the presence of Ordovician (or Silurian) plutons at Annette Island near Prince Rupert and 400 to 433-million-year-old ultramafic rocks west of Ketchikan. In Washington, Misch (1966) has implied the emplacement of Early Paleozoic plutons as part of a pre-Middle Devonian complex. Roddick, (1966), Roddick, *et al.* (1967), and Brew, *et al.* (1966) suggested that pulse-like activity extended through the Paleozoic becoming more frequent in the Mesozoic and culminating in Late Cretaceous and Early Tertiary time (Fig. 14). Gilluly (1972) has compiled the available radiometric age dates from plutonic and volcanic rocks in the Western Cordillera and indicated that plutonism was an essentially continuous process since the Carboniferous, rather than widely separated major episodes as was once widely accepted. He suggested that the apparent dominance of Tertiary plutons relates more to accessibility than volume.

The evolution of the Sierra Nevada of California (Kistler, *et al.*, 1971) and the Coast Plutonic Complex has followed similar trends. However, Hutchison (1970) pointed out that, while the Sierra Nevada includes early, mantle-derived gabbroic and ultrabasic phases, none have been found in the Prince Rupert area. He concluded that the bulk of the plutons in this segment were generated along parallel zones within the Central Gneiss Complex, and probably represent a deeper level not now exposed in the Sierra Nevada. On the basis of plutonic compositions recognized by Buddington (1927) in Alaska, Hutchison proposed the concept, later expounded by Moore (1959, 1962), of a quartz diorite line that separated first cycle granitic rocks derived from eugeosynclinal volcanic and sedimentary rocks on the west, from platform or crust-derived granitic rocks on the east. The three major parallel zones, outlined by Hutchison (1970) in the Central Gneiss Complex, represent a single Barrovian-type metamorphic belt composed of uplifted blocks with the oldest on the west and the youngest on the east. These formed at the margin of a Precambrian crust and involved continuous small contributions from the mantle. In terms of the tectonic framework of the Western Cordillera in general and the Stewart Complex in particular, the Coast Plutonic Belt has been a prominent structural feature.

In the Portland Inlet section Hutchison (1967) has shown the Central Gneiss Complex to be Late Paleozoic or older; at Terrace, Duffell and Souther (1964) indicated that Permian strata rest unconformably on a gneiss complex. Roddick (1970) has also assigned a Permian or older age for the Gneiss Complex southeast of Kitimat. At Anyox and along Portland Canal there is a narrow belt of agmatitic migmatite consisting of Hazelton Group strata veined by Hyder phase granitic material that forms the margin of Hutchison's proposed younger eastern metamorphic zone. In the Unuk River and Leduc River sections of the Stewart Complex, equivalent amphibolite-grade gneisses are overlain by Late Triassic and Early Jurassic country rocks; these are thought by the writer to represent Middle Triassic or older metamorphic rocks such as observed by Souther (1971) in the Tulsequah area. The presence of a Late Permian carbonate sequence at Oweegee Peaks, where Late Triassic faulting and younger uplift have brought a small segment of the Paleozoic basement to the surface, confirms the regional evidence that stable shelf conditions prevailed at that time. The apparent absence of Paleozoic strata within the Stewart Complex, although they have also been preserved to the west and north along the Iskut River and to the south near Terrace, suggests that pre-Late Triassic uplift and erosion, the Tahltanian Orogeny of Souther (*op. cit.*), was essentially confined to the Gneiss Complex and the Coast geanticline (Fig. 5). Early Late Triassic sedimentation and volcanism, locally expressed by the McQuillan Ridge sequence of intercalated volcaniclastics, carbonates, cherts, and thin basaltic and andesitic flows, followed the Tahltanian Orogeny. Parts of the Coast geanticline and Insular Belt remained emergent during the Late Triassic. During this time volcanism was extensive; subsidence and more stable conditions returned during the Norian epoch. Deposition of volcaniclastics, silts, and shales was followed by carbonate deposition, well represented by the Sinwa Formation that occurs in parts of the Unuk River area and as scattered thin carbonate lenses elsewhere in the Whitehorse Trough. Souther (*op. cit.*) suggested that thinning of the Sinwa Formation indicated slight emergence of the Stikine Arch. This and accompanying uplift in the Coast geanticline became more extensive and marked the early evolution of the Taku embayment in the Tulsequah area and the Bowser Basin (Souther, *op. cit.*). Extensive Late Triassic to early Early Jurassic uplift and erosion uproofed Late Triassic plutons and the gneiss complex; this resulted in deposition of the thick Early Jurassic Unuk River strata in the western part of the Bowser Basin and the Inklin strata in the Tulsequah area. Most of southeastern Alaska was emergent during Early Jurassic time resulting in a broadening of the Late Triassic Coast geanticline (Fig. 8).

In the Stewart Complex, widespread late Early Jurassic volcanism and sedimentation, assumed here to represent shallow marine conditions, were followed by post-Toarcian folding and plutonism related to regional compression. This was accompanied by cataclastic deformation, metasomatism, and normal faulting, then regional uplift and extensive erosion of the Lower Jurassic Unuk River Formation. In the Tulsequah area, Souther (*op. cit.*) included both the Lower Jurassic and Middle Jurassic sediments within the Takwahoni sequence, although he noted that it was possible that a break in deposition occurred between Early and Middle Jurassic time. A break, recognized in the Stewart area, has also been mapped by Tipper (1971) in the Smithers area. Baer (1969) suggested that a second orogenic cycle, involving andesitic volcanism, plutonism, and sedimentation in the south-central Cordillera and Coast Plutonic Complex, began during Middle Jurassic time; he cited as evidence Middle Jurassic volcanics lying unconformably on crystalline rocks of the first cycle.

Following late Early Jurassic erosion in the Stewart Complex, the early Middle Jurassic Betty Creek strata were deposited across the depressed surface, filling in trenches and troughs, essentially resurfacing the old highland. The Betty Creek Formation includes volcaniclastics, volcanic flows, and pillow lavas thought to have been largely deposited in a shallow marine environment.

Betty Creek sedimentation and volcanism were followed by normal faulting, graben development, minor folding, uplift, and erosion. Uplift and erosion appear to have been greatest along the northwest edge of the Stewart Complex and restricted to fault blocks. At Anyox, Betty Creek volcanism was followed by a conformable marine sedimentary sequence. The deposition of the Bajocian Salmon River Formation marked a time of transgression with fine-grained marine sediments again filling fault-controlled troughs in older country rocks. Sedimentation was widespread; equivalent rocks have been mapped by Souther (*op. cit.*) as the Upper Takwahoni Formation in the Tulsequah area, and a similar unit has been outlined by Tipper (*op. cit.*) at Smithers. Granitic clasts in the basal Salmon River Formation indicate the uproofing of Middle Jurassic or older plutons along the Coast Geanticline immediately to the west prior to the major depression and broadening of the basin (Fig. 11).

The Middle and Upper Jurassic units within the Stewart Complex are similar in all respects and have been separated only by a granite cobble zone lying below fossiliferous Oxfordian-Kimmeridgian strata. Tipper (personal communication) has stated that 'this is precisely the situation in Taseko Lakes and Mount Waddington, and has an analogy with Crickmay's stratigraphy in Harrison Lake'. It appears to be more than a local feature and probably represents uplift of the Coast geanticline. Deposition of the Upper Jurassic Nass Formation was largely restricted to the Bowser Basin, although Campbell (1966) recorded a narrow basin of roughly correlative rocks in a southerly remnant of the deformed Nechako trough. The Nass and Salmon River Formations exhibit similar complex disharmonic fold structures in part related to gravity tectonics and in part to Tertiary plutonism. Faults are common and the major zones of movement appear to represent revived older structures. Correlatives of the Nass Formation in northeastern British Columbia include the Fernie Passage beds. Province-wide erosion followed Nass sedimentation and was followed by deposition of the Hauterivian and Albian Skeena Group. These rocks have not been preserved in the Stewart Complex.

Tertiary plutons that occur along the margin of the Central Gneiss Belt and as satellite plutons and dyke swarms east of the margin, followed predominantly northwesterly trends that cut across northerly trends of the older gneisses, Triassic and Jurassic sediments and volcanics, and the Mesozoic plutons. Quaternary volcanism was concentrated along a northerly trending Cenozoic tension zone (Souther, *op. cit.*) and along a northeasterly zone outlined by the writer (Fig. 1). To the east, Cenozoic volcanism has been largely confined to the margins of the Bowser Basin.

Summary: The bulk of the evidence favours the evolution of the Stewart Complex portion of the Western Cordillera eugeosyncline by continuous plutonism, volcanism, and contemporaneous sedimentation. Early Paleozoic evidence of plutonism in the Coast Plutonic Complex indicates that this feature has evolved along the continental margin accompanied by trough and successor basin development along both flanks. Folding as an expression of directed stress has played a minor part in the regional tectonics. Block-like uplifts related to faults and sequential vertical tectonics have responded to and accompanied motion of the major tectonic units.

Unconformities between major stratigraphic units as well as within the units result from block movements along well-defined faults, developed in response to regional tectonism. The mainly Mesozoic Stewart Complex responded to the development of the Coast geanticline and finally, as a result of Tertiary plutonism, was essentially fused to the geanticline. Overall, lithostructural evidence supports the dominant role of vertical tectonics in the development of this region.

5

ECONOMIC GEOLOGY STUDIES IN THE STEWART COMPLEX

Mineral exploration in the Stewart Complex started in 1893 when placer miners prospected the Unuk River and its tributaries. The discovery of bonanza gold-silver ore at Premier, near Stewart, and the successful operation of the mine and smelter at Anyox led to extensive exploration of the area which is continuing. Mineral production from the Stewart Complex has included gold, silver, copper, lead, zinc, cadmium, tungsten, molybdenum, iron, arsenic, antimony, and selenium. The Stewart Complex ranks second in British Columbia in the total production of gold, silver, and copper. The Silbak Premier mine is second in silver production after the Sullivan mine at Kimberley, and third in gold after mines in the Bralorne and Rossland camps.

MINERAL DEPOSIT DISTRIBUTION IN THE WESTERN CORDILLERA

Concepts regarding mineral belt and mineral deposit distribution in the Canadian Cordillera were originally developed during the period 1871 to 1905 by Richardson, Selwyn, Dawson, McConnell, Bauerman, Brock, and others. The general concept developed by the early workers related mineral deposits to two main belts, separated by the Coast Range batholith. The westerly zone was called the Pacific belt and included the Anyox and Britannia deposits. The easterly zone, called the Interior belt, included the Silbak Premier deposit at Stewart, the Dolly Varden at Alice Arm, and small prospects near Terrace and Smithers. This concept led to the general acceptance that copper mineralization was concentrated at the western margin of the batholith and that gold, silver, and lead were localized near the eastern margin. Schofield (1921) suggested that this apparent distribution was related to the contrasting metamorphic grades found at the batholith's margins and to different levels of erosion.

Souther and Armstrong (1966) suggested that copper and molybdenum deposits in northwestern British Columbia are most frequently associated with relatively young syenitic or monzonitic phases of the Coast Range batholith. They also suggested that the Anyox, Granduc, and other large copper deposits in the Western Cordillera were closely associated with an arcuate belt of Triassic pillow lavas which extended from near Tulsequah, south through the Stikine and Iskut River areas to include the Granduc and Anyox deposits within the Stewart Complex. Recent discoveries suggest that mineralization in the Stewart Complex is related to several ages and types of plutons, not only to major Tertiary intrusives which comprise the east margin of the Coast Plutonic Complex.

The regional patterns of mineral distribution can no longer be related simply to intrusives. The Stewart Complex represents one of the marginal uplifts of the Mesozoic Bowser Basin where a variety of mineral deposits can be shown to be directly related to certain plutons, distinct structural features, and unique lithologic controls.

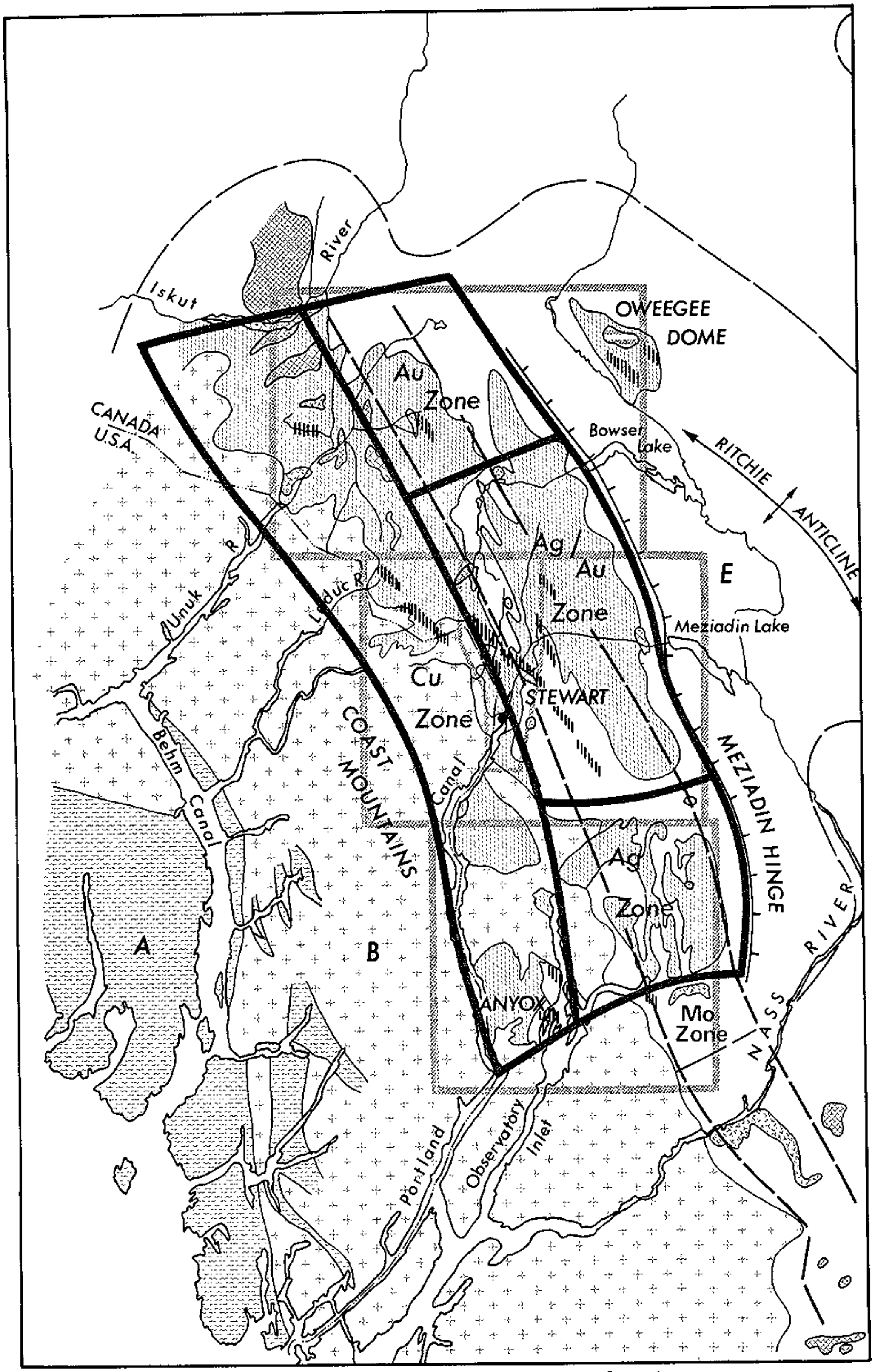


Figure 17. Metal distribution zones, Stewart Complex.

DISTRIBUTION PATTERNS OF MINERAL DEPOSITS IN THE STEWART COMPLEX

The distribution of mineral deposits in the Stewart Complex (Fig. 13) can be related to several factors. Most occur in low-lying areas accessible from the fjords and streams, and below the snow and ice cover. The blank areas reflect the presence of barren Middle and Late Jurassic sedimentary strata, and the generally barren Coast Plutonic Complex and its satellite plutons. Mineral belts in the Stewart Complex are apparently restricted to northerly trending elongate clusters. These belts follow the South Unuk River, Cascade Creek, Bear River-American Creek, and Kitsault River topographic lineaments; however, the Maple Bay and Anyox belts are apparently unrelated to topographic features. All of these mineral belts include deposits of different ages, variable mineralogy, and different local geological environments. These mineral belts, or map features, lie along the northerly structural trends, but metal zoning within each belt is difficult to relate to an overall controlling feature.

Distribution Patterns of Major Metals in the Stewart Complex: Although Hanson (1935) dismissed the possibility of local mineral or metal zoning in part of the Stewart Complex, Buddington (1929) related the vein-type mineralization in the Hyder district to the Texas Creek pluton and related local zoning of gold, silver, and sulphides to the margins of the pluton. He recognized that the Texas Creek was an older pluton, and also that the younger Hyder pluton, as well as the Coast Range batholith of Hanson (1929, 1935), were unmineralized and unrelated to the majority of the local mineral deposits. The writer has recognized metal zoning on both a local and a regional scale.

In the Stewart Complex, deposits tend to occur in linear clusters. These linears or belts appear to reflect topographic lows which in part reflect local structures. However, younger sediment cover as well as ice and snow, partially mask the overall pattern. Gold, silver, copper, lead, zinc, and molybdenum are the most important metals found in the Stewart Complex. Because of their high value and wide distribution, gold, silver, copper, and molybdenum have been the primary exploration targets, and their abundance is well documented. The writer has utilized these metals to separate the Stewart Complex into four simple areas or cells dominated by gold, silver, copper, and silver-gold (Fig. 17). In this way, a broad pattern of regional zoning of the mineral belts becomes visible. The zones outlined illustrate the dominance of silver-rich, gold-poor deposits in the Alice Arm district, silver-gold deposits in the Stewart district between Georgie River and Summit Lake, and gold-rich, silver-poor deposits in the Bowser River area. The gold and silver zones are bounded on the west by copper deposits at Anyox, Maple Bay, and Granduc Mountain, which together form a northwesterly trending zone which has been partly transected by the Tertiary Hyder pluton. The easterly boundary of the gold and silver zones is formed by the extensive cover of Middle and Upper Jurassic sediments.

Mineral zones of less abundant metals that lie within the framework of the four main zones have also been defined. The distribution of arsenic and antimony has previously been shown to be related to the margins of the Glacier Creek plutons where these bodies have intruded Middle Jurassic siltstones. Pyrrhotite is localized within the copper zone where it occurs in the massive sulphide deposits and in the vein-type copper deposits. Molybdenite is unusual in that it occurs in all four zones, where it is associated with a variety of rock types of different ages. The most important molybdenite belt is related to the Tertiary Alice Arm Intrusions that border the eastern margin of the Coast Plutonic Complex between Bear River Pass and the southern limit of the study area. This molybdenite belt can be traced along the margin of the complex from the Yukon, south through British Columbia into the United States.

Field evidence indicates that regional metal distribution is related to mineralization epochs which in turn are related to well-defined plutonic, volcanic, and tectonic events (Fig. 18). The large copper deposits concentrated at the western margin of the Stewart Complex in

PERIOD	EPOCH	TECTONIC EVENT	PLUTONS	VOLCANICS	FORMATIONS	MINERALIZATION
QUAT. 1 m.y.	RECENT TO MIOCENE	Uplift & Erosion Faulting ?	Basalt dykes	Flows		
TERTIARY	OLIGOCENE	?	Dykes, sills			Vein deposits; silver, lead, zinc
70	EOCENE PALEOCENE	Folding & Faulting	Hyder plutons etc. Alice Arm intrusions		(SUSTUT)	Vein deposits; silver, lead, zinc porphyry deposits; molybdenite
CRETACEOUS	UPPER	?	?		(SKEENA)	?
130	LOWER	? Erosion	? Satellite plutons			Vein deposits; silver, lead, zinc
	UPPER	Erosion ? Faulting & Folding	Satellite plutons		NASS (HAZELTON GROUP)	?
JURASSIC	MIDDLE	Erosion ± Faulting Erosion Faulting	Texas Creek pluton etc. Unuk River intrusions (Satellite plutons)	Rhyolite, and andesitic pillow lavas Andesite and basalt flows pillow lavas	SALMON RIVER (HAZELTON GROUP) BETTY CREEK (HAZELTON GROUP)	? Silbak Premier deposit; gold, silver Anyox deposits; massive sulphides Mitchell Creek; hydrothermal deposits, chalcopyrite, molybdenite
180	LOWER	Erosion Faulting Cataclasis Folding	Satellite plutons ?	Andesites, basalts, and rhyolite flows, pillow lavas	UNUK RIVER FM. (HAZELTON GROUP)	Granduc deposit, massive sulphide, chalcopyrite pyrite phyrrhotite; minor gold quartz veins
TRIASSIC	UPPER	Erosion Faulting Folding Faulting	Satellite plutons ?	Andesite and basalt flows	TAKLA GRP.	Max deposits; magnetite and chalcopyrite
230		Erosion	?			

Figure 18. Relationships between plutonism, volcanism, and mineralization, Stewart Complex.

the copper zone represent Late Triassic (Max), Lower Jurassic (Granduc), and Middle Jurassic (Hidden Creek) mineralization. The silver-rich deposits in the Alice Arm district, such as the Torbrit, are virtually gold-free; they represent either Late Jurassic or possibly Tertiary mineralization. At Stewart, the silver-gold deposits range in age from Middle Jurassic to Tertiary; the oldest deposits are represented by gold-rich mineralization, such as the Big Missouri and Silbak Premier; younger silver-rich deposits in the same area are cut by dykes and provide examples transitional between the Silbak Premier and Torbrit-type deposits. In the gold zone at the north end of the Stewart Complex, the mineral deposits are mainly confined to Lower Jurassic rocks.

The result of major faulting has been differential uplift of portions of the Stewart Complex; subsequent erosion has exposed the oldest country rocks in the Unuk River and Anyox areas. As a result the copper zone deposits at Anyox and Granduc Mountain, and the gold and gold-silver deposits near Stewart have been exposed. At Alice Arm where the country rocks were depressed and less eroded, only young silver-rich, gold-poor deposits are exposed. The mineral deposit distribution therefore, represents the depth of erosion within various parts of the Stewart Complex. This concept, based on the tectonic evolution of the region, eliminates the need to relate regional metal zoning to hypothetical deep-seated magmatic events or to granitization of the sediments, or to the migration of elements in response to a regional thermal gradient.

CLASSIFICATION OF MINERAL DEPOSITS IN THE STEWART COMPLEX

A study of the spatial relationships of the deposits to their wallrocks provides a simple means of separating the many deposits into groups.

The majority of the mineral deposits in the Unuk River, Stewart, Maple Bay, Anyox, and Alice Arm districts are veins that transect the country rocks. Principal examples of the vein deposits are the Esperanza mine at Alice Arm and the Prosperity-Porter Idaho mine near

Stewart. The Silbak Premier gold-silver deposit near Stewart represents a complex quartz-carbonate-sulphide replacement vein restricted to an altered portion of the Cascade Creek cataclasite zone. Extensive quartz sulphide fissure veins at Maple Bay also occur in rocks of the Maple Bay cataclasite zone. Other vein deposits are localized in granitic bodies, such as the Texas Creek pluton, many of the satellite plutons, and members of the various dyke swarms.

Gold, silver-gold, and silver-bearing minerals are localized within these tabular, quartz-rich bodies as discrete, *en echelon*, and composite lenticular shoots. The larger vein-type deposits are generally distinguished by replacement features and are typified by the Torbrit deposit near Alice Arm and the Silbak Premier deposit near Stewart. The Silbak Premier deposit was once considered (Cooke and Johnston, 1932, p. 39) to be a typical, vein-type, gold-silver British Columbia ore deposit. This concept that bonanza ore mined at Premier before 1930 was typical of these deposits was that the apparent shallow depths of the ore, as compared to Precambrian gold deposits, was related to topographic features and locally partly resulted from secondary enrichment. Two frequency distribution diagrams (Figs. 19, 20) relate the major Torbrit and Silbak Premier deposits to all the known properties in British Columbia that have recorded gold and silver production. As shown by these diagrams, the Silbak Premier property is unique in terms of rank and cannot be considered typical.

Fissure vein and replacement vein deposits in the Stewart Complex comprise a common group with simple ore and gangue minerals. Wallrock alteration associated with these deposits is generally simple and cannot be defined as a characteristic of the complex. Secondary enrichment is not significant in any of the deposits and is generally absent throughout the Stewart Complex. The orebodies are typically shallow and appear to be related to surface topography; this feature is in fact related to the general method of mine development and exploration. The orebodies at the Silbak Premier represent the maximum extent to which any of the vein deposits have been mined. These orebodies comprise a series of *en echelon* lenses which have been developed over a strike length of 1 700 metres and through a vertical range of 600 metres. The main ore zone at the Dunwell mine, north of Stewart, consisted of one main shoot 40 metres long, 1 metre wide, and 120 metres deep, lying within a quartz fissure vein having a known length of 300 metres and a depth of 170 metres. In general, the ore shoots of other vein deposits in the study area formed a smaller part of the veins.

A frequency distribution of the attitudes of veins and vein systems is shown on Figure 21. This diagram illustrates the distribution pattern for veins in the different country rocks as well as the dominant fracture systems. Northwesterly trends dominate in the Texas Creek and other plutons, as well as in the Lower Jurassic country rocks. Northerly trends dominate in Middle Jurassic rocks in the Stewart district whereas in the Hyder district the vein trends are easterly. The bulk of the veins trending northwesterly, northerly, and easterly are generally unproductive, fissure-type quartz-breccia veins. The unique Silbak Premier deposit includes both northwesterly and northeasterly vein systems but the latter predominates and, as shown on Figure 21, represent a small fraction of the vein systems in Lower Jurassic rocks. Ore shoots in the Silbak Premier vein system mainly comprise banded massive sulphide lenses and have caused considerable discussion in the past. In referring to massive sulphide deposits, Gunning (1959, p. 319) suggested that perhaps the puzzling Silbak Premier ore shoots could be placed in the general massive sulphide classification. The writer prefers to characterize the deposit as a replacement vein system.

Massive sulphide deposits at Granduc Mountain and Anyox represent the largest and most productive deposits in the Stewart Complex. These deposits are confined to volcanic-sedimentary strata which have suffered complex deformation and intrusion. Unlike the vein mineralization, these massive sulphide deposits are largely concordant with the enclosing country rocks and form a distinct class. The Max massive magnetite-chalcopyrite deposit at McQuillan Ridge is not sufficiently known to classify it.

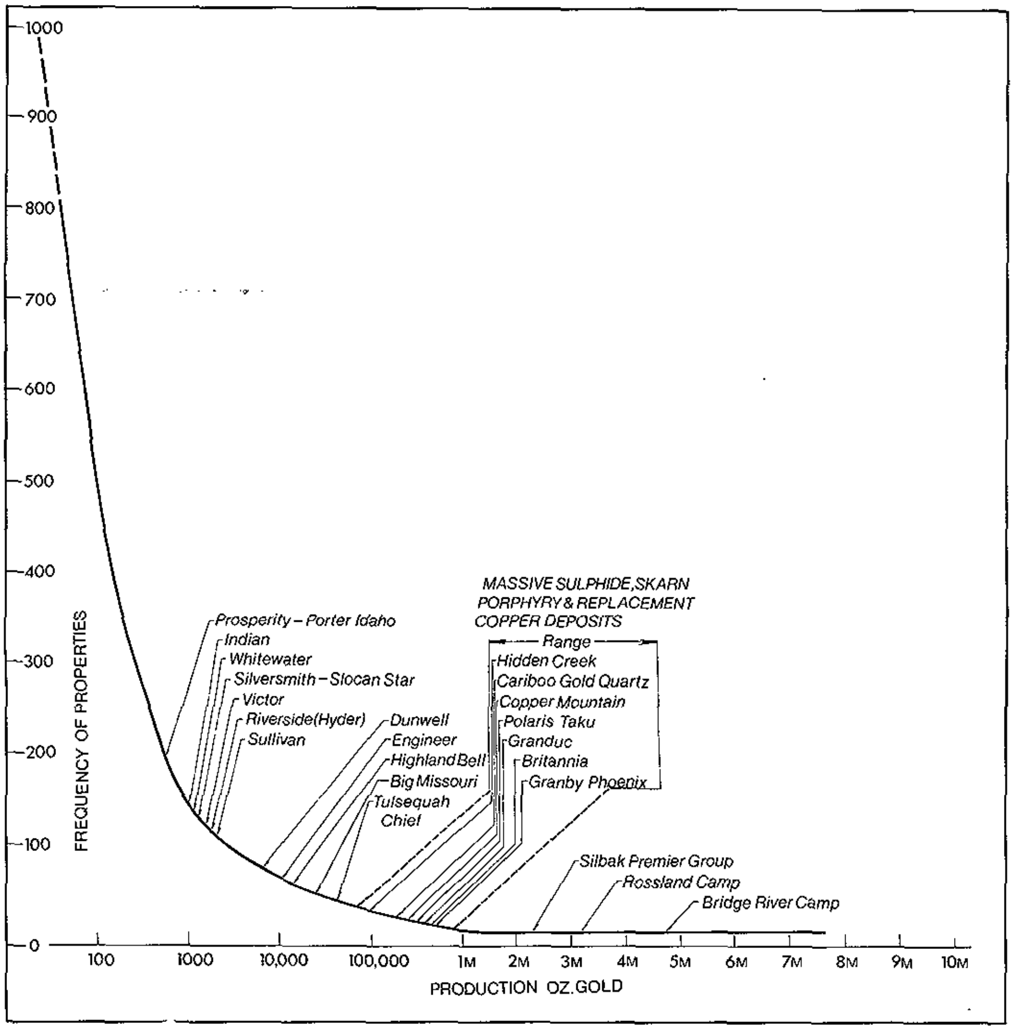


Figure 19. Frequency distribution of gold deposits in British Columbia.

Granduc has been termed a sulphide lode deposit by Ney (1966), a stringer lode deposit by Norman and McCue (1966), a lode deposit by White (1966), and a massive sulphide deposit by Sutherland Brown, *et al.* (1971). The Granduc ore zones lie within the South Unuk cataclasite zone and are extensively deformed. They can be characterized as flattened lenses and physically compare with the 'Kieslagerstatten type' described from various parts of the world (Vokes, 1969). The full extent of these orebodies has not been determined, but they are known to extend over a vertical depth of at least 900 metres, with a length of 1 700 metres, and a width of up to a few hundred metres. Granduc is presently the only known deposit of this type in the Western Cordillera.

In the past Hanson (1935), Nelson (1948), and others concluded that the Anyox orebodies represented simple contact metamorphic deposits. These deposits, which include the Hidden Creek, Double Ed, Red Wing, and Bonanza properties, are actually pipe-like to tabular massive sulphide lenses unrelated to any known intrusives. The Hidden Creek orebodies represent the largest sulphide masses in the Stewart Complex and compare in size to the ore lenses at Britannia near Vancouver. Most of the Anyox orebodies are near vertical lenses that have been traced to a depth of 500 metres, up to 250 metres in strike length, and 100 metres in width. Mapping has shown that the Anyox deposits are confined to pillow volcanics and that the contact metamorphic concept is invalid.

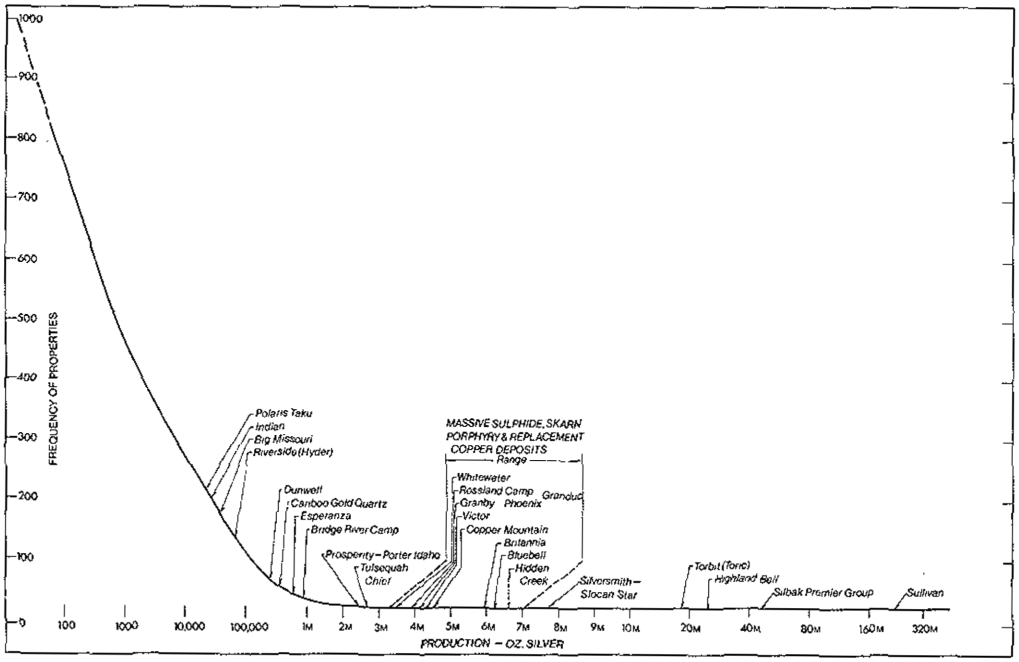


Figure 20. Frequency distribution of silver deposits in British Columbia.

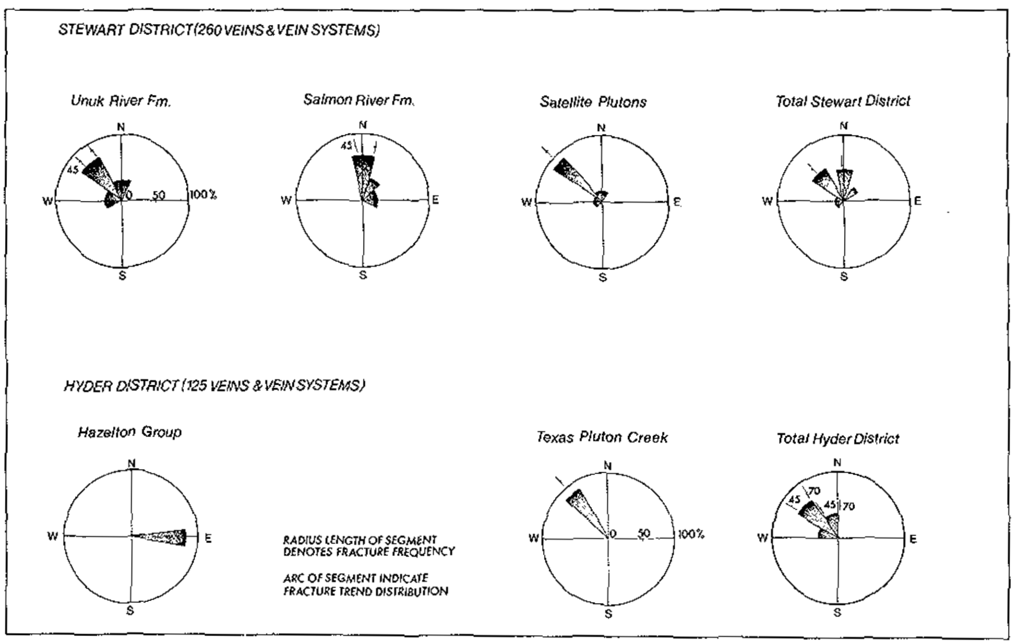


Figure 21. Frequency distribution diagram, Stewart area.

Porphyry-type deposits confined to an individual pluton are restricted to the satellite intrusives. The main representative of this class is the B.C. Molybdenum mine at Lime Creek, near Alice Arm. There are at present no known major mineral deposits in rocks of the Central Gneiss Complex, the Hyder pluton, or the basalt dykes and flows. Other mineral deposits related to stock-like plutons include the nickeliferous gabbro body at Snippaker Creek, and zones of disseminated replacement copper-molybdenum-gold mineralization related to the syenodiorite complex at Mitchell-Sulphurets Creeks.

The simple porphyry-type molybdenite deposit at Lime Creek appears to be typical of porphyry deposits in the Western Cordillera in that the economic mineralization lies entirely within a portion of a small quartz monzonite stock. The widespread copper-molybdenum mineralization at Mitchell-Sulphurets Creeks represents low-grade disseminated sulphide mineralization spatially related to differentiated intrusions and to pervasive quartz sulphide veining of the country rocks. If this deposit proves economic, it will be considered a porphyry deposit in the mining sense, that is, a deposit denoting extensive, low-grade mineralization.

The mineral deposit at Nickel Mountain represents the only known major nickel occurrence in northern British Columbia that is localized in a pipe-like basic pluton. Very little of this mineralized, stock-like body is exposed. The evidence suggests that sulphide minerals are restricted to one edge of the pluton in the upper 450 metres of the contact zone with Unuk River siltstones. Other minor nickel-bearing deposits have been found in hornfels zones near the contacts between Tertiary plutons and Unuk River strata in the area west of the Unuk River and near Anyox.

The preceding brief descriptions of a few significant mineral deposits illustrate the wide variety, character, and size of mineral deposits in the Stewart Complex. As indicated by the mineral occurrence map (Fig. 13) there are many major deposits in the Stewart Complex. These cannot be treated individually in this study but have been grouped by their major characteristics as vein, massive sulphide, and porphyry types.

Summary: The classification of mineral deposits in this area is therefore essentially based upon the relationships of these deposits to their geological environment as follows:

(1) Vein deposits — fissure veins and replacement veins.
(2) Massive sulphide deposits — stratiform and concordant.
(3) Porphyry deposits.

VEIN DEPOSITS

Fissure Veins: Vein deposits represent the largest class of mineral deposits in the Stewart Complex; they include a variety of discordant tabular epigenetic bodies dominantly composed of quartz, carbonate, and barite. Many represent fissure-filling deposits in which fragmented particles of wallrock form a significant portion of the body. Textures include banding, drusy cavities, and comb structures. Alteration is generally not a significant feature and wallrock replacement is generally minimal. Many of the massive quartz veins in the Anyox district have been mined over a length of 900 metres and to a few hundred metres in depth, and exhibit no evidence for significant replacement or alteration of the country rock. These deposits generally have low silver values, contained in argentiferous native gold; they rarely contain any sulphides. The majority of these sulphide-deficient, quartz fissure veins are spatially related to the margins of the quartz-rich Hyder pluton.

Vein deposits in the Maple Bay section are represented by fracture-controlled, tabular quartz veins characterized by drusy, finely crystalline quartz in which the open spaces are irregularly filled with interstitial chalcopyrite, pyrrhotite, and minor pyrite; ore shoots are lenticular. These veins have been traced on the surface for over 1 100 metres and are known to extend to depths of more than 600 metres. This group of veins occupies dilation features controlled by intersecting fracture sets within the ultramylonite segments of the Maple Bay cataclasite zone. They are cut by Hyder plutons and are probably epigenetic deposits related to Middle Jurassic Texas Creek plutonism.

Fissure veins in the Alice Arm district are characterized by argentiferous sulphides and native silver; they have negligible gold content. Stewart district veins are generally comparable, but have a greater variety of sulphide minerals; they commonly contain native silver and rarely native gold and electrum.

Veins localized within the regional gold zone (Fig. 17) are mainly small massive quartz lenses in Lower Jurassic country rocks. They generally carry native gold, sulphides, and low to negligible silver content.

Replacement Veins: These deposits represent the most productive gold-silver deposits in the Stewart Complex and include the Torbrit silver mine at Alice Arm and the Silbak Premier mine near Stewart. This type of vein system constitutes less than 5 per cent of all the mineral deposits within the Stewart Complex, but has contributed more than 90 per cent of the total gold, silver, lead, and zinc mined. The Torbrit deposit at Alice Arm is representative of the low-gold replacement vein deposits; it consists of discordant lenses comprising mainly banded quartz, barite, jasper, feldspar, carbonates, and minor country rock. The ore shoots include sulphides and native silver that along with the main vein material formed partly by emplacement within fractures and partly by replacement of wallrock. The principal representative of this class of vein deposit is the Silbak Premier mine.

GEOLOGY OF THE SILBAK PREMIER MINE

The Silbak Premier mineral deposit (Fig. 22), as well as a large number of small fissure veins, occurs within the boundaries of the Cascade Creek cataclasite zone (Fig. 2B). Unlike the fissure veins, Silbak Premier mineralization is within a metasomatized zone adjacent to the margin of the Texas Creek pluton (Fig. 22). During the operating life of the mine it produced in excess of 4.2 million tonnes of ore containing 56.6 million grams of gold, 1 281.4 million grams of silver, and appreciable amounts of copper, lead, zinc, and cadmium.

The Silbak Premier ore deposit lies in altered Lower Jurassic green volcanic conglomerates (Plate XVII) and intercalated crystal and lithic tuffs that are unconformably overlain by Middle Jurassic sediments and intruded by the Texas Creek pluton and numerous dykes (Fig. 22). The metasomatic, porphyritic rock in which the replacement veins occur has been called the Premier Porphyry (Plate XVIII). This porphyritic zone is characterized by intense fracturing and quartz-carbonate-K-feldspar alteration, and is the site of the sulphide ore shoots. On Figure 22 the principal types of alteration and the ore shoots are shown in relation to the generalized surface geology.

Apart from the Premier Porphyry, the nature of the parent country rock has been largely preserved in spite of the incipient dynamic metamorphism and later metasomatism. The country rock immediately surrounding the ore zones forms part of the local epiclastic volcanic sequence.

In the past, many of the cataclasites in the mine area were interpreted to be volcanic flows, possibly because of their pseudoporphyritic appearance; the deformed character of this rock type is illustrated on Plate XIX.

The Premier Porphyry is a distinctive unit in which coarse-grained pink orthoclase and medium-grained brown hornblende are conspicuous (Plate XVIII). In composition it is comparable to the border phase of the nearby Texas Creek pluton, with which it appears to be genetically related. The Premier Porphyry exhibits various stages of alteration related to mineralization. In weakly altered zones orthoclase porphyroblasts are partly altered to sericite and carbonate along cleavage and fracture planes, and plagioclase and hornblende are replaced; the groundmass alters almost entirely to a dense mixture of sericite, carbonate, epidote, and minor chlorite. In more completely altered zones orthoclase crystals are ghost-like pseudomorphs and both plagioclase and hornblende are indistinct. In most of the porphyry, blebs of quartz in the groundmass comprise 5 to 8 per cent of the rock; these grains are typical of the local cataclasites and have survived both metasomatism and subsequent mineralization-alteration. Secondary quartz is present in most of the porphyry as irregular patches with microcomb structure. Sphene and cubic pyrite are accessory minerals.

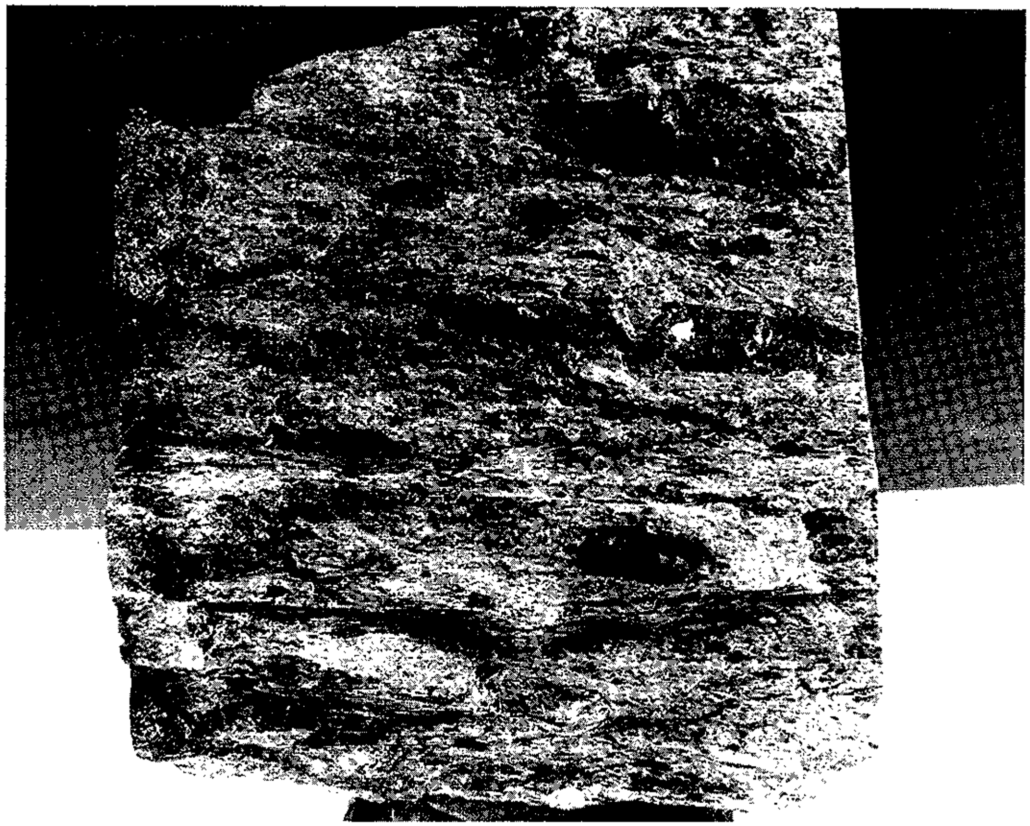


Plate XVII. Hand specimen of deformed epiclastic volcanic conglomerate, Premier area.

Country rocks immediately adjacent to the Premier Porphyry, termed greenstones in the old literature, comprise part of the Cascade Creek cataclasite zone. These rocks have been pervasively altered to fine-grained mixtures of equigranular quartz with sericite, carbonate, epidote, pyrite, and minor magnetite. These rocks generally consist of about 70 per cent quartz and 15 per cent sericite; locally pyrite is up to 25 per cent.

The numerous dykes which cut across the Silbak Premier property (Fig. 22) were described in Chapter 3. The most obvious in the mine area are dykes of the Premier swarm. Most of these swing past the ore zone but one, the 120-metre-wide Main dyke, cuts across the northern ore zone. Lamprophyre dykes occur throughout the mine with the exception of the glory hole area, where large massive sulphide lenses are localized and alteration is most intense.

Structure: The structural geology of the Silbak Premier area is shown on Figure 22 and described in Chapter 4. Steep, west-dipping, northerly trending Lower Jurassic strata, forming part of the west limb of the American Creek Anticline, are crossed at an acute angle by the Cascade Creek cataclasite zone, and unconformably overlain by Middle Jurassic.epiclastic volcanics and siltstones. The Premier Porphyry zone is elongate and lies within the cataclasite zone adjacent to the irregular contact of the nearby Texas Creek pluton. The former structural interpretation of a shallow, west-dipping volcanic sequence with interlayered 'porphyry' is inconsistent with data presented here.

In the past, incipient foliation developed in most of the country rocks in the Premier area has erroneously been taken as lithologic layering or bedding. Dominant foliation on the property trends northerly and dips 35 degrees to 45 degrees west. In detail however, trends vary from northwest to northeast and to the south dips increase and become nearly

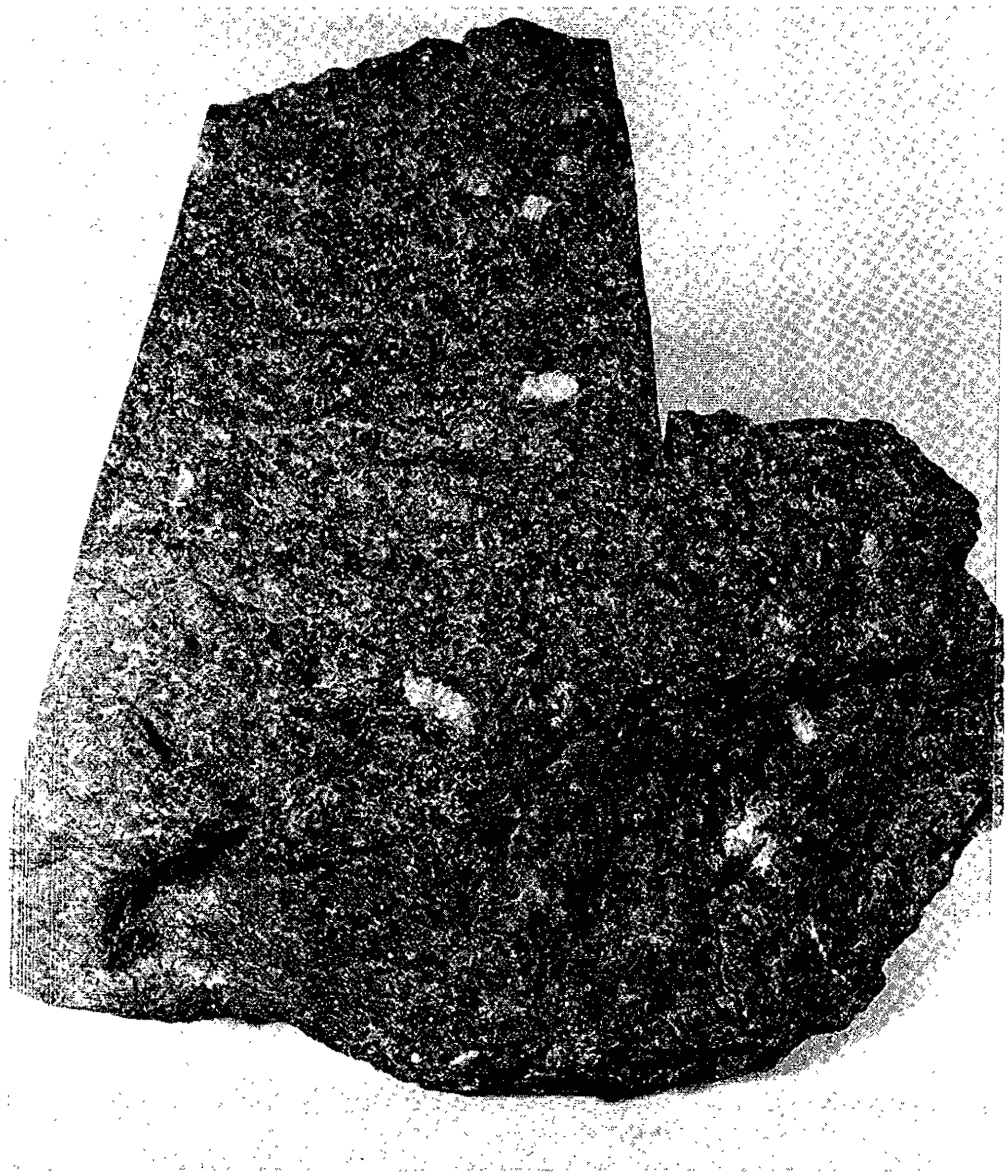


Plate XVIII. Hand specimen of Premier Porphyry, Silbak Premier mine.

vertical. Rather than intersecting shears, these variations appear to represent rolling flexures that follow the sinuous contact between Premier Porphyry and the enveloping wallrocks.

In the mine area, joint sets are well developed in most of the rocks. Patterns vary from one rock type to another and from dyke to dyke. The Premier Porphyry and ore have a distinctive vertical joint set striking north, whereas the less altered cataclasites are typified by a set dipping 45 degrees west and striking north. Dykes in the mine belonging to the same petrologic group also have distinctive joint sets. Joint patterns may be useful in the mine area and the Stewart area in general in defining the rock types where the rocks are altered.

In the mine area the dykes follow the dominant joint sets and are clearly visible on the air photographs. Northwesterly dyke swarms are also prominent on the property. The less

Plate XIX. Cataclasite, Cascade Creek cataclasite zone, Silbak Premier mine area.

conspicuous north 70-degree east trend (Fig. 21), which appears to represent a major ore control at the mine, has also been followed by the lamprophyre dykes. The Silbak Premier area is one of the few places in the Stewart district where the two intersecting joint sets are marked by extensive, intersecting dyke swarms.

Orebodies: The distribution of the orebodies at the Silbak Pemier is shown on Figures 22 and 23, which represent a longitudinal section of the ore zone and illustrate the main stope areas.

Mineralization in the Silbak Premier system consists of an extensive replacement vein with a quartz zone enclosing, or partially enclosing, a large number of sulphide-rich ore shoots from which the main gold-silver production was derived. Quartz represents the main gangue material and is accompanied by lesser amounts of calcite and barite, minor adularia, and country rock. The ore shoots contain an average of 20 per cent sulphides, but in the lenses of bonanza ore this amounted to as much as 80 per cent, the rest being altered wallrock and quartz-calcite veins. Pyrite is the most abundant sulphide and occurs in most of the sub-ore gangue and surrounding wallrock as well. The other major sulphides in decreasing order of abundance are sphalerite, galena, chalcopyrite, and pyrrhotite, with small amounts of argentite, tetrahedrite (and freibergite), polybasite, pyrargyrite, stephanite, electrum, native gold, native silver, and rare mercury.

During the early mining period at the mine, Dolmage (1920) divided the glory hole ore into the following zones:

(1) Stephanite-native silver ore in a few small veins (approximately 100 000 grams per tonne).
(2) Black sulphide ore (17 000 to 34 000 grams silver per tonne).
(3) Lower grade siliceous ore.

Since then no other reports of stephanite have been recorded. Electrum has been noted and identified in high-grade and bonanza ore shoots between the surface and 3 level but rarely below (Fig. 23, in pocket). Native gold apparently has a much more extensive distribution because of its common association with pyrite, but coarse veinlets found in the bonanza-type shoots have a very limited range. Native silver has been identified in most of the ore but none was seen in drill core from below 6 level. Both mercury and amalgam have been recognized but only in surface bonanza or black sulphide ores. Sphalerite has been found universally in the ores along with galena, chalcopyrite, and tetrahedrite from surface to the 8 level area. Within the ore shoots however, sphalerite displays colour variations and also shows an apparent overall colour change from surface to 8 level. This colour varies from black-brown at the surface to amber at depth and indicates a variable iron content within each shoot as well as over the known vertical range of the deposit. Argentite, the most prominent silver mineral at the mine, shows a general decrease in abundance with depth.

An analysis of the stope production records shows a marked decrease in silver at depth. To illustrate this change the silver-gold ratios for various stopes in the main Premier section are plotted in their respective areas on the longitudinal section (Fig. 23). The ratios clearly show a semicircular zonation with silver content decreasing from a high of 112:1 just north of the 110 sublevel projection to lower values to the west and east, and to depth, where the value 6:1 predominates. Another indication of the zoning both along strike and at depth is given in Table 5 where ore production from the four main mine zones has been summarized.

TABLE 5. SILVER-GOLD RATIOS, SILBAK PREMIER VEIN SYSTEM

Working Area	Silver-Gold *Ratio*	Copper *Per Cent*	Lead *Per Cent*	Zinc *Per Cent*
B.C. Silver	40.0:1	0.01	0.5	0.01
Premier	24.5:1	0.04	0.41	0.56
Silbak Premier	17.0:1	0.054	0.98	5.00
Premier Border	28.0:1	0.01	4.2	5.00

Various mineralogical studies of the ore revealed no anomalous features. Both Burton (1926) and White (1939) found the apparent paragenetic sequence to be normal. Supergene enrichment was thought by the early workers to have been the main process by which the bonanza and high-grade silver shoots were formed, but studies by White (*op. cit.*) found that the bulk of the silver minerals are primary. Minor amounts of secondary argentite, wire silver, and minute gold particles are present in vugs in the black sulphide ore as well as in late vuggy quartz-tetrahedrite-polybasite veins which cut the main sulphide lenses.

In the orebodies that can now be seen at the mine the sulphide banding first mentioned by Burton (*op. cit.*, p. 589) is prominent (Plate XX) in pyritic bonanza ore with altered wallrock cut by sulphides and electrum. The mineral banding reflects a late-stage deformation in which relatively soft argentite-galena-sphalerite sections flowed and recrystallized and 'hard' pyrite deformed by fracturing. Individual ore shoots are found as isolated or overlapping *en echelon*, flattened, or pipe-like lenses. These have been illustrated on Figure 22 to show approximate relationships; plunge directions are uniformly steep to the west.

Genesis: The following facts are significant in the present interpretation of the Silbak Premier ore deposit. Spatial relations indicate that this deposit has been localized in metasomatized cataclasites related to the Middle Jurassic Texas Creek pluton. This transformation process, termed ground preparation by Park and McDiarmid (1964, pp. 58, 59), tended to make the Silbak Premier zone brittle compared to the surrounding rocks. Later fracturing in this brittle zone localized deposition of vein quartz, carbonate, barite, and sulphide.

Plate XX. Deformation banding in Bonanza ore, Silbak Premier mine.

Silver-gold ratios in the vein system show gold concentrated in the lower depths and silver in the upper sections. This suggests a changing ore fluid pH from alkaline to more acid and also a possible temperature gradient decreasing from depth toward the surface (Fig. 23). The ratio values also support the field evidence that gold was more abundant in the early phases of mineral deposition than in the later. It appears likely that the late silver-rich mineral assemblages were deposited closer to the surface (lower pressure) than the gold-rich assemblages. These results are comparable to those Nolan (1935) obtained at Tonapah, Nevada, that is, they suggest a telescoped, hydrothermal deposit (Borchert, 1951) formed at shallow depth where changes in temperature and pressure are rapid.

Taylor's (1970) experimental studies of phase relations in the silver-iron-sulphur system show the importance of the silver sulphidization curve for interpreting silver-pyrite assemblages. He indicated that native silver, particularly in silver-pyrite assemblages, does not result from the breakdown of silver-bearing minerals (for example, argentite). Instead, he suggested that the invariant reaction argentite (Ag_2S) + monoclinic pyrrhotite (m-po) yields silver (Ag) + pyrite (py), in the presence of vapor (S), at 248 degrees Celsius, was important in certain massive sulphide deposits. At the silver-bearing Kidd Creek zinc deposit in the Timmins, Ontario area, where much of the silver occurs as stringers, veinlets, and blebs in pyrite, the assemblage Ag + py formed below 248 degrees Celsius, at a sulphur fugacity of less than 10^{-14} atmospheres (Taylor, *op. cit.*). The phase relationships in the silver-iron-sulphur system and the above reaction explain the apparent worldwide absence of the assemblage argentite + pyrrhotite in nature. At Silbak Premier argentite, pyrite, and native silver are concentrated in the near surface bonanza lenses, and pyrite and associated native silver extend from surface to a known depth of 360 metres. Pyrrhotite is present in minor amounts in the pyrite-galena-sphalerite assemblage *in the deep sub-ore sections but has never been recognized in the upper native silver-*argentite-pyrite assemblages. Taylor's (*op. cit.*) phase diagrams and mineral assemblage data suggest that the *Silbak Premier bonanza ore shoots formed below 248 degrees* Celsius.

Indirect evidence by analogy with other comparable silver-gold deposits also suggests a low temperature and pressure of formation for the Silbak Premier ore. Nishiwaki, *et al.* (1971, p. 412) have outlined a classification of Neogene silver-gold ores in Japan on the basis of mineral assemblages. The Silbak Premier ores compare to Nishiwaki's (*op. cit.*, pp. 413–415) *combined Type 3 argentite ore and Type 5 high silver sulphosalt ore* as characterized by the Seigoshi deposit. The preceding authors suggested that the temperature of formation of the combined Type 3-Type 5 deposits was near 200 degrees Celsius and that the depth of formation was as shallow as a few hundred metres. Shilo, *et al.* (1971) have indicated that mineral assemblages in silver-gold deposits in the northeast USSR were deposited at temperatures of 230 degrees to 300 degrees Celsius and at depths at 0.5 to 1.5 kilometres.

The evidence of mineral zoning, metal zoning, mineral assemblages, and the near surface concentration of the bonanza ores at Silbak Premier points to a rapid change in temperature and pressure during the ore-forming process which in part reflects a physical or structural control. An important structural feature recognized near Premier is that the Lower Jurassic rocks in which the Silbak Premier deposit occurs are overlain unconformably by Middle Jurassic sediments. These sediments occur as structural remnants just to the east of Premier at Bear River Ridge and just to the west at Salmon Glacier (Grove, 1971, Fig. 3). Reconstruction of the geological sections (Grove, *op. cit.*, Fig. 4) suggests that Middle Jurassic strata overlay the Premier area at a height of about 150 to 300 metres. This estimate, plus the fact that the glory hole ore is truncated by the present erosion surface, suggests that some bonanza ore once extended above the present level and has been eroded. Like the ore deposits in Japan and the USSR, the Silbak Premier ore was probably deposited near the surface.

Shilo, *et al.* (*op. cit.*) suggested that certain silver-gold ores in the northeast Russia were genetically related to postmagmatic volcanic processes. The Silbak Premier ores appear to be early Middle Jurassic in age and related to the adjacent Texas Creek pluton. The Middle Jurassic Monitor Lake rhyolite has also been related to this intrusion and diatreme-like breccia zones occur near Premier. Spatial and temporal relations suggest a complex plutonic-volcanic association with the Silbak Premier ore deposits. Red bed strata described near the base of the Middle Jurassic Betty Creek sequence are also spatially related to the mineral deposit and may have been a factor in controlling deposition of this complex ore. The general conclusion is that the Silbak Premier deposit represents a telescoped, low-temperature deposit and that most of the native silver is primary, not secondary as suggested in the old literature.

Syntectonic deformation, which induced destructive deformation along irregular zones now marked by abundant cataclasites, was probably accompanied by explosive acid volcanism. Later during the actual penetration of these zones the plutons partially granitized local physically and/or chemically favourable areas of the wallrocks. Petrographic studies in marginal zones of the Texas Creek granodiorite show lower silica content than in the main batholith; this outer zone of dioritic material thus represents an area of chemical depletion. The mobile constituents, possibly including some of the metals which were released by the granitizing process during an early stage, permeated through the country rocks and migrated along fissures to produce the initial alteration zones. Meteoric waters enriched with iron-rich complexes from the Betty Creek red beds percolated toward the fractured thermal area, mixed with the diffusing mobile elements and participated in the complex physical-chemical processes which led to deposition of the oxide-sulphide vein systems in physically favourable sites. Phases of mobilization led to formation of mineral deposits in traps in the prepared ground. Younger dyke swarm intrusions in the same altered horizons have themselves been mineralized by smaller but chemically similar mineral deposits giving a total of at least four very similar mineralizing episodes. Such apparent repetition would be unusual unless the genetic process occurred throughout more or less constant conditions.

STRATIFORM MASSIVE SULPHIDE DEPOSITS

GEOLOGY OF THE ANYOX DEPOSITS

Massive sulphide deposits in the Anyox area (Fig. 24) include at least twelve compact mineral lenses. These consist principally of pyrite, pyrrhotite, and chalcopyrite, with minor sphalerite, and gangue minerals which include mainly quartz, calcite, biotite, and sericite. These deposits are largely confined to volcanic strata; they form stratiform or bed-like bodies characterized by a low length to width ratio which sets them apart from sedimentary deposits (Dunham, 1971).

The Anyox massive sulphide deposits occur mainly within a volcanic sequence, which is overlain by generally conformable marine sedimentary strata. The major northerly trending Hidden Creek syncline has sulphide lenses near the volcanic-sedimentary contact on both limbs along a known length of 10 kilometres.

Production Record: Mineral production from the Anyox area has been mainly from the Hidden Creek and Bonanza mines (Fig. 24) which operated during the period 1914 to 1935. Total ore production from these deposits was approximately 22.4 million tonnes which contained 336 million kilograms of copper, about 218 million grams of silver, and 3.86 million grams of gold. Ore from the major Hidden Creek mine averaged 1.5 per cent copper, 1.7 grams per tonne gold, 9.25 grams per tonne silver, and contained less than 0.5 per cent combined lead and zinc. The nearby Bonanza mine, consisting of a single massive sulphide lens, averaged 2.2 per cent copper, 1.0 gram per tonne gold, 13.4 grams per tonne silver, about 1 per cent zinc, and negligible lead. Selenium was produced at the Anyox smelter as a byproduct of the massive sulphide ores.

Geologic Setting: The main rock types underlying the Anyox area (Figs. 2C, 24) include a thick succession of Middle Jurassic pillow lavas and thin-bedded marine siltstones. These rocks form part of a large pendant that is entirely isolated within the Tertiary Hyder pluton at the eastern margin of the Coast Plutonic Complex. Comparable pillow volcanic-siltstone sequences have also been mapped at Treaty Glacier and Alice Arm, but in these areas the pillow lava units are relatively minor in extent compared to those in the Anyox area and no stratiform massive sulphide deposits have been found.

The lavas at Anyox, which have been correlated to the Betty Creek Formation lavas at Treaty Glacier, consist mainly of altered, green, closely packed pillows (Plate VI). In thin section the pillow lavas consist of very fine-grained felted masses of acicular amphibole, scattered blebs of epidote, and some fresh, fine-grained biotite. The lavas are basaltic but pervasive alteration of these rocks throughout the area precludes determination of their original petrography. Five samples of relatively unaltered compact pillow lava were taken from the flows between Dam Lake and the Hidden Creek mine for chemical analysis. The results shown in Table 6 suggest that the sequence includes mainly metamorphosed tholeiitic basalt. The upper 600 to 750 metres of the pillow lava sequence include a variety of altered pillow breccias (Plate VII) which are localized in and graditional with the closely packed pillow lavas. The pillow breccia zones are used to outline the structure of the pillow succession. The pillow breccias form discrete lenses from a few metres to several metres thick which are traceable over hundreds of metres. The transition from closely packed pillow to pillow breccia takes place within a few metres, and the vertical limits are marked by sharply conformable contacts. This pillow lava sequence is largely conformably overlain by a thick sequence of thin-bedded marine siltstones that correlate with the Middle Jurassic Salmon River Formation.

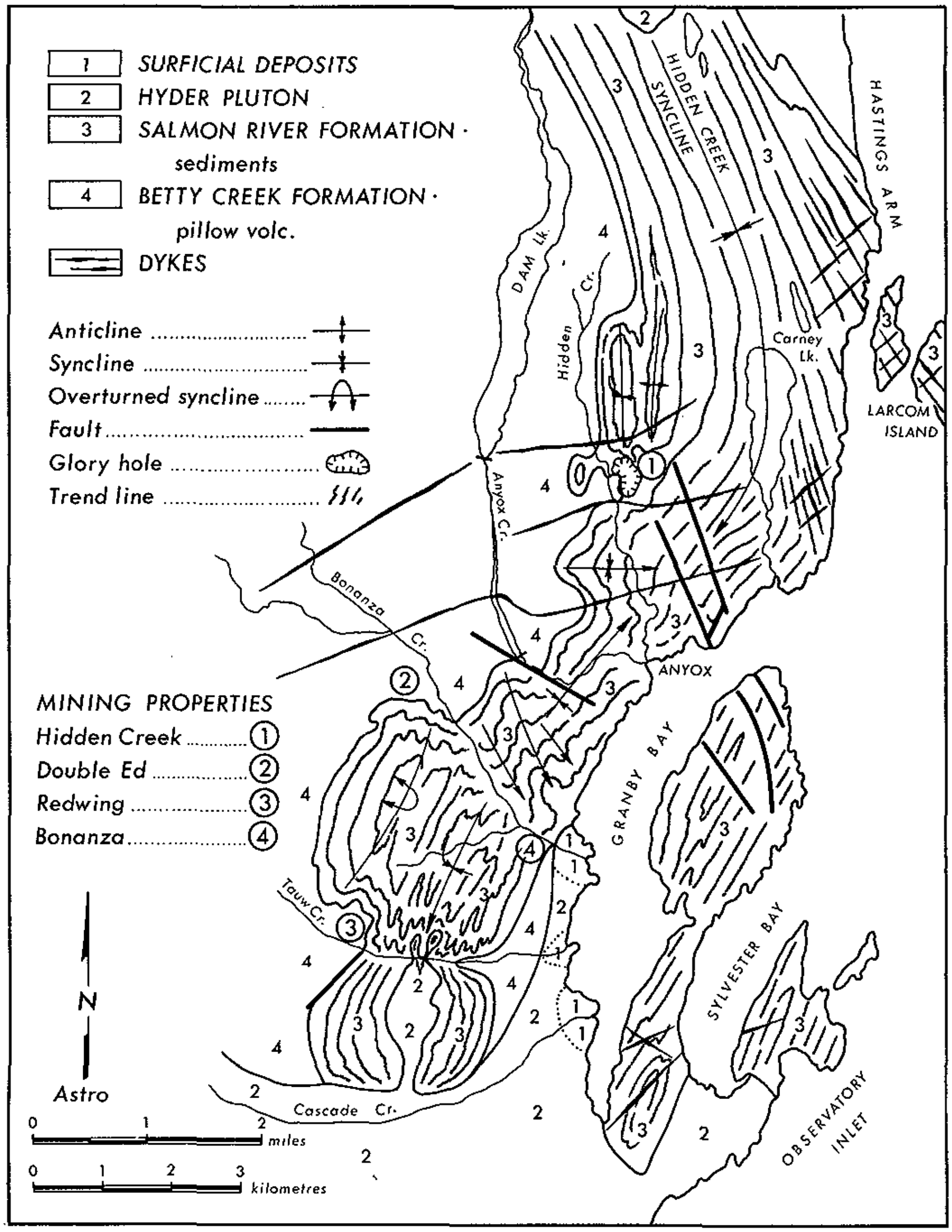


Figure 24. General geology of the Anyox area.

The nature of the contact between the pillow lavas and the siltstones varies along the length of the Bonanza syncline. In the axial zone, near the south end of the syncline, the contact is gradational through a 3 to 6-metre-thick zone of thinly banded quartzite which in turn grades into the overlying calcareous siltstone sequence (Plate VIII). Along both limbs of the syncline the contact is obscured by local deformation. In the Bonanza Creek area the contact consists of a series of thin carbonate, chert, and siltstone lenses that are intercalated with pillow lavas underlying the main siltstone sequence. At the mouth of

TABLE 6. CHEMICAL ANALYSES, ANYOX PILLOW LAVAS

	1 14819M	2 14820M	3 14821M	4 14822M	5 14823M
SiO_2	49.56	50.11	48.95	48.79	50.46
TiO_2	1.44	1.43	1.34	1.35	1.43
Al_2O_3	15.73	14.37	15.53	14.95	13.77
Cr_2O_3	0.0	0.0	0.0	0.0	0.0
Fe_2O_3	1.28	1.08	1.96	1.47	2.63
FeO	8.91	9.19	8.12	9.62	7.73
MnO	0.19	0.15	0.17	0.20	0.17
MgO	6.72	8.68	7.67	6.98	7.52
CaO	10.68	9.75	11.03	11.82	9.84
Na_2O	2.56	2.36	2.46	2.17	2.98
K_2O	0.15	0.19	0.14	0.18	0.21
P_2O_5	0.02	0.62	0.02	0.02	0.27
CO_2	0.40	0.06	0.06	0.18	0.06
H_2O+	1.68	1.41	1.50	1.07	1.90
H_2O-	0.14	0.10	0.12	0.08	0.10
Other	0.25	0.31	0.26	0.23	0.15
TOTAL	99.71	99.21	99.33	99.11	99.22

Locations: 1 — Dam Lake, No. 1 dam.
2 — No. 2 dam.
3 — Eden 1.
4 — *Double Ed* 1.
5 — Bonanza 1.

Analyses by the Analytical Laboratory, Geological Survey Branch, British Columbia Ministry of Energy, Mines and Petroleum Resources.

Bonanza Creek on the east limb, pillow lavas underlying the siltstone are intensely flattened and have commonly been misidentified as thin-bedded sediments. At Hidden Creek near the orebodies the contact between the pillow lava and overlying siltstones is sharp and conformable, but it has been complexly folded and faulted.

The overlying siltstones include abundant small limestone concretions, minor cherty lenses, and graphite zones. Disseminated fine-grained pyrite and pyrrhotite are ubiquitous within the calcareous siltstones that immediately overlie the pillow lavas. The siltstones are mainly thinly bedded, and buff to black with intercalated silty greywackes, calcarenites, and silty argillites. The siltstones are characterized by a blocky to splintery habit and weather reddish. Within the body of the Bonanza syncline, they are moderately fresh and exhibit a typical grey and black striping. Planar banding is the major primary feature, although enterolithic structures have been noted. Foliation is rare and generally limited to the margins of dykes. At contacts with the Hyder pluton the siltstones are indurated and typically display tremolite needles or clumps of needles. Elsewhere altered andalusite and fine-grained brown biotite occur as random clusters within the lower 300 to 450 metres of the siltstone sequence. Near the Hyder pluton, limestone concretions in the lower part of the succession have been altered to aggregates of calcite, quartz, epidote, and grossularite.

The extensive alteration of the pillow lavas is assumed to represent autometasomatism (Bonatti, 1967), whereas development of andalusite is interpreted to indicate Middle Jurassic lower amphibolite grade regional metamorphism. The tremolite hornfels zones are obviously related to Tertiary plutons.

The major geological structure in the Anyox area is the Bonanza syncline. This feature trends northerly and is asymmetric. Shear zones, assumed to be related to the same tectonic event, are localized within the pillow lava sequence near the intrusive contact zone south of Bonanza Creek and also along the margins of the massive sulphide deposits.

Detailed structural studies at the Hidden Creek mine have shown that the complexly folded siltstone sequence overlies the massive sulphide bodies, forming what has locally been called a structural 'nose' in the older literature (Nelson, 1948). This local feature has generally been interpreted to represent the major structural control for the localization of the massive sulphide lenses (Fig. 25). Mapping of the Bonanza, Double Ed, and Redwing properties (Fig. 24) has shown that these deposits lie entirely within the pillow lavas, but their structural situation in relation to the overlying siltstone is complicated by folding. The No. 6 orebody at Hidden Creek (Fig. 25) also lies entirely within the pillow lavas and is overlain by relatively undeformed siltstones. The folding of the Hidden Creek syncline postdates massive sulphide deposition and is assumed to be related to Middle Jurassic tectonism.

Orebodies at the Hidden Creek Mine: The principal orebodies in the Anyox area are those of the Hidden Creek mine. The Hidden Creek orebodies are pipe-like to sheet-like lenses that consist mainly of pyrite, pyrrhotite, chalcopyrite, and sphalerite with minor arsenopyrite, galena, and magnetite. The gangue minerals are principally quartz, calcite, and sericite with minor epidote and garnet. Eight separate ore lenses are known of which the largest has a length of at least 500 metres, a width of from 250 to 300 metres, and a thickness up to 100 metres. The smaller lenses are nonuniform in thickness along their length. All of the lenses at the Hidden Creek mine are nearly vertical and six major ore lenses were mined by underground and glory hole methods. Prior to closing the operation in 1935 mining procedures were attempted which resulted in extensive damage to the mine system. Access is now restricted to surface exposures in the glory holes and to limited mine workings.

The orebodies at Hidden Creek lie mainly within the pillow lava sequence at different stratigraphic levels below the siltstone contact. This general relationship is illustrated on the geological plan (Fig. 25) and on the composite geological section (Fig. 26). The contact orebodies, Nos. 1, 4, 5, and 6, exhibit complex relationships to the enclosing country rocks and, as indicated by the geological plan and section, appear to lie partly within the siltstone. The keel sections as well as the margins of these four lenses are entirely within the altered pillow lavas, but the upper, complexly deformed segment of 1-5 ore zone exhibits possible replacement of the thin-bedded siltstones. This siltstone-sulphide contact has been deformed along much of the 1-5 zone, but certain segments, particularly in the No. 5 orebody, suggest a continuity of mineral banding in the ore with apparent bedding in the siltstones. The sulphide ore in these segments is irregular and appears to transect the sediments. Elsewhere apparent replacement of siltstones by sulphides is a result of localized shearing and sulphide remobilization.

The general mineralogy of these lenses is simple. The footwall zone of the Nos. 1, 4, and 5 orebodies (Fig. 25) comprises a 230-metre-thick zone of fine-grained granular quartz and sericite characterized by a vuggy or spongy texture and very fine-grained framboidal pyrite encrusted within the cavities. In polished sections this pyrite displays radial shrinkage cracks but is otherwise textureless. The 1, 4, and 5 orebodies themselves, as compared to the footwall zone, consist almost entirely of medium-grained, massive pyrite in which chalcopyrite is present as blebs and streaks along discrete fractures. The minor amount of gangue consists of disseminated to lens-like fine-grained quartz and calcite.

The 6 orebody, one of the contact lenses, is marked by well-defined centimetre-scale mineral banding defined by pyrite, pyrrhotite, and quartz-sericite gangue (Plate XXI). In this orebody chalcopyrite is also concentrated within the pyrrhotite-rich central zone. In hand specimen the chalcopyrite and pyrrhotite occur as veinlets and streaks cutting the banding in the pyrite gangue as a response to late-stage deformation.

The narrow footwall of the 2 and 3 orebodies, which are entirely enclosed in the pillow lavas, is uniquely characterized by the presence of very fine-grained epidote and grossularite garnet as specks and streaks in the sulphide matrix. These orebodies comprise principally medium to coarse-grained pyrite, pyrrhotite, and chalcopyrite, with

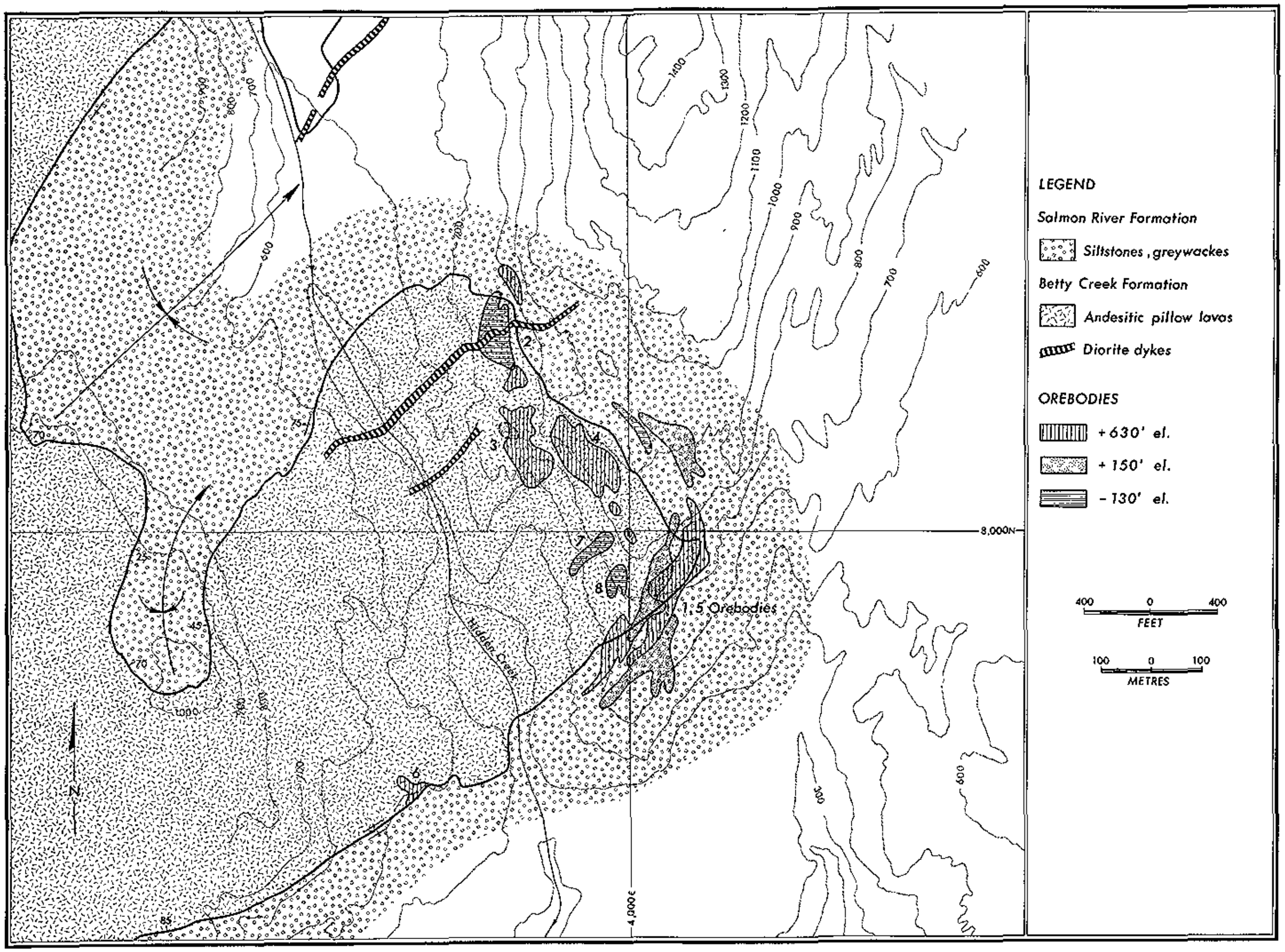


Figure 25. Plan of orebodies, Hidden Creek mine, Anyox.

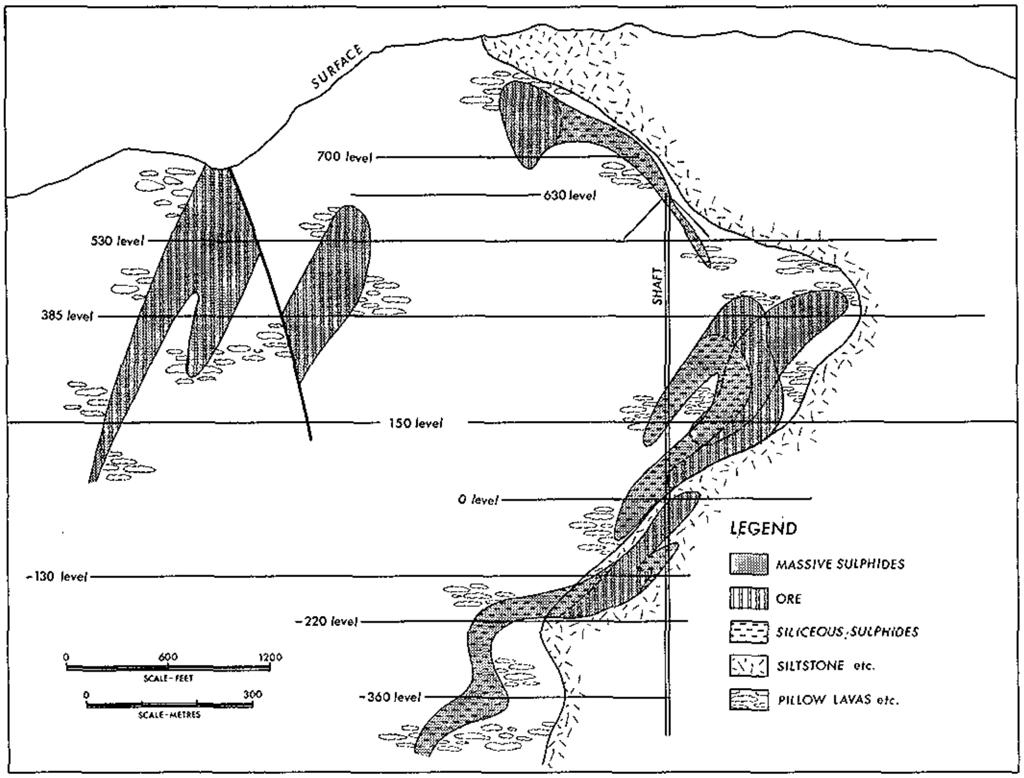


Figure 26. Generalized cross-section, Hidden Creek mine, Anyox.

minor magnetite and quartz. In the 2-3 ore zone, chalcopyrite is associated with pyrrhotite, which is localized within the central part of the ore lenses. The 7 and 8 orebodies, also confined to the pillow lavas, consist almost entirely of granular pyrite and pyrrhotite, disseminated chalcopyrite, and fine-grained quartz. These two orebodies have not been completely studied and are known only from exploration drill-core data.

The chemical compositions of the major orebodies at Hidden Creek have been calculated from the smelter records and are shown in Table 7.

In summary, the sulphide orebodies at the Hidden Creek mine consist primarily of pyrite, pyrrhotite, and chalcopyrite with minor sphalerite, magnetite, galena, and arsenopyrite. The principal gangue minerals include quartz, calcite, and sericite with some epidote and garnet. The orebodies can be characterized as conformable massive sulphide deposits in the terminology of Dunham (1971).

On the basis of the observed mineralogy, mineral zoning, and bulk chemical composition, the individual orebodies can be divided into three distinct groups:

(A) The contact orebodies, represented by 1, 4, 5, and 6, which are primarily pyrite masses with associated pyrrhotite, chalcopyrite, quartz, calcite, and sericite.
(B) Orebodies 2 and 3, which lie entirely within the pillow lava sequence, consist of pyrite and pyrrhotite, with chalcopyrite entirely confined to the central pyrrhotite zone; the gangue includes calc-silicates, quartz, and minor sericite, but is notably deficient in calcite.
(C) Sub-ore masses such as the 7 and 8 lenses which are spatially intermediate between groups A and B and are relatively deficient in chalcopyrite.

The bulk chemical composition of the Hidden Creek orebodies (Table 7) has been presented to complement the mineralogical variations outlined and to characterize the

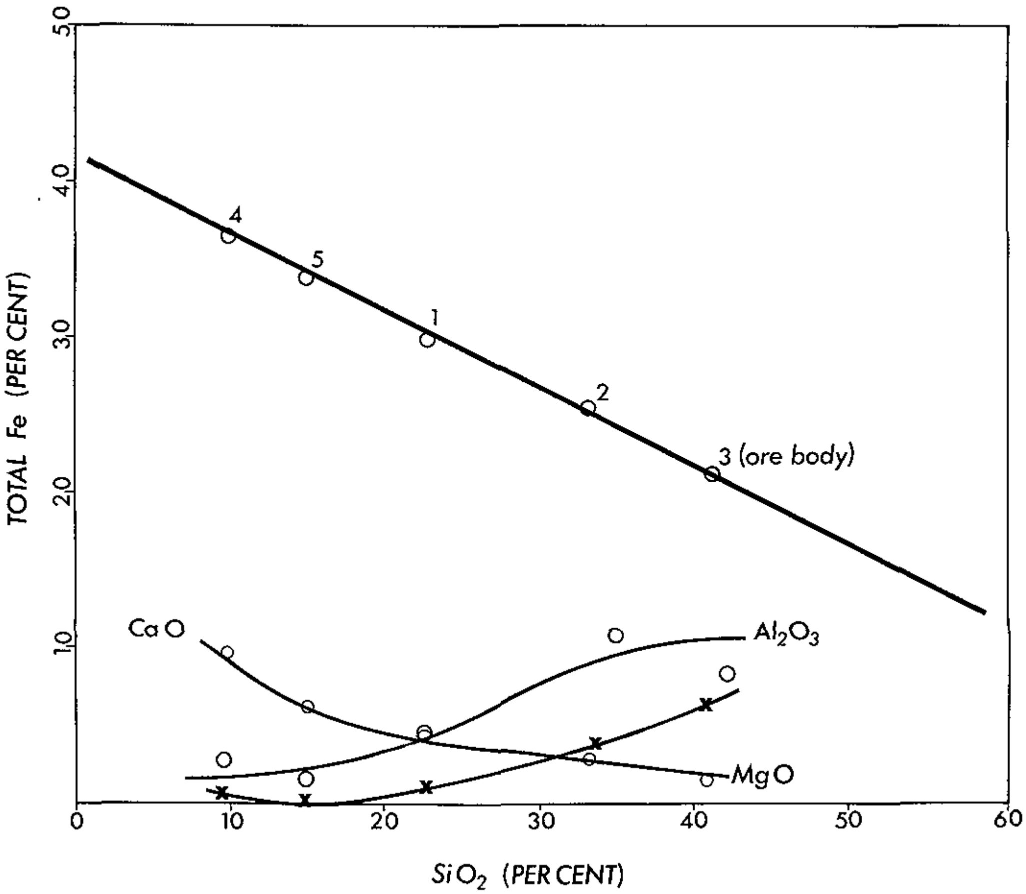


Figure 27. Variation diagram, chemical composition, Hidden Creek orebodies, Anyox.

deposit. The chemical composition of the individual orebodies suggests that lenses in the Hidden Creek deposit are co-genetic. This is illustrated on Figure 27 where the major constituents have been plotted on a variation diagram.

Alteration in the Hidden Creek Mine Area: The Hidden Creek orebodies are enveloped in a thin, film-like zone of quartz-sericite schist which varies in thickness from a few metres to tens of metres, where the alteration is gradational with the footwall vuggy quartz framboidal pyrite zone. The pillow volcanics outside the schist zone exhibit the widespread amphibole alteration previously described, but apart from local iron staining, they show no apparent alteration that is spatially related to the massive sulphide lenses. Similarly, the overlying siltstones exhibit no significant alteration near the massive sulphide lenses that is related to the sulphide lenses alone. Locally silicification and secondary brown biotite appear to be more prominent near the orebodies than along the nonproductive contact in the siltstones but this may merely reflect rock exposure, regional metamorphism, or personal bias.

Several extensive quartz, carbonate, and magnetite alteration zones have been outlined along the pillow lava-siltstone contact south of the Hidden Creek mine. Extensive exploration diamond drilling of these areas has not led to discovery of any significant massive sulphide or disseminated sulphide mineralization. These zones, like the many barren quartz veins in the Anyox area, are probably of Tertiary age.

TABLE 7. CHEMICAL COMPOSITION, HIDDEN CREEK OREBODIES

(Per Cent)

Orebody	Cu	SiO_2	Fe	CaO	S	Al_2O_3	MgO
1	2.37	22.4	29.6	4.7	30.0	5.1	1.3
2	2.24	33.2	25.6	3.0	18.0	10.8	4.0
3	1.82	40.8	21.6	1.5	7.9	11.5	6.6
4	1.52	9.2	37.0	9.8	30.5	3.0	0.8
5	3.02	14.8	34.0	5.9	33.3	1.6	0.0

Other Massive Sulphide Deposits: Three other stratiform massive sulphide deposits, the Double Ed, Redwing, and Bonanza, occur near the contact between the pillow lavas and the siltstones south of the Hidden Creek mine. The first two occur on the west limb of the Hidden Creek syncline, while the Bonanza deposit is the only known occurrence on the east limb (Fig. 24). All three deposits are within the pillow lavas and are enveloped in a narrow, variably chloritic, quartz biotite schist zone. These deposits are mineralogically similar to the group 1 contact zone orebodies. They are characterized by medium to coarse-grained, frequently granular pyrite, streaky pyrrhotite lenses, scattered chalcopyrite, and prominent bands of dark brown sphalerite (Plate XXII).

The Bonanza deposit consists of a flattened, pipe-like lens that plunges at a shallow angle to the north below the pillow lava-siltstone contact near the axis of the Hidden Creek syncline. The known length of this lens is about 750 metres; it has a thickness of up to 40 metres and width of up to 120 metres. The grades and mineralogy are comparable to the contact lenses at the Hidden Creek mine. The Bonanza deposit is cut by several dyke swarms and intruded by Tertiary intrusives near the north end.

The Redwing and Double Ed deposits, also localized within chloritic biotite schist envelopes within the pillow lavas, are similar in grade and mineralogy to the Bonanza and Hidden Creek deposits. Both the Redwing and Double Ed deposits were slightly deformed, probably during the regional tectonic episode (Fig. 18). These deposits exhibit flattened, pipe-like forms and plunge steeply within the pillow lava sequence; like all these deposits they are essentially parallel to the pillow lava-siltstone contact.

Exploration west of the contact revealed several siliceous massive pyrrhotite-chalcopyrite replacement zones. These are confined to pillow breccia and broken pillow breccia zones. Surface work and diamond drilling indicate these zones are about 100 metres in diameter and steeply inclined; they are not related to any simple fracture system or to plutons.

The fact that the stratiform massive sulphide and sulphide breccia deposits in the Anyox area are associated in every instance with lavas is evidence of a genetic relationship (Dunham, 1971, p. 169). The fact, that the length to width ratios of these sulphide lenses are lower than almost all known sedimentary deposits, also argues for a volcanogenic association. Detailed studies at Anyox have not revealed plutons spatially related to the sulphide deposits. On the basis of chemical composition of the eight sulphide lenses at the Hidden Creek mine and lithostructural and mineralogical similarity at the other sulphide deposits, the sulphide lenses are probably volcanogenic, but hydrothermal processes may have been involved.

The bulk of the hydrothermal vein deposits in the Stewart Complex suggests a similarity of process indicated by large amounts of quartz and carbonate gangue compared to relatively minor sulphide content. A calculation based on the Silbak Premier deposit indicates that the overall ratio of gangue material to sulphide in the vein system is about 700:1. A general study of the vein deposits suggests that the minimum gangue to sulphide ratio is greater than 500:1. In contrast the Anyox volcanogenic massive sulphide deposits are characterized by a low volume of gangue mineral which at Anyox forms less than half the material in the lenses, so that the ratio is less than 1:1 (Table 7).

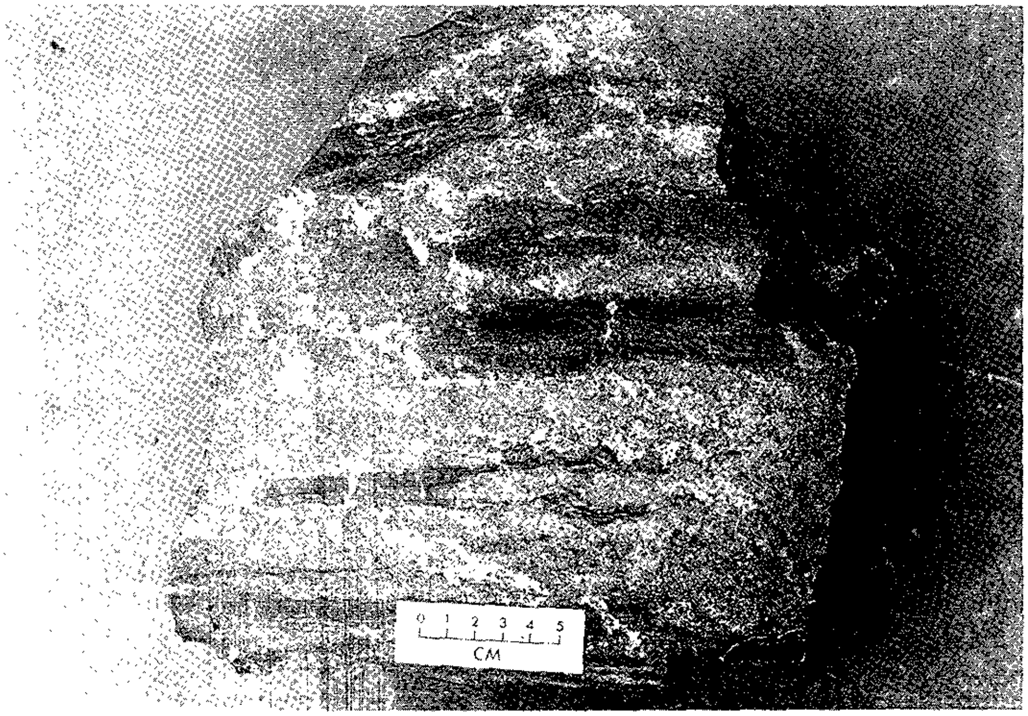


Plate XXI. Mineral banding in massive sulphide ore, No. 6 orebody, Hidden Creek mine.

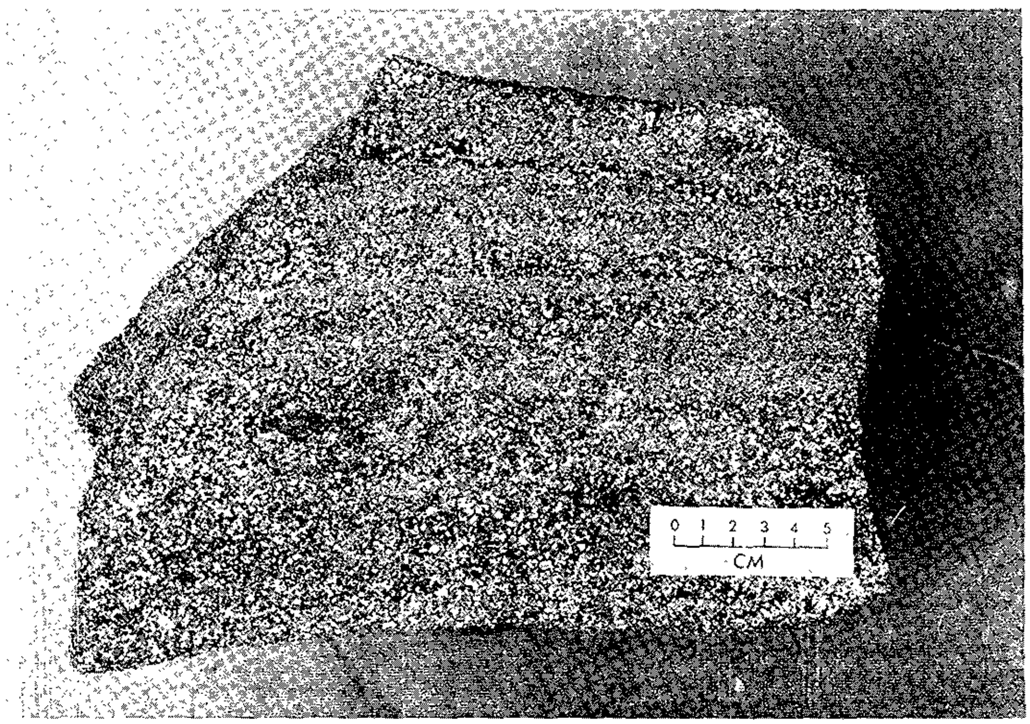


Plate XXII. Mineral banding in massive sulphide ore, Bonanza mine.

The massive sulphide deposits at Anyox appear to form part of a continuous volcanic sequence deposited during the late stages of submarine activity prior to regional, shallow marine sedimentation.

Clark (1971), Hutchinson and Searle (1971), and others have reviewed the geological setting of the cupriferous massive sulphide deposits of Cyprus. The various workers have generally concluded that these ore deposits have formed periodically related to subaqueous exhalations or effusions, followed by distinctive iron oxide, silica-rich chemical sedimentation. They have also suggested that the precipitation and accumulation of colloidal sulphide in sea floor depressions occurred in a reducing environment. Hutchinson and Searle (*op. cit.*) concluded that the water, metals, and sulphur in the volcanic emanations were derived from a mantle source in accord with the character of the Troodos Complex as a whole.

The general relationships of the Anyox massive sulphide deposits, including age, size, shape, composition and texture, timing, and in part the sedimentation record, correspond closely to the Cyprus deposits. By analogy, the similarity between the extensively altered pillow lavas, the presence of mineralized volcanic breccias, plus the possible colloidal nature of part of the Anyox deposits as expressed by the framboidal pyrite and vuggy quartz zones suggests a comparable ore-forming process.

Because of deformation and folding few of the Anyox massive sulphide lenses are readily accessible. Reconstruction and unfolding of the deposits suggest a partly preserved centrifugal pattern for the sulphide bodies radiating from the Hidden Creek area. To the writer this pattern suggests a common vent source for sulphide flows controlled by submarine canyons which may have first been distorted by caldera collapse and later by regional deformation.

On the basis of the geological evidence and the comparability of the Anyox and Cyprus sulphide orebodies, it is suggested that the Anyox massive sulphide deposits formed principally by subaqueous fumarolic and synvolcanic processes related to Middle Jurassic plutonic-volcanic activity. In the Anyox area in particular and the Stewart Complex in general, widespread Tertiary plutonism has erased evidence of any Middle Jurassic pillow lava-ophiolite affiliation, if it ever existed. More importantly Tertiary plutonism may have destroyed, or even recycled, other Anyox-type massive sulphide deposits.

CONCORDANT MASSIVE SULPHIDE DEPOSITS

GEOLOGY OF THE GRANDUC DEPOSIT

The only representative of this class of mineral deposit in the Stewart Complex is the Granduc property located at Granduc Mountain 40 kilometres northeast of Stewart. This large deposit was discovered in 1951 when ablation of the South Leduc Glacier revealed a small area of mineralization at the 1 100-metre elevation (Fig. 4). Published ore reserves indicated 49 million tonnes of ore with a grade of about 1.55 per cent copper and 6.9 grams per tonne silver, with minor gold, lead, and zinc. The deposit represents the largest concordant massive sulphide deposit in the Canadian Cordillera (Dunham, 1971).

The Granduc ore deposit lies near a conspicuous reentrant in the eastern margin of the Coast Plutonic Complex (Fig. 13). The sulphide lenses comprising the ore deposit are entirely confined to a 120-metre-wide zone located near the easterly margin of the South Unuk cataclasite zone. The zone is locally bounded on the west by northerly trending mixed granodiorite gneisses and on the east by variably deformed epiclastic volcanic conglomerates and indurated, altered pillow volcanics. South of Granduc Mountain the country rocks, including the ore-bearing cataclasites, are cut by Tertiary plutons. Because strata in the Granduc Mountain area are deformed, the original nature of the ore-bearing strata and enclosing wallrocks is based on study of the least deformed rock units in the general mine area. Away from the ore lenses the country rocks include a complex volcanic-sedimentary sequence dated by fossils as Pliensbachian, and referred to in this study as part of the middle member of the Unuk River Formation (Fig. 9).

Extensive, thick, andesitic volcanics east of the Granduc orebodies form part of a northerly trending zone of shallow marine, closely packed pillow lavas intercalated within graphitic siltstones, thin-bedded lithic and crystal tuffs, and volcanic sandstones. This sequence is overlain by a sequence of strata, including the ore zone, which includes graphitic siltstones, thin-bedded lenticular gypsum-bearing limestones, quartz pebble and quartz cobble conglomerate lenses, banded volcanic tuffs, quartzites, and cherts. Strata north of the ore zone at North Leduc Glacier are intruded by a variety of Lower Jurassic plutons previously described as the Unuk River Intrusions. Several of these small plutons as well as the country rocks have been deformed and form part of the South Unuk cataclasite zone. In addition to cataclasis the mine area underwent several periods of later deformation, intrusion, alteration, faulting, and erosion culminating in Tertiary time with Hyder plutonism.

The ore deposit at Granduc Mountain lies along part of the deformed, overturned, west limb of a pre-Middle Jurassic, possibly Aalenian, northerly trending anticlinal fold. The west limb of this fold is crossed at a low angle by the South Unuk cataclasite zone. In the cataclasite zone, structure at Granduc Mountain is outlined by lenses of deformed recrystallized limestone, thick lenticular ultramylonite sheets, and mineral banding in the mylonites and phyllonites. Both the petrology and structure of this cataclasite zone in the mine area have been described in previous chapters. South of the ore zone at South Leduc Glacier the country rocks are weakly deformed and consist of thick-bedded andesitic volcanic conglomerates with minor fine-grained sediments.

Orebodies: All known ore-grade mineralization at Granduc is confined to a 120-metre-wide, vertical zone within the northerly trending South Unuk cataclasite zone. The relationship of the various ore zones within the mylonite-phyllonite sequence is shown on Figure 28. Each ore zone includes several lenses of massive sulphides separated mainly by barren cataclasite or by country rock cut by stockwork-like sulphide stringer zones. Ore zones comprise pancake-like, overlapping, and commonly merging lenses which are known to extend vertically from about 450 to 1 200 metres elevation and extend laterally for at least 1 200 metres. The massive sulphide lenses have been assigned letters A through F to partially systematize the complex pattern (Fig. 28 and Fig. 4).

In detail individual ore zones consist of massive lenses, irregular streaks and blebs, and veinlets of sulphide with rapidly changing outlines. Breccia texture in the massive sulphide, largely represented by rotated blocks of mylonite and also abundant evidence of chalcopyrite and pyrrhotite remobilization as veins, indicates pervasive sulphide deformation at several periods. As a result of repeated deformation the massive sulphide lenses and orebodies have an irregular, feathery nature and have been called stringer lodes by the mine geologists (Norman and McCue, 1966).

The Granduc orebodies consist principally of pyrite, chalcopyrite, pyrrhotite, sphalerite, and galena in order of relative abundance. Arsenopyrite is ubiquitous and cobaltite has been identified in the upper part of the 'A' zone. Magnetite is a common constituent in both the ore zones and wallrocks but appears to be more abundant along the western limit of the ore horizon. In the massive sulphide lenses, gangue includes blocks of brecciated country rock, quartz as lenses, stringers and blebs, and moderately abundant recrystallized coarse-grained calcite as lenses and stringers.

In each orebody the massive sulphide lenses are concordant with the thinly banded wallrocks. The major ore zones (Fig. 28) consist of numerous massive sulphide lenses, each up to a few tens of metres thick, which extend laterally up to hundreds of metres within the confining cataclasites. Wallrocks intercalated with the massive sulphide lenses

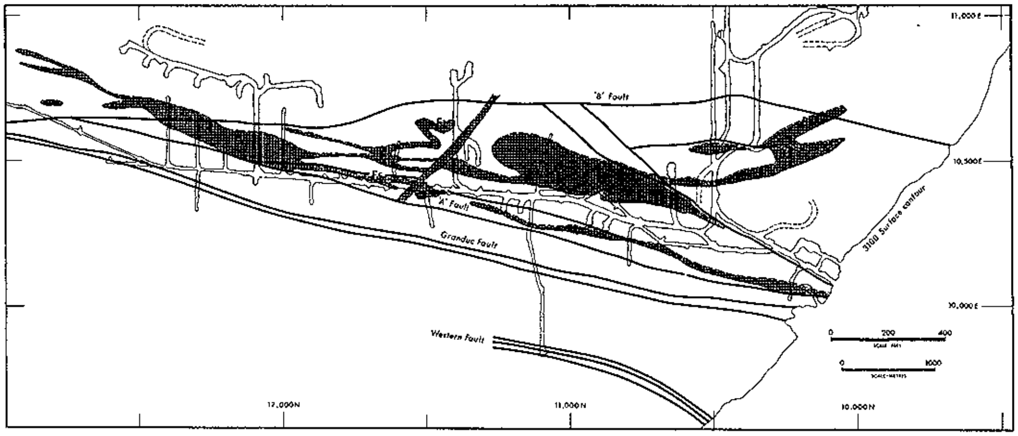


Figure 28. Plan of 3100 level, Granduc mine.

contain a multitude of concordant millimetre-scale sulphide lenticles as well as a reticulated stockwork of fine sulphide veins and veinlets that consist mainly of chalcopyrite. These veinlets generally extend outward from the massive sulphide lenses into and across the country rock for distances of a few tens of metres; locally they transect other massive sulphide lenses within the ore zones. Chalcopyrite and, to a lesser extent, pyrrhotite comprising these veinlets are assumed to have been remobilized (Mookherjee, 1970) by local post-cataclastic deformation. As a result, locally wallrock between sulphide lenses in the ore zones has been mined.

In the massive sulphide lenses galena and sphalerite are concentrated with quartzose material and occur as irregular augen throughout the lenses. In contrast to the fine-grained pyrite, chalcopyrite, and pyrrhotite in these lenses, galena and sphalerite are coarse-grained and exhibit little evidence of deformation. The galena, sphalerite, and host quartz are also veined by chalcopyrite and pyrrhotite veinlets. Contrary to experimental evidence (J. E. Gill, personal communication), chalcopyrite and pyrrhotite appear to have been remobilized in preference to galena. However, the galena and sphalerite may have been protected by their close association with quartz lenses.

Crude mineral banding and flow-like structures occur rotated around country rock inclusions in the massive sulphide bodies (Plate XXIII). Pyrite in the lenses is coarse grained; it consists of irregular, angular fragments, and also forms pods or streaks (Plate XXIV) surrounded and veined by chalcopyrite and pyrrhotite. Complex bands of magnetite occur throughout the ore lenses. Both the chalcopyrite and pyrrhotite are generally fine-grained, show recrystallization and segregation, and form the matrix for the angular ore and gangue materials. The protoclastic textures of the ore and gangue minerals indicate that the massive sulphide lenses, like the country rocks, were subjected to deformation. This is expressed by the cataclastic textures, mineral differentiation, and irregular mineral recrystallization.

As Stanton (1959, 1960, 1964) and others have suggested, textures in deformed sulphide ores are not evidence of a normal paragenetic sequence. Instead the textures reflect the intensity of the deformational event and can commonly be expressed as a crystalloblastic series. In the Granduc ore, because of unusual conditions, chalcopyrite and pyrrhotite have also been remobilized and recrystallized at a late stage in preference to the normally more mobile galena.

The mobility of the chalcopyrite has been an important factor in determining commmercial ore limits at Granduc. McDonald (1967) cited experimental and physical evidence for the mobility of chalcopyrite and for the associated preferential enrichment of wallrocks by veining as a result of differential movement. At Granduc, chalcopyrite and to a lesser

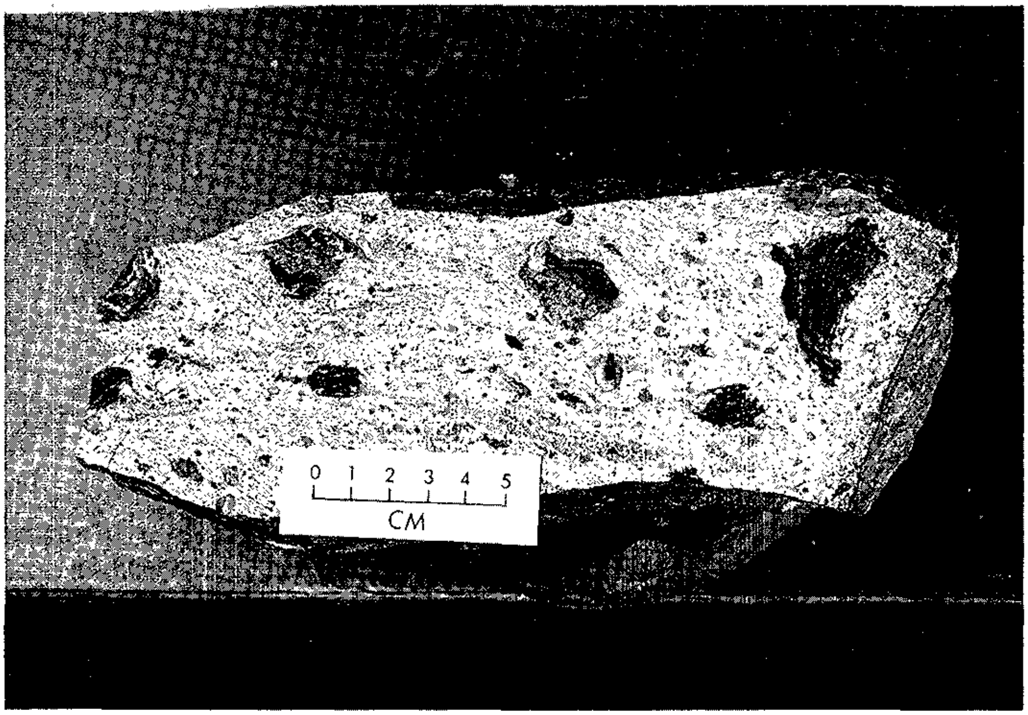


Plate XXIII. Massive sulphide ore from the Ch zone, Granduc mine, showing related country rock inclusions.

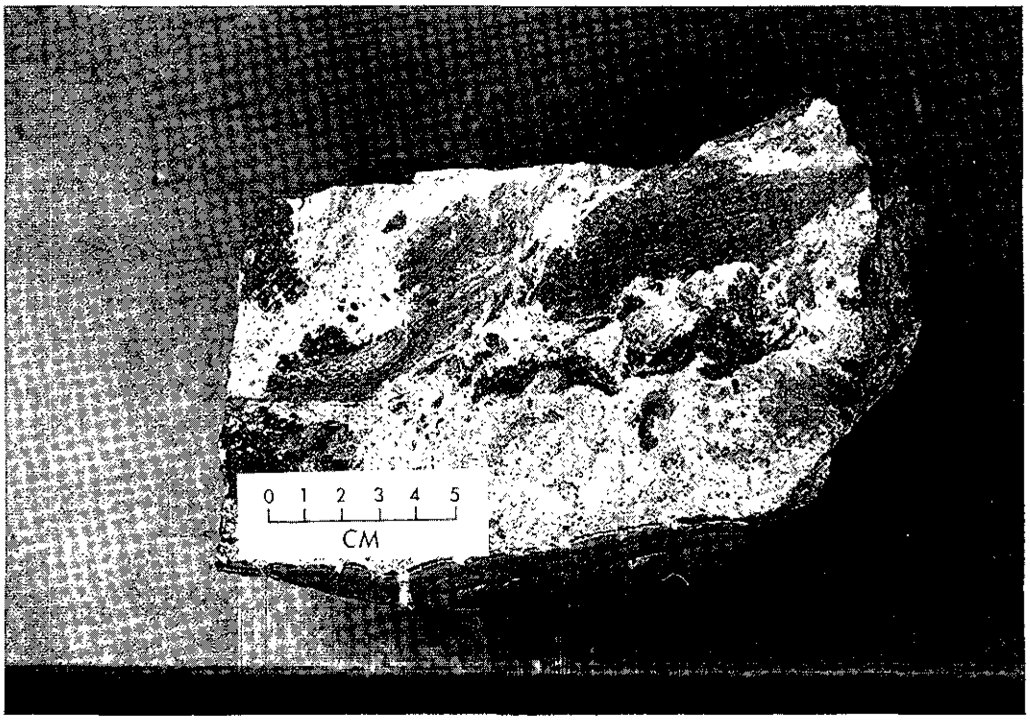


Plate XXIV. Massive sulphide ore from the C zone, Granduc mine, with fragmented pyrite and magnetite as streaks.

extent pyrrhotite have veined both country rock and massive sulphide lenses. This indicates that veining is post cataclastite and suggests that sulphide remobilization occurred after local relaxation. The event is assumed to have been related to Tertiary faulting which cuts the ore zones, however it could also indicate the presence of a chemically reactive medium and fluid transport as suggested by McDonald (*op. cit.*, p. 213).

Vokes (1969) noted that ores healed by fine-grained products of deformed sulphide are very commonly found in the greenschist facies environment of the Norwegian Caledonides. Composition, particularly the presence of abundant chalcopyrite, appears to partly control mineral textures in massive sulphide deposits deformed under such a low-grade regime. Thus the Granduc ores are massive and compact in contrast to the sandy pyritic deposits at Anyox and Cyprus. As Vokes and many others have pointed out, a banded structure common to most sulphide ores is generally oriented parallel to bedding or country rock stratification and is characteristic of metamorphosed 'kieslagerstatten' ore deposits.

Alteration: There is no apparent macroscopic or microscopic alteration related to the massive sulphide lenses at Granduc. Calc-silicate lenses are found within the ore as well as throughout the cataclasite zone at the Granduc property. Tourmaline is found as clasts in the mineralized areas as well as in the footwall phyllonite unit but, like the widespread calc-silicate minerals, has no direct spatial relationship to ore. Brecciated remnants of dykes and small plutons occur in the ore horizon but these appear to be spatially restricted and unrelated to ore zones, calc-silicates, and tourmalinized wallrock. The apparent absence of an alteration halo may be a result of cataclastic deformation in the ore horizon but it may also be a function of ore genesis.

Genesis: The Granduc ore deposit comprises a series of concordant massive sulphide lenses localized within a complex sequence of volcanic-sedimentary rocks that have been deformed by cataclasis. Norman and McCue (1966) suggested that the orebodies occur in a folded metasedimentary sequence and formed when mineralizing fluids were channeled along a swarm of andesitic dykes. They concluded that the introduction of chalcopyrite was preceded by the formation of abundant magnetite, epidote, actinolite, small amounts of garnet, and tourmaline. Also the presence of biotite in the phyllonites has been interpreted as an alteration halo possibly related to migrating solutions associated with nearby dioritic plutons. Norman and McCue (*op. cit.*) have classified the Granduc deposit as a pyrometasomatic stringer lode while others (Ney, 1966; White, 1966) referred to it as a sulphide lode or lode deposit. Because of extensive destructional deformation along the South Unuk cataclasite zone, original structures and textures, and relationships between the ore and the country rocks are obscured. As a result, any genetic interpretation regarding the Granduc orebodies must rely on indirect evidence.

The intimate association of apatite, magnetite, calcite, and calc-silicate minerals in the ore horizon and in the country rocks suggests an indirect relationship. The normal range of apatite in igneous rocks is from 0.1 to 1.0 per cent by volume (Grobler and Whitfield, 1970). They indicated that in olivine-apatite-magnetite bands in the Villa Nora deposit in the Bushveldt Igneous Complex magnetite averaged 20 per cent and apatite 22 per cent by volume. Philpotts (1967) summarized literature on magnetite-ilmenite-apatite occurrences; they appear to be restricted to certain alkaline complexes and to rocks of the anorthosite suite. He concluded that these minerals resulted from fractional crystallization, and formed at minimum temperatures of 850 degrees to 1 000 degrees centigrade. Magnetite-apatite deposits are also well known in the Palabora area of northeast Transvaal, where they occur as veins and disseminated deposits in pyroxenite and syenite, and near carbonatite complexes (Schwellnus, 1938; Haughton, 1969). Naldrett (1970) reports widespread occurrences of magnetite-apatite-hypersthene cumulus layers within oxide-rich gabbro in the Sudbury irruptive.

At the Granduc property, the magnetite-apatite-calcite mineral assemblage occurs as thinly banded layers intercalated with calc-silicates, limestone bands up to 6 metres thick, graphitic quartzofeldspathic cataclasites, and the massive sulphide lenses. Thin section studies show that apatite comprises up to 25 per cent by volume in the calc-silicate layers and averages about 10 per cent in most of the rocks. Bulk analyses of country rocks outside the ore zone indicate an average composition of about 4.4 per cent total iron, 2.42 per cent $Ca(PO_4)_2$, 0.02 per cent copper, 0.008 per cent lead, and 0.005 per cent zinc.

The initial evidence from the Granduc rocks suggests that the magnetite-apatite-calcite zones are random within the local sequence and have not been concentrated as veins related to alkaline, carbonatite, or basic intrusives. This lack of relationship to intrusives indicates the possibility of a sedimentary origin with concentration of iron and phosphorous-rich material in close association with organic-rich sediments and carbonates.

A hydrothermal origin for Granduc mineralization has had a few proponents but direct evidence is lacking. Granduc ore, like Anyox ore, has a gangue to sulphide ratio of approximately 1:1, even including country rock breccia. Hydrothermal veins in the study area have a minimum gangue to ore ratio of 500:1, and the Silbak Premier system, which is known in detail, has a gangue to sulphide ratio of 700:1. The possibility of metamorphic dispersal of the gangue from the sulphide has been considered but this appears to be unlikely. The mobility of both sulphide and gangue material is very limited under low-grade metamorphic conditions, and there are no significant quartz or quartz-carbonate veins in the Granduc area.

After considering various theories for the origin of massive sulphides at Granduc, a volcanogenic-sedimentary origin is preferred. As Krauskopf (1971) noted the association of massive sulphide deposits with volcanogenic-sedimentary processes eliminates the enrichment stage generally related to hydrothermal and other processes, and also provides a metal source directly in magma. Clues to possible genesis of the Granduc mineralization can be found in the local stratigraphic sequence and in the wallrocks. The strata comprise a variety of gypsiferous grey limestone lenses, graphitic marine siltstones, volcanic sandstones, lithic and crystal tuffs, cherts, quartz conglomerates, and volcanic conglomerates. This sequence overlies thick pillow lavas, rhyolite flows, cherts, and various volcanic sediments. To the north and south this complex stratigraphic sequence grades rapidly into thick epiclastic volcanic conglomerates and marine sediments. The Granduc massive sulphide lenses occur in a sequence of shallow water marine, possibly brackish, near shore or restricted basinal deposits. The original rock assemblage is assumed to have included primary calcite, organic matter, iron oxides, gypsum, and phosphate. It is likely that significant acid volcanism was active during deposition of the sedimentary assemblage.

On the basis of the stability field diagram for iron oxides (Krumbein and Garrels, 1952), the writer assumes that the lithologic assemblage at Granduc was deposited in a restricted, shallow marine environment marked by a low negative Eh and a pH about 7.8. Apparent cyclic deposition in this basin, which is evidenced by alternating apatite-magnetite, calc-silicate, limestone, and quartzofeldspathic rocks, possibly represents fluctuations in the acidity of the basin (Sakamoto, 1950). There were periodic incursions of volcanic ash. The massive sulphide lenses at Granduc are present within a 230-metre-thick sequence as a series of overlapping lenses separated by originally unmineralized basinal sediments suggesting that these widely separated sulphide layers formed periodically. The evidence at Granduc suggests a sedimentary-volcanogenic origin analogous to other well-known deposits.

The relatively unmetamorphosed Kuroko-type deposits of Japan provide a model for bedded sedimentary sulphides related to submarine volcanic processes. Kuroko-type deposits formed under conditions of nearly neutral pH and low Eh (Horikoshi, 1965). A comparison of the chalcopyrite-rich sulphide lenses at Granduc to Japanese deposits indicates a similarity to the yellow, massive cupriferous iron sulphide Oko ores (Matsukuma, *et al.*, 1970). The Oko ores are apparently transitional between siliceous breccia ores and the sphalerite and galena-rich Kuroko ores. This distinction is not as readily made at Granduc, although galena and sphalerite are mainly concentrated in the A and Ch zones which stratigraphically lie at the top of the ore horizon. The B and F footwall zones at Granduc, like Kuroko deposits, include a higher proportion of pyrite and siliceous material than the overlying zones. Matsukuma, *et al.*, (*op. cit.*) have also noted that gypsum deposits, which are spatially related to Oko ores, have never been found directly adjacent to acidic volcanics but are generally associated with small lenses of silicifed rocks. Apparently, these rocks have commonly been mistaken for rhyolite, but actually represent silicified pyroclastic zones. At Granduc siliceous ultramylonite lenses are intimately related with the massive sulphide lenses and are comparable in size and extent to siliceous zones related to Oko ores.

The Granduc ore horizon lies within a sequence marked by abundant graphite and carbonate. There are no known occurrences of graphite associated with Kuroko deposits and no carbonate minerals in Kuroko ores (Kajiwara, 1970). Calcite is a common minor gangue mineral in the Granduc sulphide lenses and graphite is characteristic of the footwall phyllonite country rocks. It appears that, although the general ore environment at Granduc compares to certain Kuroko features, there are significant variations which imply a somewhat different ore-forming process.

Lambert and Bubela (1970) studied the processes leading to formation of banded sedimentary sulphide ores. In these experiments (Bubela and McDonald, 1969; Lambert and Bubela, *op. cit.*), the pH of the suspension was held between 7 and 8, and the aqueous sodium sulphide solution was inoculated with the sulphate-reducing organism *Desulfotomacumul nigrificans*. The sulphate-fixing bacterium requires nutrients in order to promote cell growth; both nitrogen and phosporus are essential to organic growth and to the activity and regeneration of these organisms. Nitrogen is generally available as the NH_4^+ ion, and phosphorus, which supports the primary function of storing and transferring energy, is supplied by phosphate. At Granduc, phosphate is now represented by abundant apatite in both the ore horizon and the country rocks; it appears to have been present in more than adequate amounts to promote bacterial growth and perpetuate the bacterial sulphate-fixing cycle in the sedimentary-volcanic sequence.

The writer concludes that the concordant Granduc massive sulphide deposits represent deformed syngenetic sulphide. These deposits were probably formed in a restricted, shallow marine, sedimentary-volcanic environment where sedimentation was accompanied by hydrothermal or fumarolic enrichment of metal, where biogenic sulphur was available and where phosphorus was supplied by upwelling currents.

PORPHYRY DEPOSITS

PORPHYRY MOLYBDENUM DEPOSITS

The Tertiary Lime Creek quartz monzonite stock is one of the Alice Arm Intrusions, all of which bear a close petrological resemblance and all of which have accessory molybdenite. The Alice Arm Intrusions are part of an extensive belt of Tertiary quartz monzonite stocks that parallel the eastern margin of the Coast Plutonic Belt. G. Pouliot (personal communication) studied producing mines in this belt of Tertiary stocks from Alice Arm to Montana, and has been impressed with their similar petrogenic characteristics. In northwestern British Columbia the age of these stocks has been determined by K/Ar methods as about 50 to 52 Ma.

PORPHYRY COPPER-MOLYBDENUM DEPOSITS

These deposits are characterized by their large size, complex geological environment, and the presence of both copper, molybdenite, and accessory silver mineralization. A low-grade disseminated mineral zone in the Stewart Complex is the Mitchell-Sulphurets property north of the Granduc mine (Fig. 2A). The deposit is a chalcopyrite-pyrite-bornite and molybdenite replacement feature spatially related to a differentiated syenodiorite stock and dyke complex. Major features indicating large-scale replacement are alteration haloes of porphyroblastic microcline, pyrite, quartz, and sericite in the country rocks enveloping the stock (Kirkham, 1968). The country rocks include preferentially altered and replaced Lower Jurassic volcanic conglomerates and less altered volcanic breccias and sandstones. Both the mineralized zone and the intrusives are deformed and eroded. The mineralized zone is unconformably overlain by part of the Middle Jurassic Betty Creek Formation, which in turn has been faulted and eroded, and is disconformably overlain by the Middle Jurassic Salmon River Formation.

The secondary potash feldspar represents an early widespread hydrothermal alteration phase. Subsequent sericite and quartz alteration is restricted to the northeast margin of the zone, where country rocks were pervasively altered to a sericitic quartz stockwork. Quartz veins are common along the east margin of the zone. Extensive massive quartz emplacement at the north side of Mitchell Glacier suggests a major hydrothermal event. Talc schists along parts of the eastern hydrothermal aureole appear to have developed as a result of local deformation related to plutonism.

METALLOGENIC EPOCHS IN THE STEWART COMPLEX

The complexity of the tectonic evolution of the Stewart Complex, as well as the great abundance of mineral deposits in the area, has hindered the development of a metallogenic model for the region. The metallogenic epochs presented below are directly applicable to the Stewart Complex but could be adapted to an overall metallogenic hypothesis for the Western Cordillera.

(1) Epoch 1: Upper Triassic — copper, magnetite.
(2) Epoch 2: Lower Jurassic — copper, molybdenum, gold, silver.
(3) Epoch 3: Middle Jurassic — copper, gold, silver, lead, zinc.
(4) Epoch 4: Late Jurassic-Cretaceous — copper, lead, zinc, gold, silver, antimony, arsenic.
(5) Epoch 5: Tertiary — molybdenum, silver, lead, zinc, tungsten.

Epoch 1: One type of mineral deposit characterizes the Upper Triassic mineralization in the Stewart Complex. This is a massive magnetite-chalcopyrite occurrence on the north side of McQuillan Ridge in the Unuk River area. The Max deposit has not been studied in detail but ore appears to be confined to the anticlinal crest of a folded granular limestone sequence which has been partially intruded and weakly deformed by Late Triassic quartz diorite. Physically the Max deposit is a conformable, stratabound, massive oxide-sulphide deposit. The writer suggests that this has been formed by syngenetic sedimentary-volcanogenic processes, rather than contact metamorphic processes.

Epoch 2: Lower Jurassic deposits in the Stewart Complex include simple fissure veins which exhibit high gold-low silver ratios, hydrothermal replacement porphyry-type copper-molybdenum deposits, and the conformable cupriferous massive sulphide deposits at Granduc Mountain. Structural and stratigraphic evidence indicates that these deposits formed during the Hettangian to Toarcian stages prior to Aalenian or Early Bajocian orogeny.

Epoch 3: Characteristic Middle Jurassic mineral deposits include gold-silver fissure veins, vein-replacement mineralization, characterized by the Silbak Premier deposits, and stratiform cupriferous pyritic deposits localized in the Anyox area. The simple fissure vein and transitional vein-replacement deposits are characterized by low silver-gold ratios and have been correlated with a spatially related Middle Jurassic granitic intrusion and acid volcanism.

Epoch 4: These deposits are generally fissure vein or replacement deposits spatially related to the margins of minor intrusions. None of these deposits has produced a significant tonnage of ore.

Epoch 5: This epoch is characterized by high silver-low gold fissure and vein-replacement deposits, porphyry deposits, and minor contact skarn deposits. The B.C. Molybdenum mine at Lime Creek characterizes the Tertiary porphyry deposits. Significantly, there are no known major mineral deposits found in the local Hyder pluton, in the large satellitic granitic bodies, or in the gneissic segment of the Coast Plutonic Complex.

Discussion: The metallogenic sequence developed for the Stewart Complex indicates that mineralization from the Late Triassic to Tertiary periods has an overall similarity as a result of comparable genetic processes but is marked by certain distinct features. One feature which readily separates the groups of deposits is the silver-gold ratio in the ores. The Stewart Complex exhibits broad metal zoning (Fig. 17) which can be directly related to metallogenesis. The Upper Triassic and Lower Jurassic vein deposits have high gold-low silver ratios, the Middle Jurassic vein deposits low silver-gold ratios of about 30:1, and the younger Jura-Cretaceous and Tertiary deposits high silver to gold ratios. At the Torbrit deposit, for example, the silver-gold ratio is about 100 000:1, and the Dolly Varden ratio is about 1 400 000:1.

As a general rule, vein deposits in the Stewart Complex have high gangue to sulphide ratios; at Silbak the ratio was about 700:1; it is even higher in the less productive fissure vein systems. The various massive sulphide deposits are characterized by gangue to sulphide ratios of 1:1 or less which appears to be indicative of a syngenetic volcanic-sedimentary environment. The silver-gold ratios of the volcanogenic massive sulphide ores range from about 30:1 to 60:1 which is approximately the same as the values calculated for the vein-replacement deposits (for example, Silbak Premier) related to a plutonic-volcanic environment.

The evolution of the Stewart Complex has been characterized by repeated cycles of volcanism, sedimentation, plutonism, uplift, and erosion. Within this orogenic cycle, metallogenesis, related to volcanic, sedimentary, and plutonic processes during each major tectonic phase, has produced broad mineral zoning and a large array of mineral deposits, which characterize this portion of the Western Cordillera.

APPENDICES

APPENDIX I — STRATIGRAPHIC SECTIONS

SECTION 1
UNUK RIVER FORMATION (MAP UNIT 12)
UPPER MEMBER

Section was measured at Tim Williams Glacier (Unuk River map sheet). It is exposed on the northeast limb of a broad northerly trending anticline. The uppermost beds are unconformably overlain by sedimentary beds of the Salmon River Formation. The lower contact with the middle member of the Unuk River Formation is obscured by permanent ice and snow.

Unit		Thickness (metres) Unit	Total From Base
SALMON RIVER FORMATION			
UNCONFORMITY			
7	Shale, silty shale, and siltstone; monotonous succession, thinly laminated; interbedded with stringers of very fine-grained sandstone and silty argillite; 60 per cent shale, 20 per cent silty shale, 15 per cent sandstone, and 5 per cent argillite; sandstone and argillite beds less than 30 centimetres thick throughout sequence; silty shale, olive-green, weathers grey, angular blocky fragments, limonitic stain general; abundant fossil fragments.	365	1 170
6	Greywacke, with intercalated subgreywackes, siltstone, and silty argillite; light to medium salt and peppery grey, medium grained, medium to light greenish grey, weathers darker grey with limonitic stain; blocky fragments, fissile argillite weathers to platy blocks; abundant fossil fragments form coquina with greywacke beds.	36	835
5	Andesitic to dacitic lapilli and lithic tuffs, olive-green, maroon, and light grey, well bedded, locally 0.5 metre in thickness, mainly lack distinct units; covered for most part by andesitic debris and shows as isolated outcrops; bedding down to 1 centimetre in thickness where exposed; generally siliceous alteration, some pyrite.	64	799
4	Volcanic breccia and agglomerate interbedded with tuffaceous greywacke, medium dark grey, composed of lithic fragments, mainly andesitic; clasts dark green to grey, fine-grained amygdaloidal andesite, angular to subrounded, 1 to 10 centimetres in diameter, poorly sorted, with obscure bedding, generally massive and structureless; matrix, tuffaceous andesite with interbedded fine-grained lithic tuffs forming beds locally 30 to 60 centimetres thick.	305	735
3	Interbedded tuffaceous greywacke and quartz granule conglomerate; partly covered, intermittent outcrops, 15-centimetre to 1-metre beds with flat, regular bedding planes and no obvious partings; weathers dark grey; 75 per cent greywacke, 25 per cent pebble conglomerate; quartz pebble conglomerate prominent near base, very well sorted having a mean of 2.5 centimetres and rarely over 3 centimetres or under 2 centimetres across.	125	430
2	Interbedded tuffaceous greywacke and quartz pebble conglomerate, partly covered limonitic stained outcrop, well bedded, 15 centimetre to 1.2-metre beds with flat, regular bedding planes, no obvious partings; blocky, dark weathering, 50 per cent greywacke, 50 per cent quartz pebble conglomerate; pebble conglomerate well sorted, quartz pebbles well rounded; fossil fragments locally abundant; matrix quartz-rich near base, decreasing upward and replaced by medium-grained greywacke.	183	305
1	Polymictic conglomerate, well-rounded boulders and cobbles of hornblende granodiorite, with andesitic and basaltic pebbles, thick bedded, sandy dark greywacke as matrix; coarse-grained, thick-bedded dark greywacke intercalated within predominantly conglomeratic sequence; 1 to 2-metre beds; gradational into overlying conglomerates; abundant moderately well-preserved fossil fragments.	122	122
UNCONFORMITY			

SECTION 2
UNUK RIVER FORMATION (MAP UNITS 11 AND 12)
MIDDLE MEMBER

The composite section was measured in the Twin John Peaks-Mount Madge and Mount Einar Kvale-Mount George Pearson areas. The succession is partly obscured by permanent ice and snow. These rocks are unconformably overlain by the upper member in the Tim Williams Glacier area as well as by members of the Betty Creek and Salmon River Formations in the Unuk River area. The base of the section is exposed at Twin John Peaks where it unconformably overlies the lower member of the Unuk River Formation.

Unit		Thickness (metres) Unit	Total From Base
UNCONFORMITY			
13	Interbedded volcanic sandstone, limestone, tuffaceous greywacke, lithic and crystal tuff, quartz pebble conglomerate, chert, and rhyolite; unit marked by its diversity and by discontinuity of the individual members; sandstones about 60 per cent of the thickness, typically greyish green, salt and pepper appearance in thin to medium beds which often exhibit channeling; limestone, medium grained, granular white to bluish grey, forming discrete lenses a few centimetres to several metres thick; tuffs, greenish grey, rarely red or maroon, graded 5 to 25-centimetre beds, generally andesitic and intercalated with grey planar-bedded tuffaceous greywacke; chert and rhyolite, thinly banded grey with intercalated quartz sandstone, forming beds 5 centimetres to 75 centimetres thick; argillaceous siltstone forms thin shaly partings within the various members throughout the unit; incipient schistosity is general and hornfelses developed adjacent to plutons; graphite, pyrite, and ankerite typical alteration minerals and limestone stain widespread; fossil fragments rare.	305	5 974
12	Gracey Creek limestone member, medium to coarse grained, mottled buff to blue-grey, massive, rare shale partings, no evidence of fossil debris, grey weathering.	183	5 669
11	Volcanic sandstone, andesitic tuff, argillaceous graphitic siltstone, limestone, chert, and rhyolite with sandstone comprising up to 40 per cent of this complexly interbedded unit; limestone as recrystallized, gypsiferous lenses a few centimetres to several metres thick, up to 30 per cent of the unit; thinly banded, altered rhyolite and grey chert lenses, 20 per cent of the unit; thinly laminated andesitic crystal and lithic tuff and dark siltstone form partings throughout the sequence; deformation produced incipient schistosity; most members recrystallized, generally altered, and variably hornfelsed; fossil fragments rare.	762	5 486
10	Pillow lava, extensively altered, variably hornfelsed, generally andesitic; cherty quartz sandstone, siltstone, and limestone, lens-like partings a few centimetres to approximately a metre thick form less than 10 per cent of this generally massive unit; generally dark green in colour, weathering medium green.	914	4 724
9	Volcanic conglomerate, clasts subangular to subrounded; 90 per cent andesite, 5 per cent volcanic sandstone, and 5 per cent volcanic siltstone as partings; massive, medium to light green, weathering dark green; variably schistose, hornfelsed, and marked by irregular mineralization, including scattered magnetite-rich zones.	914	3 810
8	Volcanic sandstone, siltstone, conglomerate, and some breccia interlayered, in about equal amounts; light to dark green, massive, locally marked by shaly partings, generally structureless; clasts and matrix generally andesitic, variably schistose and hornfelsed.	610	2 896
7	Pillow lava, variably altered, generally massive, andesitic with rare chert, quartz sandstone, and siltstone partings; dark green, weathers medium green; pillows outlined by altered rims.	914	2 286
6	Siltstone, medium olive-green to grey-brown on surface, mainly thin bedded, weathers to chips, slope-forming unit; weakly schistose or hornfelsed.	122	1 372
5	Pillow lava, olive-green, weathers medium green, massive, rare chert partings, generally altered, probably andesitic; hornfelsed and indurated near intrusive contacts.	275	1 250
4	Volcanic conglomerate and greywacke interbedded, conglomerate clasts subangular to subrounded, comprise 90 per cent andesite, 10 per cent greywacke and siltstone; conglomerate matrix poorly sorted andesite clasts; medium green, weathering grey to brown; variably schistose and irregularly altered and hornfelsed.	457	975

Unit		Thickness (metres) Unit	Total From Base
3	Siltstone, somewhat argillaceous, pencil weathering, medium olive-grey, weathering light grey, weakly schistose, variably indurated, slope-forming unit.	152	518
2	Interbedded thinly banded rhyolite, rhyolite breccia, feldspathic and quartz sandstone, and cherty spherulitic rhyolite; pink to greenish grey, white weathering; nodular structure well developed in cherty rhyolite, block mosaic typical of breccia lenses; sandstone forms laminations and matrix in spherulitic rhyolite; 80 per cent rhyolite, with 20 per cent sandstone; irregular alteration.	122	366
1	Siltstone, mainly black, thin bedded, with minor irregular beds and lenses of light to medium grey siltstone; grades upward into fine-grained greywacke; generally carbonaceous, variably graphitic, hornfelsed near intrusions; planar bedding well developed, laminae 0.6 centimetre to 5 centimetres marked by colour banding; fossiliferous at base of unit.	244	244
UNCONFORMITY			

SECTION 3
UNUK RIVER FORMATION (MAP UNIT 12)
LOWER MEMBER

Section was measured along the axial zone of a major anticline between Treaty Creek and Jack Glacier, and from West McTagg Glacier to Twin John Peaks. Base of the section is obscured by ice and snow and the section is overlain unconformably by the middle member of the Unuk River Formation.

Unit		Thickness (metres) Unit	Total From Base
UNCONFORMITY			
15	Volcanic conglomerate (70 per cent) with interbedded lithic tuff (30 per cent) form resistant ridge; clasts dominantly greenish grey andesite, angular to subrounded, 1 centimetre to 20 centimetres across; poorly sorted, crudely stratified with erratic augite basalt clasts to 15 centimetres; fine-grained tuff alternating red-green, planar bedding, channel features prominent.	244	8 809
14	Rhyolite, rhyolite breccia, light grey to pink-buff, weathering white; ribbon banding and pavement mosaic typical; flow banding irregular; cliff forming.	15	8 565
13	Volcanic conglomerate, volcanic sandstone with 20 per cent siltstone, interbedded with lesser thin augite basalt flows; clasts dark green, 1 centimetre to 10 centimetres, andesitic with andesitic clastic matrix; sandstone, thinly banded red-green, medium grained, planar bedded; siltstone thinly laminated, colour banded, grey-olive, weathering grey; basalt dark, weathering green, limonite stain; fossils.	46	7 940
12	Conglomerate, polymictic; clasts, 40 per cent hornblende quartz diorite; well-rounded boulders, cobbles, pebbles, basalt cobbles and pebbles, 25 per cent; quartz and chert pebbles and cobbles, 10 per cent; matrix, red sandstone; poorly sorted, chaotic crossbedding, poorly stratified; striking red colour, forms craggy spires.	152	8 503
11	Volcanic sandstone, siltstone, and tuff, interbedded; sandstone grey to green, medium grained, indistinct layering; shaly partings; siltstone grey-black, planar bedding, members 30 centimetres to 1 metre thick, intercalated with sandstone; tuff red, maroon to green, regular, even 10-centimetre to 40-centimetre planar bedding.	274	8 351
10	Volcanic conglomerate, siltstone, interbedded; clasts angular andesite, minor basalt; thin andesite lenses interbedded; siltstone fine grained grey-green, thinly laminated; 70 per cent conglomerate, 25 per cent siltstone, 5 per cent flows; limonitic stain, variably pyritic, indurated.	518	8 077
9	Rhyolite, ribbon chert; grey to pinkish, white weathering; thinly laminated; irregular pavement breccia in lower member.	61	7 559
8	Siltstone, black-grey, thinly laminated, fissile, pencil weathering; slope forming.	91	7 498

Unit		Thickness (metres) Unit	Total From Base
7	Greywacke, siltstone, argillite, interbedded; grey-black; some indistinct layering; flaggy weathering siltstone and argillite, blocky greywacke; thin bedded from 15 centimetres to 3 metres thick with argillite partings.	549	7 407
6	Volcanic breccia, sandstone interbedded with lesser amounts of andesitic lava, minor thin basalt lenses; clasts angular, dark green fine-grained andesite; 1 centimetre to 60 centimetres poorly sorted, crudely stratified, thick beds, poorly defined, generally massive appearance; sandstone green, medium grained, angular, mainly andesite with 10 to 15 per cent augite; lava dark green, black, generally porphyritic, massive, limonite stained.	457	6 558
5	Volcanic sandstone, greywacke, and siltstone interbedded; greenish grey; thin alteration of beds throughout unit; clasts mainly andesite; fossil fragments.	305	6 401
4	Volcanic breccia, 1 centimetre to 60 centimetres, angular to subangular clasts, greenish andesite in andesitic matrix; massive, structureless.	549	6 096
3	Interbedded monotonous succession of volcanic sandstone, siltstone, shale, and minor breccia and rare limestone; general grey-green aspect; well bedded; 15 centimetres to several metres, rhythmic sequence marked by shaly partings; planar bedding typical, structures rare; fossiliferous at top and base.	4 572	5 547
2	Volcanic conglomerate, sandstone; gradational with overlying sandstone succession; massive appearance, thick bedded, shaly partings; grey-green to olive-green, brown weathering; blocky, cliff forming; limonite stained, pyritic, altered.	305	975
1	Volcanic flows, breccia, interbedded; massive thick-layered porphyritic and amygdaloidal andesitic flows; dark green, grey weathering, limonite stained, pyritic; breccia as intercalations, clasts to 1 metre, andesitic with andesitic matrix.	670	670

BASE OF FORMATION NOT EXPOSED.

SECTION 4
BETTY CREEK FORMATION (MAP UNIT 13)

Section measured at Betty Creek, on the south side, west of Betty Glacier. The uppermost beds are conformably to disconformably overlain by sedimentary rocks of the Salmon River Formation and underlain unconformably by units of the upper member of the Unuk River Formation. Part of the succession is obscured by snow and talus.

Unit		Thickness (metres) Unit	Total From Base
SALMON RIVER FORMATION			
CONFORMITY — DISCONFORMITY			
4	Interbedded volcanic conglomerate and sandstone; dominantly brick red to maroon, mottled green to grey; clasts entirely greenish to olive-green, fine-grained to porphyritic andesite, angular to subrounded, 1 centimetre to 10 centimetres across; poorly sorted, moderately well stratified, crossbedding and oscillation ripples well developed in fine-grained members; sandstone about 50 per cent of succession, 95 per cent medium-grained angular andesite clasts; coloration impacted by iron oxide-rich matrix in both conglomerate and sandstone; generally massive in overall aspect.	122	823
3	Interbedded volcanic sandstone and conglomerate; dominantly dark olive-green to almost black; massive; apparently moderately indurated and variably hornfelsed; bedding indistinct; clasts mainly dark green andesite, with 1 to 5-centimetre angular fragments dominant; sedimentary structures other than planar laminations rare; scattered fossil fragments.	274	701
2	Interbedded volcanic sandstone and conglomerate; alternating red and green laminations, bedding planar; crossbedding and oscillation ripples common; clasts 1 to 10 centimetres, mainly andesite, up to 10 per cent granitic fragments, thin red shaly		

Unit		Thickness (metres) Unit	Total From Base
	partings common; matrix red or green andesite clasts, medium to fine grained; beds 15 centimetres to 1 metre thick; compact, weakly indurated, ridge-forming member; scattered fossil fragments.	335	427
1	80 per cent red volcanic sandstone, 20 per cent conglomerate; massive, beds approximately 1 metre to 2 metres thick; crossbedding frequent; clasts dominantly dark green andesite, matrix andesitic with abundant oxide which imparts overall colour.	92	92

APPENDIX II

FOSSIL LOCALITIES

TAKLA GROUP

(Identifications by E. T. Tozer)

Report on Triassic fossils from the Unuk River area, Stikine River map-area, Cassiar district, northern British Columbia, submitted by G. W. H. Norman, Newmont Mining Corporation, 1961.

GSC locality 44414; elevation 1 520 metres; west side of Harrymel Creek; latitude 56° 34′, *longitude* 130° 37′.
Aulacoceras sp.
Age: Late Triassic, probably Karnian

GSC locality 44417; elevation 1 370 metres; east slope of McQuillan Ridge; latitude 56° 24′, longitude 130° 32′.
Halobia? sp.
Age: Triassic, probably Late Triassic

GSC locality 44418; elevation 1 370 metres; east slope of McQuillan Ridge; latitude 56° 24′, longitude 130° 32′.
Halobia sp.
Crushed ammonite indet.
Age: Late Triassic

UNUK RIVER FORMATION

GSC locality 44416; elevation 1 690 metres; on ridge 3.2 kilometres south of toe of Treaty Glacier; latitude 56° 36′, longitude 130° 20′ (determination by E. T. Tozer).
Psiloceras canadense Frebold
Weyla sp.
Pleuromya? sp.
Gastropods
Age: Hettangian

Field No. 67-F-7; *elevation 1 690 metres; on ridge 2.9 kilometres south of toe of Treaty Glacier*; latitude 56° 36′, longitude 130° 20′ (determination by W. R. Danner).
Indeterminate ammonite
Weyla sp.
Indeterminate gastropod
Pleuromya sp.
Large pecten
Lima sp.?
Entolium sp.?
Oxytoma sp.?
Psiloceras canadense
Horn corals, one form resembles *Kraterostrobilos bathys* Crickmay
Age: Early Jurassic (collection similar to localities near Ashcroft)

GSC locality 44413; elevation 1 340 metres; west side of Jack Glacier; latitude 56° 35′, longitude 130° 21′ (determination by E. T. Tozer).
Weyla sp. indet.
Age: Early Jurassic

GSC Locality 44412; elevation 1 310 metres; west side of Jack Glacier; latitude 56° 37′, longitude 130° 20′ (determination by E. T. Tozer).
Belemnoid fragments indet.
Pecten sp. indet.
Age: Probably Early Jurassic

GSC locality 86264; elevation 1 950 metres; west side of Twin John Peaks; latitude 56° 33′, longitude 130° 25′ (determination by H. Frebold).
Pelecypods
Weyla sp.
?*Cardinia* sp. indet.
Age: The genus *Weyla* is only known from Lower Jurassic beds. Identification of the species would probably enable a more precise age determination. The material will be sent to H. W. Tipper who is a *Weyla* expert. The author suggests a Hettangian or Sinemurian age.

GSC locality 44419; elevation 1 890 metres; west side of Twin John Peaks; latitude 56° 34′, longitude 130° 25′ (determination by H. Frebold).

Poorly preserved ammonites, *Arieticeras*? in shale
Weyla sp. and other poorly preserved pelecypods in limestone
Age: Early Jurassic, probably younger than GSC locality 44416

GSC locality 86265; elevation 1 340 metres; southwest slope of Twin John Peaks; latitude 56° 31′, longitude 130° 26′ (determination by H. Frebold).

Pelecypods — very poorly preserved
?*Weyla* sp. — referred to H. W. Tipper
Age: Probably Early Jurassic

GSC locality 87061; elevation 1 450 metres; east side of small unnamed glacier 7.2 kilometres south of Treaty Creek (determination by H. Frebold).

Ammonoids
Dactylioceras sp. (fine ribbed)
Age: Not Cretaceous; the genus *Dactylioceras* is mainly characteristic of the Toarcian but some species occur already in the Upper Pliensbachian (also in British Columbia). As there are no other guide ammonoids in this collection the exact age cannot be determined at present — Late Pliensbachian or Toarcian.

GSC locality 44411; elevation 1 520 metres; on ridge 2.4 kilometres east of King Creek; latitude 56° 31′, longitude 130° 42′ (determination by H. Frebold).

Belemnoid and pelecypod fragments indet
Age: Probably Early Jurassic

GSC locality 86261; elevation 1 580 metres; on ridge 2.6 kilometres east of King Creek; latitude 56° 31′, longitude 130° 41′ (determination by H. Frebold).

Pelecypods — numerous but very poorly preserved specimens; no species can be identified
Age: Possibly Middle Jurassic

GSC locality 86273; elevation 1 705 metres; on west ridge of Nickel Mountain; latitude 56° 44′, longitude 130° 35′ 30″ (determination by H. Frebold).

Ammonoids
Imprints and flattened specimens of Hildocerataceae in shale; some specimens somewhat similar to *Haugia* and related genera but no safe identification of genus can be made; better material requested
Age: Possibly Toarcian

BETTY CREEK FORMATION

(Determinations by H. Frebold)

GSC locality 86283; elevation 1 740 metres; north side of Mitchell Glacier; latitude 56° 33′, longitude 130° 13′.

Ammonoids
Sonninia sp.
?*Sonninia* sp. indet.
Subfamily Graphoceratinae Buckman; few more or less unsatisfactorily preserved specimens somewhat similar to *Graphoceras*
Belemnoids — according to J. A. Jeletzky — undeterminable
Pelecypods
Ostrea sp.
Pleuromya sp.
?*Trigonia* sp. Other poorly preserved fragments of pelecypods
Gastropods — undeterminable
Age: Upper part of Early or Middle Bajocian

SALMON RIVER FORMATION

(Determinations by J. A. Jeletzky and H. Frebold)

GSC locality 69404; elevation 1 050 metres; Divide Lake, east shore; latitude 56° 11′, longitude 129° 58′.

Generically indeterminate representatives of Trigoniidae of general Jurassic or Cretaceous affinities
Age and Correlation: According to E. T. Tozer (personal communication) these generically indeterminate trigoniids could hardly be Triassic in age. They must therefore be of a general Jurassic or Cretaceous age — cannot be dated any closer

GSC locality 69405; elevation 1 310 metres; on Bear River Ridge, east of Long Lake; latitude 56° 07′, 129° 58′.

Indeterminate belemnite-like Coleoidea
Indeterminate pelecypods
Age and Correlation: Presumably Mesozoic — cannot be dated any closer

GSC locality 69403; elevation 1 520 metres; west slope of Mount Dillworth; latitude 56° 09′, longitude 130° 02′.

Cylindroteuthis (*Cylindroteuthis*?) sp. indet.
Trigonia (*Haidaia*?) sp. indet.
Pelecypods, genus and species indet.
Solitary corals, genus and species indet.
Age and Correlation: Presumably of the Middle (Bajocian or Bathonian) to early Upper (Callovian to Early Oxfordian) Jurassic age but cannot be dated definitively because of extremely poor preservation of all fossils available

GSC locality 86260; elevation 1 580 metres; west slope of Mount Dillworth; latitude 56° 09′, longitude 130° 02′ 30″.

Pelecypods
Ctenostreon gikshanensis McLearn (fragment)
Trigonia aff. *T. guhsani* McLearn
Pecten sp. indet.
Other pelecypods too poorly preserved to warrant safe identification
Belemnoids — referred to J. A. Jeletzky
Age: Probably Middle Bajocian

GSC locality 86259; elevation 1 400 metres; east side of Bruce Glacier; latitude 56° 36′, longitude 130° 17′ 20″.

Ammonoids
?*Sonninia* sp. indet.
Belemnoids — undeterminable
Pelecypods
Trigonia sp. aff. *T. guhsani* McLearn — similar to some of the *Trigonia* in 86267
?*Ctenostreon* aff. *C. gikshanensis* McLearn
Gastropods — undeterminable
Age: Probably Middle Bajocian
GSC locality 86267; elevation 1 280 metres; between Bruce and Jack Glaciers; latitude 56° 37′, longitude 130° 21′
Ammonoids — one fragment of a larger ammonoid, undeterminable
Belemnoids — according to J. A. Jeletzky, undeterminable
Pelecypods
Trigonia sp. — large specimens, poorly preserved
Age: Probably Middle Jurasssic

GSC locality 86268; elevation 1 070 metres; on south slope of ridge 2.4 kilometres northeast of Tom MacKay Lake; latitude 56° 40′, longitude 103° 25′.

Ammonoids — poorly preserved imprints, deformed, undeterminable
Pelecypods
Inoceramus sp. indet.
Age: Jurassic

GSC locality 86266; elevation 1 110 metres; south end of Tom MacKay Lake; latitude 56° 36′, longitude 130° 31′.

Ammonoids — squashed and deformed specimens possibly belonging to the genus *Kheraiceras* Spath; as far as a comparison is possible these fragments seem to be similar to *Kheraiceras* species from the Smithers area
Age: Early Callovian

NASS FORMATION

(Identifications by H. Frebold)

GSC locality 69406; elevation 485 metres; at Meziadin Lake, northwest side, along road; latitude 56° 07′, longitude 129° 22′.

Buchia concentrica Sowerby
(? = *Buchia bronni* Rouillier)
Large perisphinctid (?) ammonites — referred to H. Frebold
Cylindroteuthis (*Cylindrotheuthis*) sp. indet.
Age and Correlation: *Buchia concentrica* zone, Upper Oxfordian or Lower Kimmeridgian in terms of the international standard stages; in western British Columbia this zone occurs on the west coast of Vancouver Island in the upper part of Division A of J. A. Jeletzky (*Geol. Surv., Canada*, Paper 50-37), in the lower part of the so-called Eldorado Group in Taseko Lakes map-area (92O), and in the unnamed Upper Jurassic rocks in Tatlayoko Lakes map-area.

GSC locality 86269; Snowslide Range, west of Bell-Irving River; latitude 56° 38′, longitude 120° 46′.

Ammonoids — one poor imprint of a small ammonoid, undeterminable belemnoids — referred to J. A. Jeletzky
Age: Probably Oxfordian

GSC locality 86270; Snowslide Range, west of Bell-Irving River; latitude 56° 38′ 30″, longitude 129° 46′ 25″.

Ammonoids

Subfamily Cardioceratinae Siemiradzki — small fragments of *Cardioceras*? *sensu lato* or *Amoeboceras*? *sensu lato*

Belemnoids — fragments to J. A. Jeletzky

Age: Oxfordian

GSC locality 86271; Snowslide Range, west of Bell-Irving River; latitude 56° 38′ 30″, longtidue 129° 45° 30″.

Belemnoids — referred to J. A. Jeletzky

Pelecypods

Pecten sp.

Age: ?Oxfordian

GSC locality 86272; Snowslide Range, west of Bell-Irving River; latitude 56° 39′, longitude 129° 46′ 30″.

Ammonoids

Subfamily Cardioceratinae Siemiradzki; very poorly preserved, numerous small specimens, probably belonging to the genus *Amoeboceras* Hyatt or some of its subgenera; some speciemsn resemble also *Plasmatoceras* Buckman, a subgenus of *Cardioceras*

Age: Oxfordian

Queen's Printer for British Columbia ©
Victoria, 1986

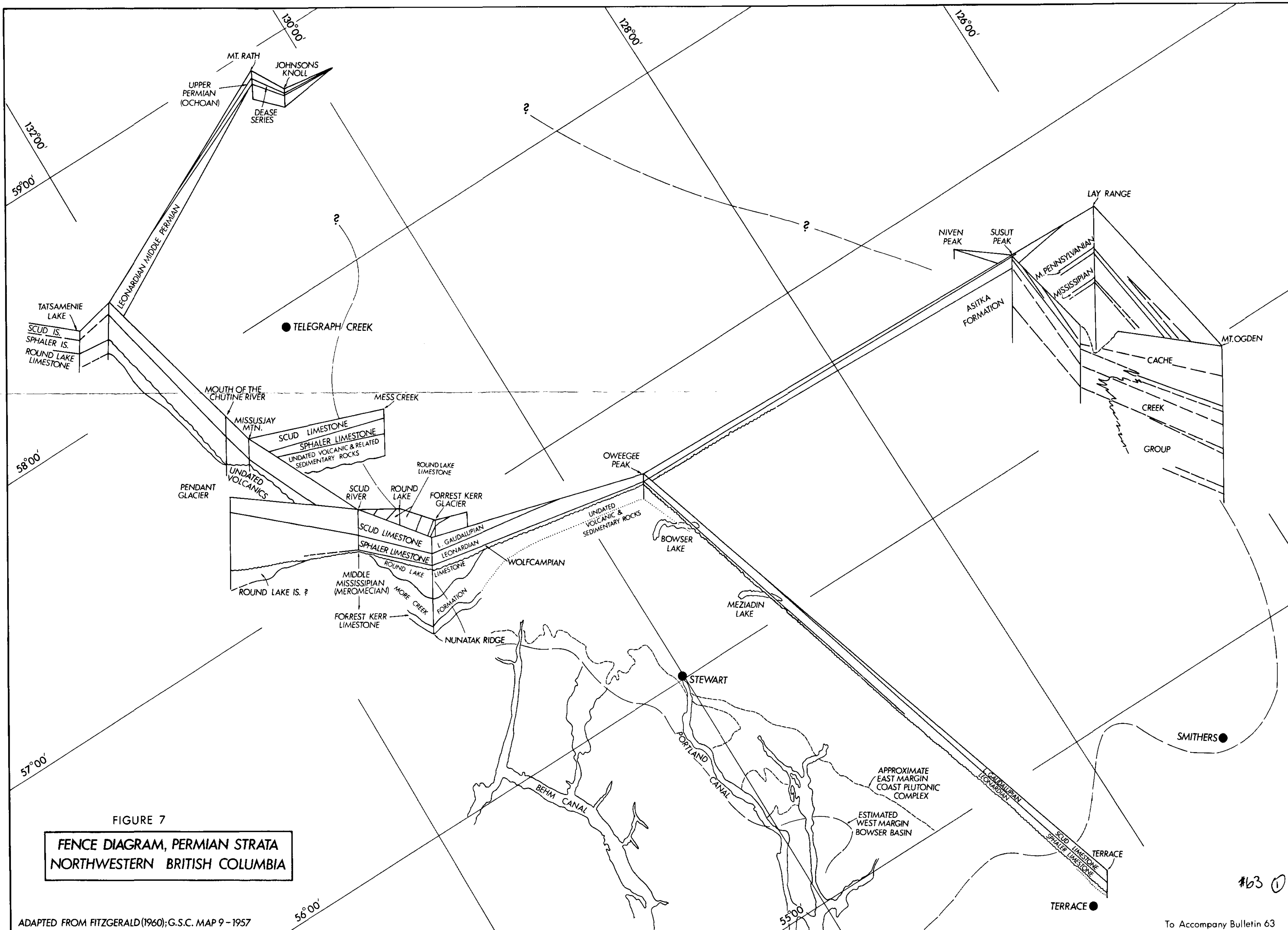
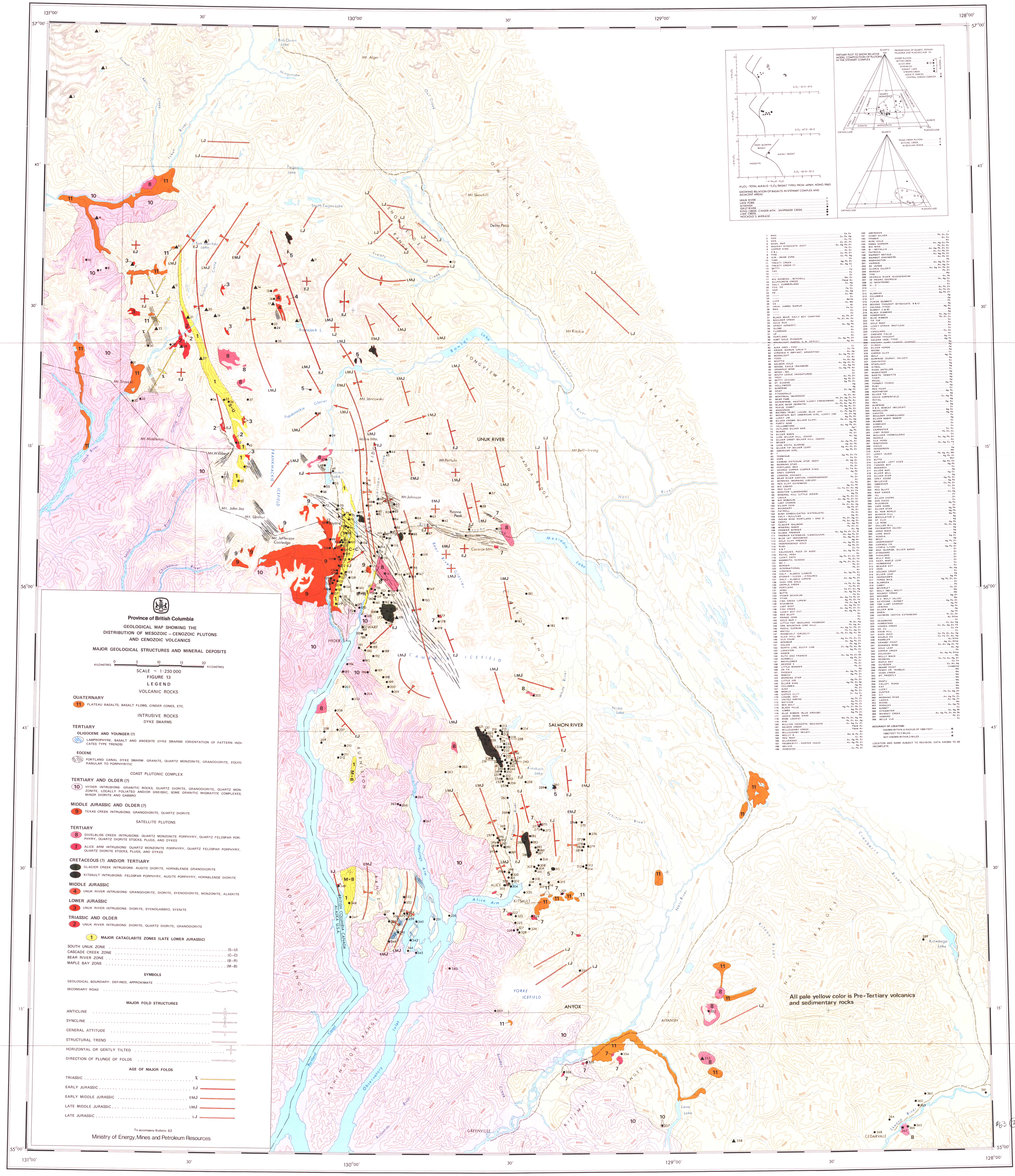


FIGURE 7

FENCE DIAGRAM, PERMIAN STRATA NORTHWESTERN BRITISH COLUMBIA

ADAPTED FROM FITZGERALD (1960); G.S.C. MAP 9 – 1957

To Accompany Bulletin 63



Province of British Columbia
GEOLOGICAL MAP SHOWING THE DISTRIBUTION OF MESOZOIC – CENOZOIC PLUTONS AND CENOZOIC VOLCANICS
MAJOR GEOLOGICAL STRUCTURES AND MINERAL DEPOSITS
KILOMETRES 0 5 10 15 20 KILOMETRES
SCALE ~ 1:250 000
FIGURE 13
LEGEND
VOLCANIC ROCKS
QUATERNARY
11 PLATEAU BASALTS, BASALT FLOWS, CINDER CONES, ETC.
INTRUSIVE ROCKS
DYKE SWARMS
TERTIARY
OLIGOCENE AND YOUNGER (?)
LAMPROPHYRE, BASALT AND ANDESITE DYKE SWARMS (ORIENTATION OF PATTERN INDICATES TYPE TRENDS)
EOCENE
PORTLAND CANAL DYKE SWARM: GRANITE, QUARTZ MONZONITE, GRANODIORITE, EQUIGRANULAR TO PORPHYRITIC
COAST PLUTONIC COMPLEX
TERTIARY AND OLDER (?)
10 HYDER INTRUSIONS: GRANITIC ROCKS, QUARTZ DIORITE, GRANODIORITE, QUARTZ MONZONITE, LOCALLY FOLIATED AND/OR GNEISSIC, SOME GRANITIC MIGMATITE COMPLEXES, MINOR DIORITE AND GABBRO
MIDDLE JURASSIC AND OLDER (?)
9 TEXAS CREEK INTRUSIONS: GRANODIORITE, QUARTZ DIORITE
SATELLITE PLUTONS
TERTIARY
8 DIVELBLISS CREEK INTRUSIONS: QUARTZ MONZONITE PORPHYRY, QUARTZ FELDSPAR PORPHYRY, QUARTZ DIORITE STOCKS, PLUGS, AND DYKES
7 ALICE ARM INTRUSIONS: QUARTZ MONZONITE PORPHYRY, QUARTZ FELDSPAR PORPHYRY, QUARTZ DIORITE STOCKS, PLUGS, AND DYKES
CRETACEOUS (?) AND/OR TERTIARY
6 GLACIER CREEK INTRUSIONS: AUGITE DIORITE, HORNBLENDE GRANODIORITE
5 KITSAULT INTRUSIONS: FELDSPAR PORPHYRY, AUGITE PORPHYRY, HORNBLENDE DIORITE
MIDDLE JURASSIC
4 UNUK RIVER INTRUSIONS: GRANODIORITE, DIORITE, SYENODIORITE, MONZONITE, ALASKITE
LOWER JURASSIC
3 UNUK RIVER INTRUSIONS: DIORITE, SYENOGABBRO, SYENITE
TRIASSIC AND OLDER
2 UNUK RIVER INTRUSIONS: DIORITE, QUARTZ DIORITE, GRANODIORITE
1 MAJOR CATACLASITE ZONES (LATE LOWER JURASSIC)
SOUTH UNUK ZONE .... (S–U)
CASCADE CREEK ZONE .... (C–C)
BEAR RIVER ZONE .... (B–R)
MAPLE BAY ZONE .... (M–B)
SYMBOLS
GEOLOGICAL BOUNDARY: DEFINED, APPROXIMATE
SECONDARY ROAD
MAJOR FOLD STRUCTURES
ANTICLINE
SYNCLINE
GENERAL ATTITUDE
STRUCTURAL TREND
HORIZONTAL OR GENTLY TILTED
DIRECTION OF PLUNGE OF FOLDS
AGE OF MAJOR FOLDS
TRIASSIC .... Ṯ
EARLY JURASSIC .... EJ
EARLY MIDDLE JURASSIC .... EMJ
LATE MIDDLE JURASSIC .... LMJ
LATE JURASSIC .... LJ
To accompany Bulletin 63
Ministry of Energy, Mines and Petroleum Resources
All pale yellow color is Pre-Tertiary volcanics and sedimentary rocks
UNUK RIVER
SALMON RIVER
ANYOX
STEWART
HYDER
ALICE ARM
KITSAULT
AIYANSH
CEDARVALE
GREENVILLE
CAMBRIA ICEFIELD
FRANKMACKIE ICEFIELD
YORKE ICEFIELD
BRITISH COLUMBIA
ALASKA U.S.A.

Figure 22
GENERAL GEOLOGY
OF THE
SILBAK PREMIER MINES LTD. AREA
SHOWING ORE SHOOT PROJECTIONS

To Accompany Bulletin 63 Ministry of Energy, Mines and Petroleum Resources

Figure 23

SILBAK PREMIER MINES

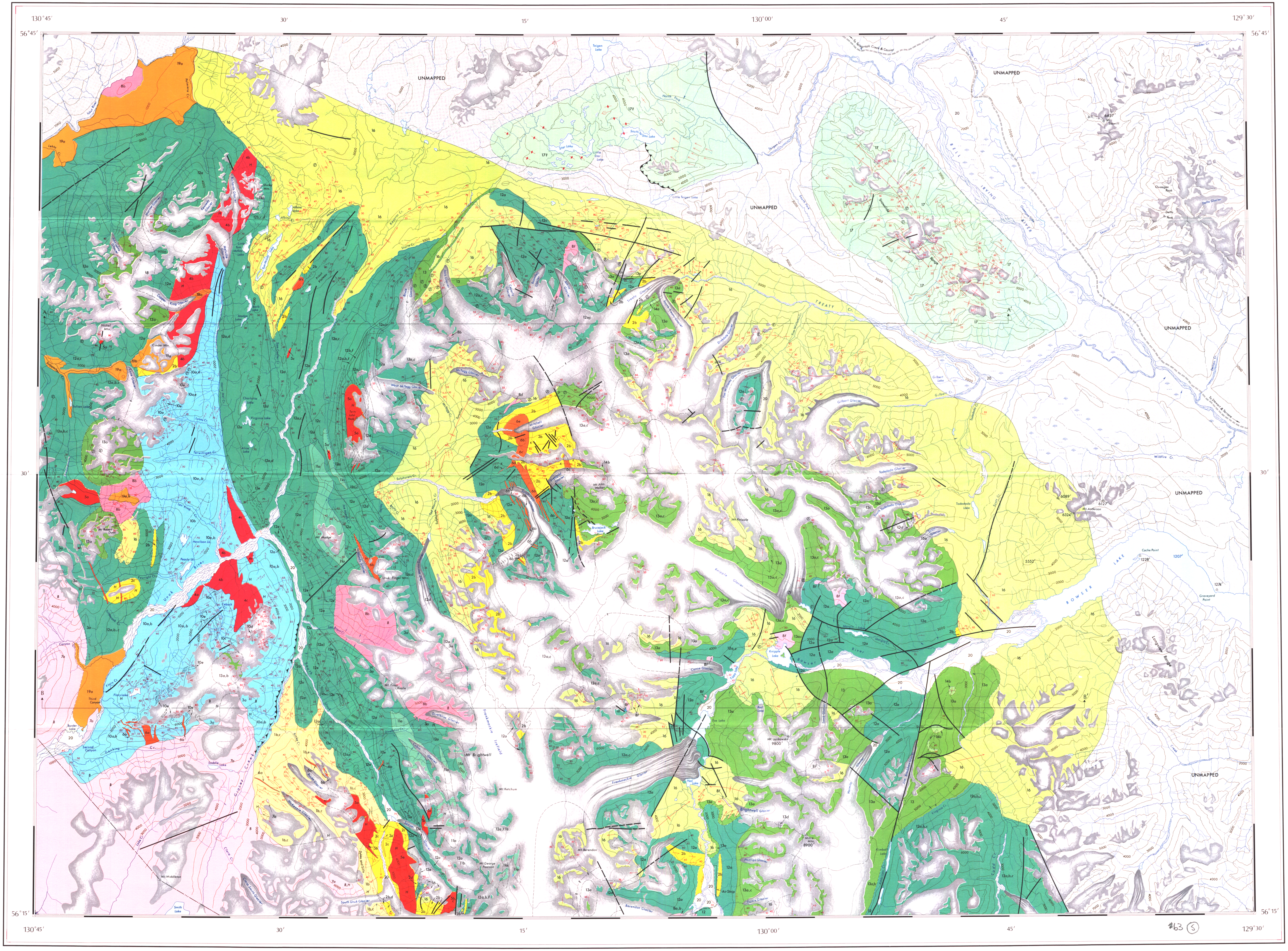
Longitudinal Projection on N 40°E

#63 (4)

To Accompany Bulletin 63

Ministry of Energy, Mines and Petroleum Resources

UNUK RIVER

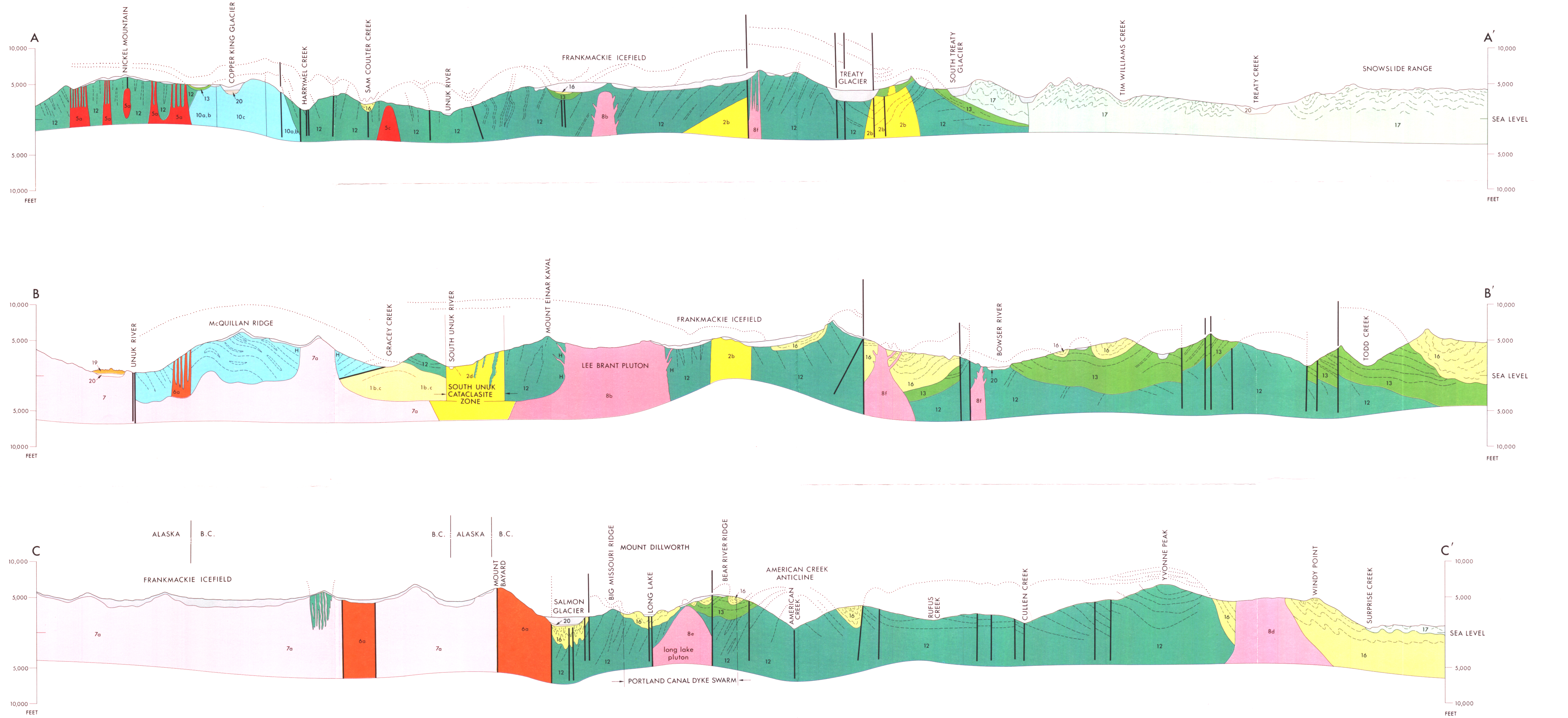


UNUK RIVER ~ SALMON RIVER ~ ANYOX AREA

NORTH, CENTRAL, AND SOUTH SHEETS

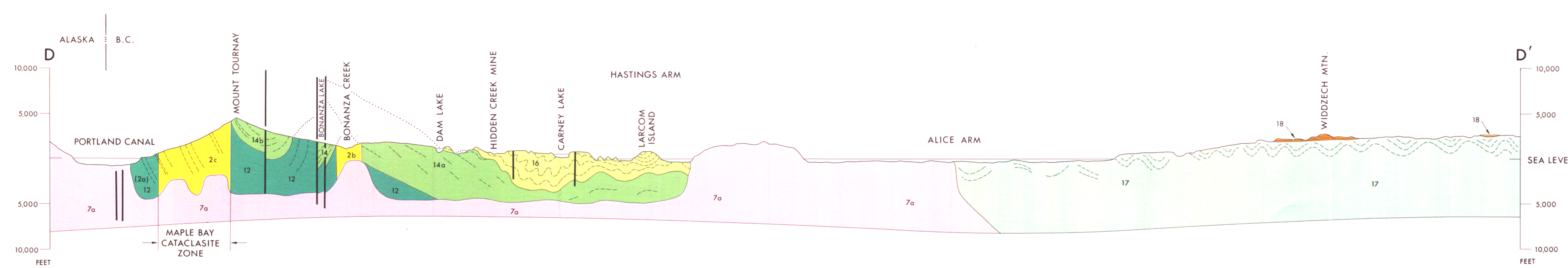
UNUK RIVER (N.T.S. 104 A/5,12, and 104 B/7,8,9,10)

RELEASED AUGUST 1982



GEOLOGICAL CROSS-SECTIONS
UNUK RIVER, SALMON RIVER, AND ANYOX MAP AREA
STEWART COMPLEX

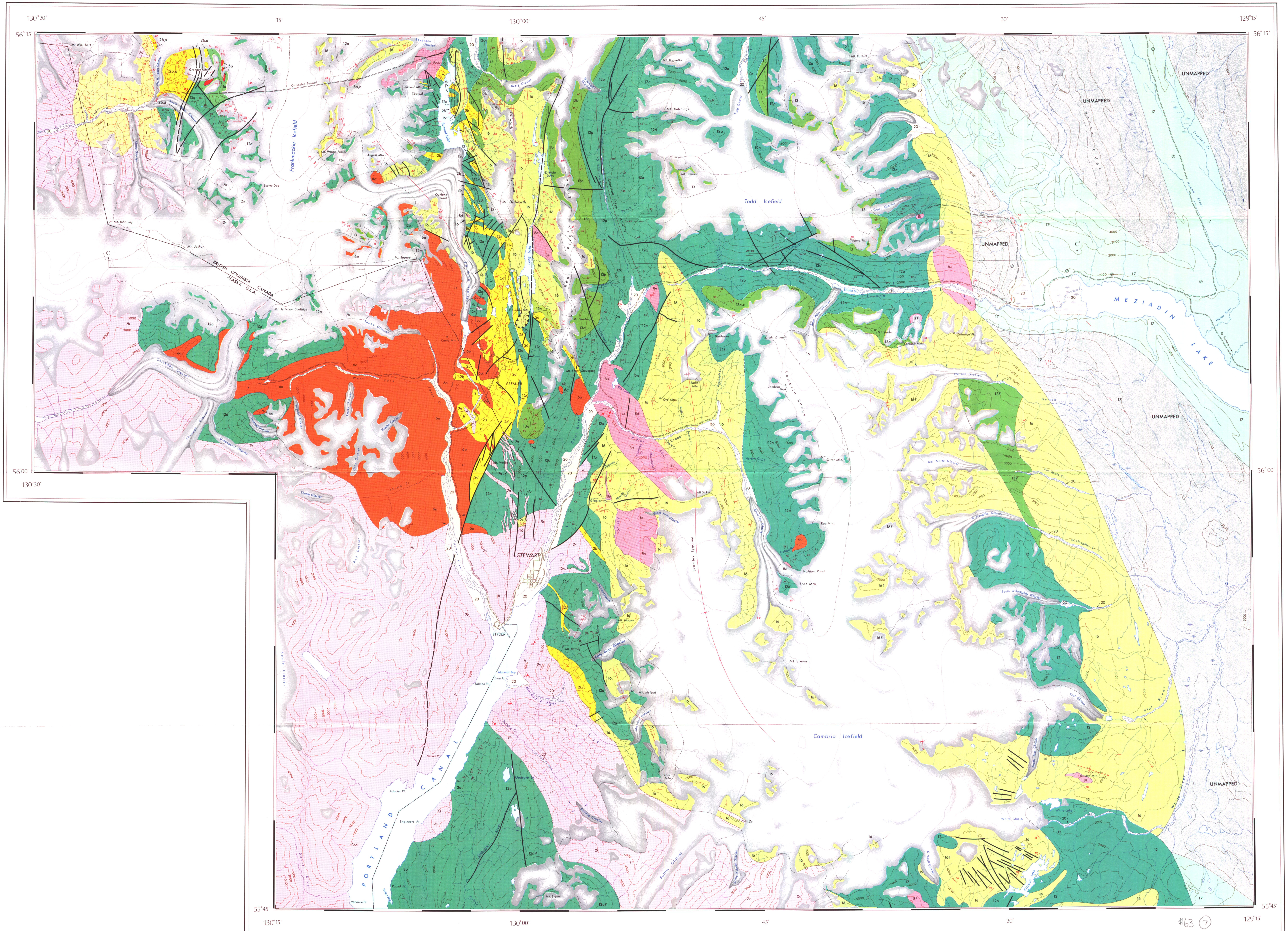
FOR LEGEND SEE ANYOX SHEET



#63 (6)

UNUK RIVER – SALMON RIVER – ANYOX AREA
GEOLOGICAL CROSS-SECTIONS
RELEASED AUGUST 1982

SALMON RIVER



#63 (7)

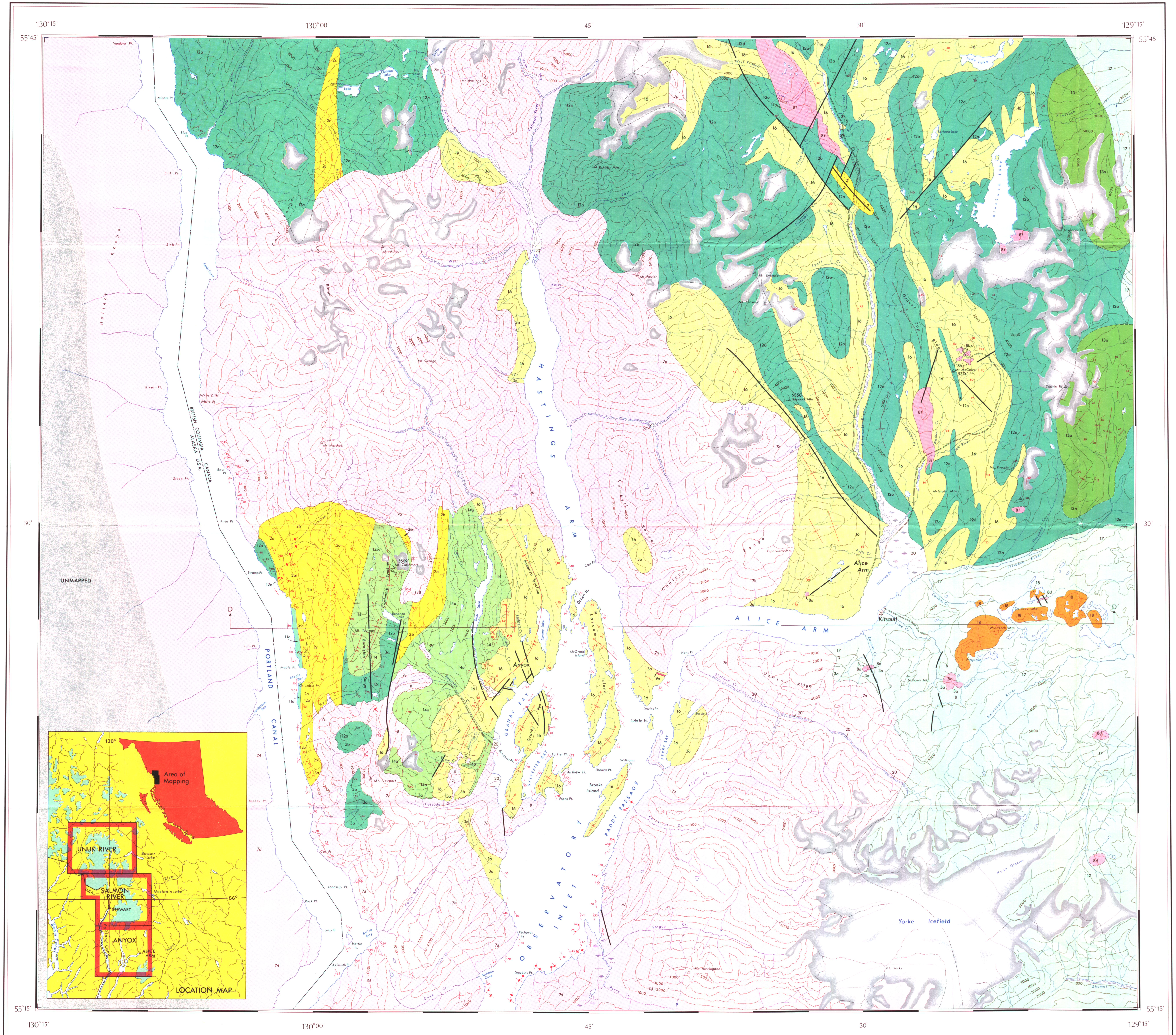
UNUK RIVER ~ SALMON RIVER ~ ANYOX AREA

NORTH, CENTRAL, AND SOUTH SHEETS

SALMON RIVER (N.T.S. 103 P/13, 14, and 103 O/16, and 104 A/3, 4, and 104 B/1)

RELEASED AUGUST 1982

ANYOX



Province of British Columbia
Ministry of Energy, Mines and Petroleum Resources

GEOLOGY OF THE UNUK RIVER ~ SALMON RIVER ~ ANYOX MAP AREA

KILOMETRES 0 — 10 KILOMETRES

SCALE ~ 100 000

LEGEND

SEDIMENTARY AND VOLCANIC ROCKS

CENOZOIC

QUATERNARY

RECENT

20 UNCONSOLIDATED DEPOSITS; RIVER FLOODPLAIN, ESTUARINE, RIVER CHANNEL AND TERRACES, ALLUVIAL FANS, DELTAS AND BEACHES, OUTWASH, GLACIAL LAKE SEDIMENTS, TILL, PEAT, LANDSLIDES, VOLCANIC ASH, HOTSPRING DEPOSITS

19 BASALT FLOWS (a), CINDERS, ASH (b)

PLEISTOCENE AND RECENT

18 BASALT FLOWS

MESOZOIC

JURASSIC

HAZELTON GROUP

UPPER JURASSIC

NASS FORMATION

17 SILTSTONE, GREYWACKE, SANDSTONE, SOME CALCARENITE, ARGILLITE, CONGLOMERATE, MINOR LIMESTONE, MINOR COAL (INCLUDING EQUIVALENT SHALE, PHYLLITE, AND SCHIST)

MIDDLE JURASSIC

SALMON RIVER FORMATION

16 SILTSTONE, GREYWACKE, SANDSTONE, SOME CALCARENITE, MINOR LIMESTONE, ARGILLITE, CONLOMERATE, LITTORAL DEPOSITS

15 RHYOLITE, RHYOLITE BRECCIA; CRYSTAL AND LITHIC TUFF

BETTY CREEK FORMATION

14 PILLOW LAVA, BROKEN PILLOW BRECCIA (a); ANDESITIC AND BASALTIC FLOWS (b)

13 GREEN, RED, PURPLE, AND BLACK VOLCANIC BRECCIA, CONLOMGERATE, SANDSTONE, AND SILTSTONE (a); CRYSTAL AND LITHIC TUFF (b); SILTSTONE (c); MINOR CHERT AND LIMESTONE [INCLUDES SOME LAVA (+14)] (d)

LOWER JURASSIC

UNUK RIVER FORMATION

12 GREEN, RED, AND PURPLE VOLCANIC BRECCIA, CONGLOMERATE, SANDSTONE, AND SILTSTONE (a); CRYSTAL AND LITHIC TUFF (b); SANDSTONE (c); CONGLOMERATE (d); LIMESTONE (e); CHERT (f); MINOR COAL (g)

11 PILLOW LAVA (a); VOLCANIC FLOWS (b)

TRIASSIC

UPPER TRIASSIC

TAKLA GROUP (?)

10 SILTSTONE, SANDSTONE, CONGLOMERATE (a); VOLCANIC SILTSTONE, SANDSTONE, CONLOMGERATE (b); AND SOME BRECCIA (c); CRYSTAL AND LITHIC TUFF (d); LIMESTONE (e)

PLUTONIC ROCKS

CENOZOIC

OLIGOCENE AND YOUNGER

9 DYKES AND SILLS (SWARMS), DIORITE (a); QUARTZ DIORITE (b); GRANODIORITE (c); BASALT (d)

EOCENE (STOCKS, ETC.) AND OLDER

8 QUARTZ DIORITE (a); GRANODIORITE (b); MONZONITE (c); QUARTZ MONZONITE (d); AUGITE DIORITE (e); FELDSPAR PORPHYRY (f)

7 COAST PLUTONIC COMPLEX: GRANODIORITE (a); QUARTZ DIORITE (b); QUARTZ MONZONITE, SOME GRANITE (c); MIGMATITE – AGMATITE (d)

MESOZOIC

JURASSIC

MIDDLE JURASSIC AND YOUNGER ?

6 GRANODIORITE (a); DIORITE (b); SYENODIORITE (c); MONZONITE (d); ALASKITE (e)

LOWER JURASSIC AND YOUNGER ?

5 DIORITE (a); SYENOGABBRO (b); SYENITE (c)

TRIASSIC

UPPER TRIASSIC AND YOUNGER ?

4 DIORITE (a); QUARTZ DIORITE (b); GRANODIORITE (c)

HORNBLENDE PREDOMINANT . . . . H
BIOTITE PREDOMINANT . . . . B

METAMORPHIC ROCKS

TERTIARY

3 HORNFELS (a); PHYLLITE, SCHIST (b); SOME GNEISS (c)

JURASSIC

2 HORNFELS (a); PHYLLITE, SEMI-SCHIST, SCHIST (b); GNEISS (c); CATACLASITE, MYLONITE (d); TACTITE (e)

TRIASSIC

1 SCHIST (a); GNEISS (b); CATACLASITE, MYLONITE (c)

HORNBLENDE OR AMPHIBOLE DEVELOPED . . . . H
BIOTITE DEVELOPED . . . . B
POTASSIUM FELDSPAR DEVELOPED . . . . K

AREA UNMAPPED

SYMBOLS

ADIT
ANTICLINE (NORMAL, OVERTURNED)
BEDDING (HORIZONTAL, INCLINED, VERTICAL, CONTORTED)
BOUNDARY MONUMENT
CONTOURS (INTERVAL 1,000 FEET) 5000
FAULT (DEFINED, APPROXIMATE)
FAULT (THRUST)
FAULT MOVEMENT (APPARENT)
FOLD AXES, MINERAL LINEATION (HORIZONTAL, INCLINED)
FOSSIL LOCALITY Ⓕ
GEOLOGICAL CONTACT (DEFINED, APPROXIMATE)
GLACIAL STRIAE
GRAVEL, SAND, OR MUD
HEIGHT IN FEET ABOVE MEAN SEA LEVEL •6234'
INTERNATIONAL BOUNDARY
JOINT SYSTEM (INCLINED, VERTICAL)
MARSH
MINING PROPERTY
RIDGE TOP
SCHISTOSITY (INCLINED, VERTICAL)
SYNCLINE (NORMAL, OVERTURNED)
TUNNEL
VOLCANIC CONE

Compilation and geology by E. W. Grove, 1964 to 1970, with assistance by N. H. Haimila and R. V. Kirkam, 1966 and James T. Fyles, 1967. Geology of the Alice Arm area by N. C. Carter, 1964 to 1968.

#63 (8)

UNUK RIVER ~ SALMON RIVER ~ ANYOX AREA
NORTH, CENTRAL, AND SOUTH SHEETS
ANYOX (N.T.S. 103 P/5.6.11.12. and 103 O/8.9)
RELEASED AUGUST 1982