BRITISH COLUMBIA
Ministry of Energy and Mines
Energy and Minerals Division
Geological Survey Branch

Geology and Industrial Minerals of the Tertiary Basins, South-Central British Columbia

By Peter B. Read
Geotex Consultants Ltd.

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PREFACE

This publication provides the first comprehensive description of the Eocene stratigraphy of the Tertiary basins in south-central British Columbia and documents the numerous, related mineral occurrences. These basins are highly prospective for a variety of industrial minerals, including diatomite, zeolite, perlite, bentonite and kaolin.

The field work on which this publication is based was conducted from 1986 to 1989. Progress reports were published in seven Open File maps and led to the discovery of a number of new occurrences, including an economic zeolite deposit. This compendium was written in 1991 and does not describe any of the recent industrial mineral discoveries in these basins. The reader is referred to the provincial MINFILE records for detailed descriptions of these new occurrences. This publication will be of benefit to those interested in industrial mineral opportunities within the province.

W.R. Smyth
Director, Geological Survey
B.C. Ministry of Energy and Mines

TABLE OF INDUSTRIAL MINERAL DISCOVERIES DURING THE 1990s

MINFILE #	Name	Commodity	NTS Map	Location	
082LSW158	Will	kaolinite	082L05E	50°27′39″	119°40′59″
082LSW159	Pinaus	diatomite	082L05E	50°23′41″	119°36′45″
092HSE160	Tulameen Bentonite	bentonite	092H07E	49°26′33″	120°34′5″
092HSE162	Similkameen Bentonite	bentonite	092H07E	49°23′55″	120°32′21″
092HSE163	Ashnola Bentonite	bentonite	092H07E	49°22′49″	120°32′27″
092HSE166	Bromley Vale Zeolite	zeolite	092H07E	49°25′18″	120°35′42″
092HSE167	Tailings Tephra	zeolite	092H07E	49°25′7″	120°31′17″
092HSE243	Bromley Creek Zeolite	zeolite	092H07E	49°25′25″	120°33′50″
092INW095	Ranchlands	zeolite	092l14W	50°49′44″	121°16′24″
092O 081	Churn Creek Bentonite	bentonite	092O09W	51°31′30″	122°18′35″
092O 098	Crow’s Bar	bentonite	092O08E	51°18′12″	122°11′38″
092O 100	Lot 3155	zeolite	092O08E	51°19′11″	122°13′35″
092O104	Mooney’s Ranch	volcanic glass	092O01E	51°8′30″	122°6′13″
092O 107	North Mooney’s	zeolite	092O01E	51°9′18″	122°5′21″
092O 108	South Mooney’s	zeolite	092O01E	51°7′51″	122°5′12″
092O 117	Churn Creek Zeolite	zeolite	092O09W	51°31′17″	122°19′55″
092O 118	2700 Road	zeolite	092O09W	51°30′2″	122°18′30″
092O 119	Central Empire Valley Rd.	zeolite	092O08W	51°29′7″	122°17′45″
092O 120	Grinder Creek Zeolite	zeolite	092O08E	51°23′55″	122°14′35″
092P 096	Deadman River	diatomite	092P02W	51°3′39″	120°52′46″
092P 097	North Snohoosh	diatomite	092P02W	51°5′54″	120°52′4″

SUMMARY

This geological investigation concentrated on areas of sediment-dominated successions of Eocene age with occurrences of industrial minerals. Most of the areas lie close to major transportation routes and to nearby markets.

The Princeton and Tulameen basins share a common Eocene stratigraphy in which Eocene sediments of the Allenby Formation overlie Eocene volcanic rocks of the Cedar Formation. Widespread waterlain rhyolite tephra and a distinctive conglomerate permit a stratigraphic subdivision of the more than 2000-metre thickness of sediments into 12 informal members. The detailed stratigraphic subdivision spans a 12-kilometre outcrop gap to the Tulameen basin but does not span an 8.5-kilometre gap to the southern outlier of the Princeton basin near Sunday Creek. The detailed stratigraphy yields a correlation scheme for coal seams of the Princeton basin which, although largely similar to others, differs in correlating the Bethlehem and Bethlehem lower seams with the Golden Glow and Bromley Vale #1 seams respectively. The most extensive clinoptilolite-rich zeolite occurrences (eight showings) and the only bentonite past producer in the province (one past producer and seven showings) are in the Princeton basin.

The Merritt basin contains four widely separated, sediment-dominated sequences of the Eocene Coldwater Formation which locally overlie small erosional remnants of Eocene volcanic rocks of the Cedar Formation. Bentonite (two showings) is the only industrial mineral known in the basin.

Along the southern edge of the Cache Creek and Arrowstone hills area, from the village of Cache Creek to Battle Creek, tuffaceous sediments and rhyolite tephra form several sedimentary lenses up to 100 metres thick that underlie a dacite-andesite$\pm$basalt flow and tephra sequence up to 2000 metres thick. The basal sedimentary lenses contain four heulandite-clinoptilolite showings, and where the intermediate tephra is waterlain near the base, it is bentonite-rich (two showings). In the Arrowstone Hills, the Chilcotin Group consists of up to 500 metres of olivine basalt flows of the Chasm Formation overlying up to 400 metres of rhyolite tuff and ash, and tuffaceous, fluviatile and locally lacustrine sediments composing the Deadman River Formation. The sediments and rhyolite tephra fill mainly northwestward-flowing Miocene drainage channels up to 450 metres deep and 5 kilometres wide, which were mapped for over 45 kilometres from southeast of Deadman River to northwest of Bonaparte River, but probably extend much farther. Diatomite-bearing sediments are restricted to the channel fillings and intercalations among the immediately superjacent basalt flows (one producer and 23 showings).

At Hat Creek, over 1600 metres of Eocene and(?) Oligocene sediments overlie up to a few hundred metres of Eocene volcanics and as many as 400 metres of mid- Cretaceous sediments. With the exception of the Eocene volcanic rocks, this stratigraphy subcrops beneath 100 metres or less of overburden that mantles most of the valley floor. The Eocene and Cretaceous rocks form two northerly trending synclines separated by a locally faulted anticline. Northerly oriented strike-slip faults with minor dip-slip components have offset the folds by as much as 5000 metres. The Cretaceous and Tertiary rocks, including Miocene basalt flows, compose bedrock slide blocks of Quaternary age that are up to 4000 metres long. They have moved up to 2500 metres from either valley wall towards the present valley axis along extensive bentonitic horizons (one bentonite showing).

Along the Fraser River from north of Lillooet to Gang Ranch, the Fraser fault slices through Eocene and older rocks. A 200-metre-thick panel of easterly dipping Eocene volcanic rocks and waterlain ash lies between Slok Creek and Fraser faults for at least 12 kilometres between the mouths of Fountain and Slok creeks (one bentonite showing). A few kilometres to the north, a thin, westerly dipping panel of Eocene volcanic rocks and ash underlies a 10-kilometre-long wedge east of the fault (two bentonite showings). Mapping and radiometric dating indicate a 10-kilometre gap in Eocene rocks straddles Leon Creek near the fault. Extending for over 65 kilometres northward from the junction of the Fraser and Hungry Valley faults, Eocene volcanic and overlying sedimentary rocks form a panel 1600 metres thick, which dips gently eastward and terminates against the Fraser fault. Most of the industrial mineral occurrences are in waterlain rhyolite (nine heulandite-clinoptilolite showings) and intermediate tephra (eight bentonite showings) in the upper part of the Eocene volcanic succession. Volcanic glass (three showings) and perlite (two showings and one past producer) form in rhyolite flows and hypabyssal intrusions. The Cretaceous rocks are devoid of industrial minerals.

This investigation concentrated on the occurrences of zeolites, bentonite, kaolinite, perlite and volcanic glass, and diatomites in Cenozoic rocks. The geological setting of the previously known occurrences, combined with the known or inferred chemical and physical conditions of the 63 occurrences discovered during this study, lead to the following conclusions:

Of the areas investigated, industrial zeolite occurrences are restricted to the Princeton and Tulameen basins, basal sedimentary lenses near McAbee, and waterlain rhyolite tephra along the Fraser River. In the Princeton basin, zeolitized tephra horizons are up to 3.5 kilometres long and 30 metres thick. Some samples have cation exchange ca-

pacities (CEC) similar to those of the products from operating mines in the western United States. Along the Fraser River, a few intermediate CEC values suggest an industrial zeolite potential.

Bentonite is widespread in sedimentary and adjacent volcanic rocks of Eocene age. Although few of the areas have been explored, drilling at Hat Creek has outlined significant thicknesses. From a few exchangeable cation analyses, divalent cations dominate except for showings in the south end of the Princeton basin and a showing in the Deadman River valley.

Known kaolinite occurrences in British Columbia are the result of subtropical weathering of granitic or compositionally equivalent volcanic rocks on unconformities ranging in age from Early Cretaceous to Late Eocene. Kaolinite occurrences are in sediments overlying such an unconformity developed on granitic rocks, but sediments are absent within the area investigated. They occur to the southwest in the Georgia Basin and may have developed to the northwest in the Chilcotin-Nechako region.

Perlite develops in glassy rhyolite which is a part of the little-altered Eocene volcanic sequence along the Fraser River. Similar rocks may occur farther north along and west of the river.

Diatomaceous earth occurs in Miocene and younger rocks in the sedimentary fill of the deep drainage channels buried beneath the widespread basalt flows of the Chilcotin Group. All of the showings in the Arrowstone Hills are in the sediments of this northwestward-flowing drainage system, and those north of Gang Ranch are in sediments in a north-draining channel. This Miocene drainage system subparallels the Fraser and undoubtedly has tributaries to the west, in the Chilcotin-Nechako area.

Although not a subject of this investigation, the discovery of a major northwesterly to northerly flowing Miocene drainage system opens the possibility of Miocene placer gold and provides a framework to guide the prospecting for such occurrences.

Uninvestigated areas of greatest potential for industrial minerals in Cenozoic rocks are near Kamloops, parts of the Queen Charlotte Islands, and those parts of the Chilcotin-Nechako area close to transportation.

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PUBLISHED MAPS PREPARED DURING THE COURSE OF FIELDWORK FOR THIS STUDY:

Open File

1987-19: Tertiary Stratigraphy and Industrial Minerals, Princeton and Tulameen Basins, British Columbia (92H/2, 7, 8 9, 10) by P.B. Read (1:25 000), 1 sheet.

1988-15: Tertiary Stratigraphy and Industrial Minerals, Merritt Basin, Southern British Columbia (92I/1, 2) by P.B. Read (1:25 000), 1 sheet.

1988-29: Tertiary Stratigraphy and Industrial Minerals: Fraser River, Lytton to Gang Ranch, British Columbia (92I/5, 12, 13; 92J/16; 92O/1, 8; 92P/4), by P.B. Read (1:50 000), 1 sheet.

1988-30: Tertiary Stratigraphy and Industrial Minerals, Cache Creek Map Area, Southwestern British Columbia (92I/14, by P.B. Read (1:50 000), 1 sheet.

1989-21: Tertiary Stratigraphy and Industrial Minerals, Bonaparte to Deadman Rivers (92P/2, 3),by P.B. Read (1:50 000), 1 sheet.

1989-27: Geology and Industrial Minerals in the Gang Rach Area (92O/8W, 9W), by K. Green (1:50 000), 1 sheet.

1990-23: Cretaceous and Tertiary Stratigraphy and Industrial Minerals, Hat Creek, Southern B.C. (92I/12, 13, 14), by P.B. Read (1:25 000), map with notes.

CHAPTER 1 INTRODUCTION

PURPOSE

In the southern end of the Intermontane Belt, widespread stratified rocks of Tertiary age locally contain coal, zeolites, clays and diatomaceous earth. The presence of past producers of bentonite (Showing B6, near Princeton) and perlite (Frenier mine, P2, near Gang Ranch), existing producers of ceramic and refractory clays (Sumas Mountain) and diatomaceous earth (Red Lake, D2, near Kamloops), and potential producers of kaolinite (Lang Bay) and zeolites (showings Z4 to Z7, near Princeton) suggest that there is a potential for economically viable industrial mineral deposits in the Tertiary rocks.

The main objective of this investigation was to assess the industrial mineral potential of the Tertiary stratified rocks between Princeton and Gang Ranch, southern British Columbia. This was accomplished by the geological mapping of several areas of Tertiary rocks to locate known and find new occurrences of industrial minerals, and to determine their geological setting. The mapping yielded regional correlations of Tertiary rocks and led to some understanding of the parameters necessary for the development of several industrial minerals. By the use of x-ray diffraction, wholerock and exchangeable cation analyses, and other tests, some of the parameters of many of the industrial minerals showings were quantified and compared to each other and to the products of operating mines in the western United States.

LOCATION AND ACCESS

All of the areas investigated contain extensive Tertiary rocks in which sediments are an important if not the dominant component of the stratigraphy (Figure 1). From southeast to northwest these areas are:

- Princeton to Tulameen
- Merritt to Quilchena to Guichon
- Bonaparte to Deadman rivers
- Hat Creek
- Fraser River: Lillooet to Gang Ranch

The areas lie south of latitude 52N and, with the exception of parts of the area along the Fraser River, they straddle major highways and railways. Access is easy as secondary and logging roads, in differing states of disuse, penetrate all the areas except for parts of the west side of the Fraser River. A rolling topography ranging from 600 to 1400 metres (2000 to 4500 feet) in elevation typically develops on the Tertiary rocks; only along the Fraser River are the slopes steep and descend to less than 300 metres (1000 feet).

Poor bedrock exposures offset the advantages of the gentle topography and easy access. Everywhere the Tertiary volcanic rocks form better outcrops than the sedimentary rocks. Of the sediment-dominated areas, the 5% outcrop of the Princeton to Tulameen area is the best, followed by Merritt and vicinity, and ending with the less than 0.25% exposure in upper Hat Creek valley. Drilling to assess the coal resources of the Eocene rocks augments the surface information and, in upper Hat Creek valley, the geological interpretation also relies on geophysical surveys and trenching. Where bentonite is part of the sedimentary succession, the possibility of large slide blocks, such as those at Hat Creek, is an additional complexity. Exposures of Miocene sediments are very poor along the Fraser River and the Bonaparte and Deadman rivers and tributaries. The few outcrops are restricted to rare road and stream cuts. As a result of the near absence of outcrop, the presence of sediment chips in the soil on steep slopes and in upturned tree roots must be used to map much of the distribution of the Miocene sediments.

Because most of the industrial minerals found in Tertiary rocks, such as kaolinite, bentonite and diatomaceous earth, are associated with sediments and form exposures that slump easily, they are preferentially covered by overburden. Drill logs do not augment the poor surface information. With the exception of the Hat Creek area, the logs of holes drilled for coal exploration usually do not record the presence of industrial minerals. Experience in the Princeton area indicates that drillcore of the zeolitized tuff has not been recognized. Except for a few holes near Chartrand and Enright lakes close to Deadman River, drilling has not penetrated Miocene sediments.

In contrast to the sediments that host the forementioned industrial minerals, zeolitized tuff preferentially outcrops. However, because the presence of even significant amounts of zeolites cannot be determined by eye, such zeolite occurrences, even those on major highways such as Highway 3 south of Princeton, have been overlooked for decades.

Any assessment of the potential of these industrial minerals without trenching or drilling must be regarded as preliminary and incomplete.

GEOLOGICAL WORK

The results of geological mapping and investigations undertaken by the author in 1977 and 1978 for Canadian Occidental Petroleum Ltd. (Read, 1977, 1978) are included in this report. In the Princeton area, this work led to the discovery of all the major occurrences of zeolites. Starting in 1986 and continuing for parts of the summers and falls of four years, for a total field time of 8 months, the author geo-

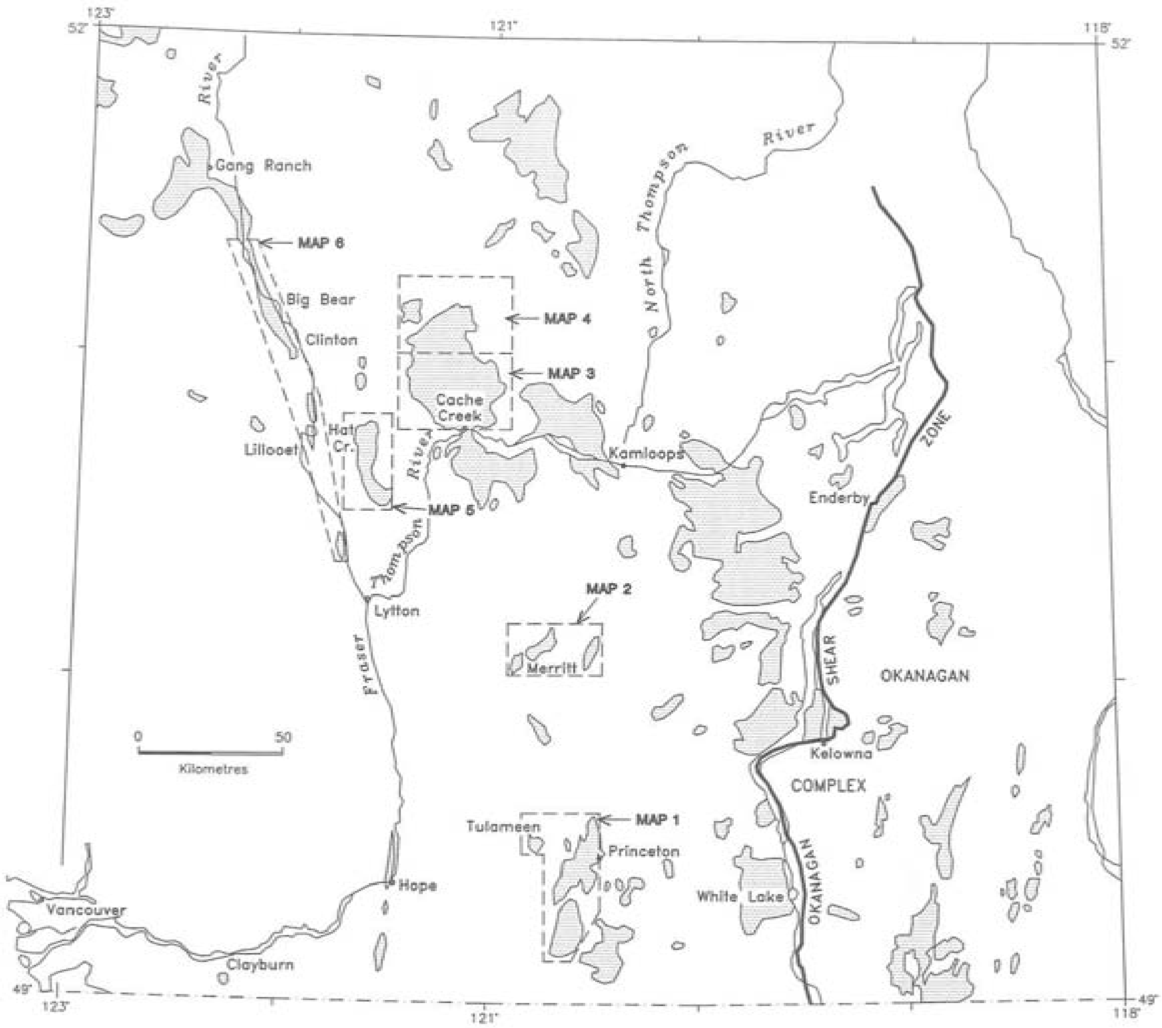

Figure 1.1. Map of southwestern British Columbia showing Eocene rocks (shaded), Okanagan Valley fault, Okanagan Complex and the location of areas mapped in this investigation.

logically mapped the Princeton to Tulameen and upper Hat Creek valley areas and parts of the Merritt basin at 1:25 000 scale, and the remainder of the areas at 1:50 000 (Read 1987a, 1987b, 1988a, 1988b, 1988c, 1988d, 1988e, 1989a, 1989b, 1990a). This work was done under contract to the British Columbia Ministry of Energy, Mines and Petroleum Resources as part of the 1985-1990 Mineral Development Agreement between Canada and British Columbia.

A total of 726 x-ray diffractograms, 295 exchangeable cation analyses and cation exchange capacity measurements, and 8 perlite expansion and pyrometric cone tests quantify the mineralogical, chemical and physical characteristics of the samples of industrial minerals collected during the fieldwork. In addition, 143 palynologic, 4 micropaleontologic, and 12 radiometric age determinations, all unpublished, have been combined with the new geological mapping and form the basis for the modification of earlier mapping and interpretations.

These geological investigations provided a unique opportunity for one person to map and study the major Eocene and Miocene sedimentary accumulations in southern British Columbia west of the metamorphic core complexes. In addition to 63 new occurrences of industrial minerals discovered during the investigations, contributions have been made to the Eocene and Miocene regional stratigraphy and depositional setting (Read, 1990b). This report joins the more than twenty publications issued by the British Columbia Ministry of Energy, Mines and Petroleum Resources on the broad spectrum of industrial minerals known in British Columbia, but differs from most in the strong emphasis on the regional geology of the areas of industrial mineral occurrences. Open File maps (1987-19, 1988-15, 1988-29, 1988-30, 1989-21, 1989-27, and 1990-23) are an integral part of this study and should be referred to by the reader of this report.

ACKNOWLEDGMENTS

During the course of this investigation many people contributed their knowledge and expertise. In particular, Z.D. Hora's knowledge of industrial minerals, attention to many requests, and patience during difficulties were vital to its success. W.E. Kilby made vitrinite reflectance determinations and, with V.A. Preto, provided funding for critical palynology determinations that not only aided in the understanding of the Hat Creek area, but together with W.R. Smyth's guidance, allowed the completion of this project. K.C. Green studied the Gang Ranch area and contributed most of the information on the industrial mineral occurrences there. The author is indebted to J.M. Newell and B. Grant for their editorial expertise and to Dave Melville for preparing the maps for publication.

All of the micropaleontology and some of the palynology were done through the kindness of the Geological Survey of Canada by M.J. Orchard (conodonts) in Vancouver and A.R. Sweet and J.M. White (palynology) at the Institute of Sedimentary and Petroleum Geology in Calgary. The Geological Survey of Canada permitted the use of some of C.J. Hickson's and P.B. Read's geological mapping near Gang Ranch prior to its publication. J.W.H. Monger contributed from his regional mapping and knowledge which extend far beyond the areas mapped in this study.

From the Department of Geological Sciences at The University of British Columbia, G.E. Rouse made most of the palynological determinations, which permitted a new interpretation for Hat Creek, and W.H. Mathews shared his knowledge of Cenozoic stratigraphy and structure in British Columbia and provided unpublished and new radiometric age determinations.

P.T. McCullough of B.C. Hydro not only shared his knowledge of Hat Creek and critically reviewed that portion of the study, but also provided boxfuls of geological data from Hat Creek, obtained the permission to publish about 70 palynology determinations made for B.C. Hydro, and arranged access to the core for further sampling.

Most of the fieldwork was done on private or leased lands and ranchers, too numerous to name, not only permitted access, but on many an occasion served a meal and provided a roof for the weary.

CHAPTER 2 GEOLOGY OF PRINCETON, TULAMEEN BASINS

INTRODUCTION

The Princeton basin (NTS 92H/7 to 10) is a northerly trending trough filled with Eocene volcanic rocks of intermediate composition composing the Cedar Formation, and an overlying mid-Eocene sedimentary sequence comprising the Allenby Formation (Figure 2.1). Basaltic andesite flows clearly overlie the Allenby Formation only at the north end of the basin. The basin contains up to 1370 metres of volcanic rocks overlain by 1600 to 2100 metres of sandstone, tuffaceous sandstone, shale, waterlain rhyolite tephra and coal (McMechan, 1983). In contrast, to the south, Sunday contains at least 1500 metres of volcanic rocks overlain by 320 metres of volcanic conglomerate, sandstone and zeolitized rhyolite tephra of the Allenby Formation.

To the west of the Princeton basin lies the Tulameen basin. It contains 1300 metres of Eocene volcanic and sedimentary rocks that overlie the Upper Triassic Nicola Group and underlie two remnants of the Miocene Chilcotin Group (Church and Brasnet, 1983). Up to 500 metres of grey, sparsely porphyritic hornblende dacite flows, and locally rhyodacite to rhyolite flows and waterlain tuffs of the Cedar Formation underlie a 790-metre thickness of sedimentary rocks of the Allenby Formation.

Geological data from Shaw (1952a, 1952b), Preto (1972, 1979), McMechan (1983) and numerous coal assessment reports have been used extensively in the preparation of the geological map (OF 1987-19).

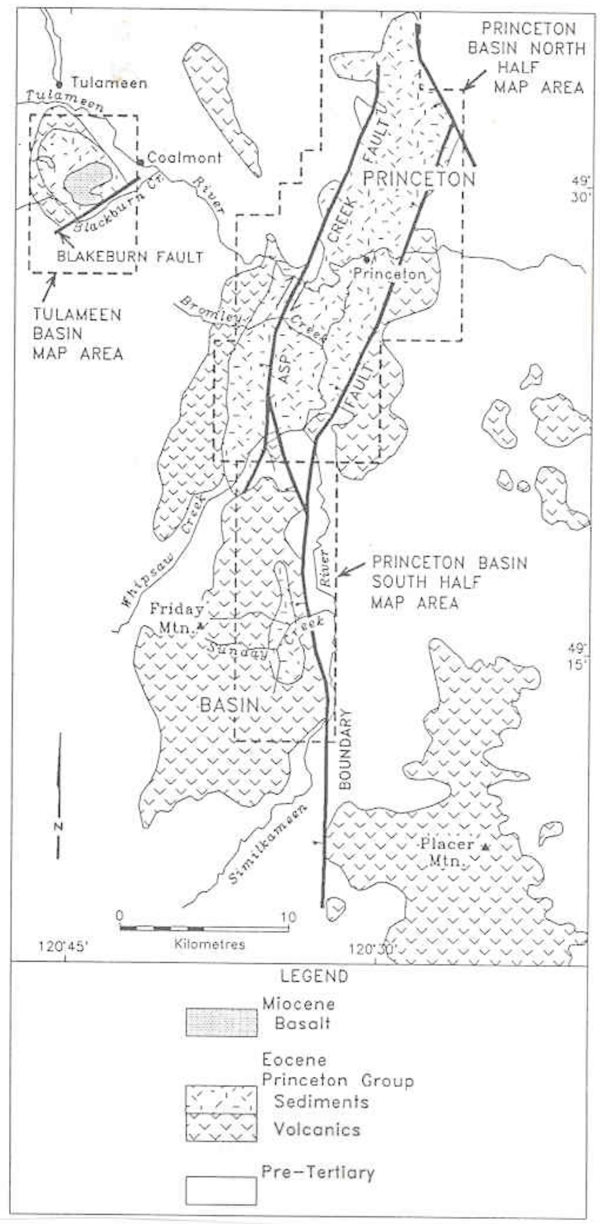

Figure 2.1. Simplified geological map of the Princeton and Tulameen basins showing the distribution of Eocene rocks, faults and the outlines of mapped areas.

STRATIFIED ROCKS

Volcanic and minor sedimentary rocks of the Upper Triassic Nicola Group form most of the basement for the Eocene basins. Along the east side of the Princeton basin, Eocene rocks either overlie Nicola or are faulted against Early Jurassic intrusions along the Boundary fault. Along the southeast side of the Tulameen basin, the Blakeburn fault juxtaposes the Eocene rocks against the Nicola Group. Elsewhere in the basins, the contact is an unconformity buried beneath hundreds of metres of Eocene volcanics. However, in the northern part of the Princeton basin and the eastern edge of the Tulameen basin, where the Eocene sediments are the thickest, Eocene volcanic rocks are thin to absent and Eocene sediments usually lie directly on the Nicola Group (OF 1988-29).

PRINCETON GROUP

Camsell (1907), Shaw (1952a), Hills (1962) and McMechan (1983) subdivided the Tertiary stratigraphy of the Princeton area into upper and lower volcanic packages and an intervening sedimentary unit. Rice (1947) called the Tertiary sedimentary and volcanic rocks the Princeton Group, and Shaw (1952a) proposed the threefold subdivision of `Lower Volcanic', Allenby and `Upper Volcanic' formations. In the Tulameen basin, Camsell (1913) named the Eocene volcanic rocks underlying the Tertiary sediments the `Cedar volcanic series' after a now unnamed creek immediately west of Mount Jackson. Although Camsell included in the Cedar Formation some volcanic rocks now known to belong to the Spences Bridge Group (Monger, 1989a), most of Camsell's description involved the volcanic rocks of the Princeton Group. Church and Brasnet (1983) recognized the priority of Camsell's (1913) `Cedar volcanic series' for the Tertiary volcanic rocks underlying the Tertiary sediments of the Tulameen basin. This name has been retained as Cedar Formation, in place of the informally named `Lower Volcanic' formation and applied to the Eocene volcanic rocks of the Princeton Group underlying the sedimentary rocks of the Allenby Formation. McMechan (1983) followed Hills' (1965) suggestion that the `Upper Volcanic' formation should be included within the Allenby Formation.

CEDAR FORMATION (UNITS Epvd and Epvr)

In the Tulameen basin, Camsell (1913) described the volcanic rocks as ranging from basalt to dacite with andesite dominant. Basalt flows and breccia are common in the lower part of unit Epvd, and sparsely porphyritic hornblende dacite flows prevalent in the upper part. Along Blakeburn Creek, the upper contact of unit Epvd lies at the top of aphanitic rhyodacite to dacite flows that underlie an unbedded sedimentary breccia composed exclusively of fine (1 to 2 cm) volcanic detritus. On the east side of the basin, Cedar Formation is completely eroded.

In the Princeton basin, Cedar Formation mainly consists of grey, sparse hornblende and plagioclase-bearing dacite flows and tephra (Epvd), and near the Tulameen River, red-brown andesite and basaltic andesite lahars and tephra with subordinate flows and volcaniclastic sediments (Epvd). South of Whipsaw Creek, in the Sunday basin, dacite flows form a unit which overlies a unit rich in dacite breccia (Section E-F, OF 1987-19), but northward this distinction disappears. All areas that Shaw (1952a) mapped as `Upper Volcanic' formation and McMechan (1983) mapped as `volcanic member', except one on the northern edge of the basin, are now part of the Cedar Formation. Because unit Epvd lacks industrial mineral potential, it formed the limit of mapping and was not studied in detail.

On the east side of the Princeton basin south of the Similkameen River and east of the Boundary fault, cream and light pink and grey aphanitic to slightly porphyritic rhyolite flows and breccia of unit Epvr are up to a few hundred metres thick. The unit lies on volcanics of the Nicola Group for nearly 10 kilometres from August to Smelter lakes. The same unit lies immediately west of the Boundary fault opposite the mouth of Whipsaw Creek. Here the rocks are rusty weathering, slightly pyritized and hydrothermally altered. Near the fault, the rhyolite is locally massive, but it grades outwards through unbedded breccia, to bedded lapilli and ash tuff intercalated with sediments of the Allenby Formation. Two interpretations seem possible for the genesis of unit Epvr west of the fault: it may represent a faulted remnant of an underwater rhyolite centre which was active during deposition of the Allenby Formation immediately to the north, or it may represent a basement that was onlapped by overlying sediments of the Allenby Formation. Because the rhyolite apparently truncates the Summers Creek sandstone (OF 1987-19), it may have been erupted near the boundary between the deposition of the Summers Creek sandstone and the overlying Ashnola shale. Although the deposition of Tailings ash and Bromley Vale tephra occurred near this boundary, neither unit thickens toward the possible vent, but instead both thin and disappear several kilometres to the north. An explanation favouring formation during the deposition of the Allenby Formation would result in the rhyolite being part of the volcanic member of the Allenby Formation, as mapped by McMechan (Figure 2, 1983). If the rhyolite is part of an onlapped basement, then the bedded lapilli and ash tuffs and intercalated sediments have developed as a result of the products of local erosion of the rhyolite being mixed and deposited with nontuffaceous sediments derived from the north. This latter explanation is consistent with both the thinning and disappearance of Bromley Vale tephra and Tailings ash several kilometres to the north, and correlation of the rhyolite across the Boundary fault. It results in the rhyolite west of the Boundary fault being part of the underlying Cedar Formation and is the favoured interpretation.

Whole-rock K/Ar dating yields a Middle Eocene age for the Cedar Formation (Appendix B)

ALLENBY FORMATION

The Allenby Formation contains the Eocene sedimentary rocks of the Princeton, Sunday and Tulameen basins. In the Princeton basin, the recognition of widespread, waterlain rhyolite tephra units in the Allenby Formation and a distinctive conglomerate allow a detailed stratigraphic subdivison of more than 2000 metres of sediments. In ascending stratigraphic order the tephra are: Sunday Creek tephra in the Sunday basin and in the Princeton basin; Snowpatch ash and Asp Creek ash northwest of Princeton; Princeton ash through Princeton and Tailings ash and Bromley Vale tephra south of Princeton. A distinctive polymictic pebble conglomerate extends for 11 kilometres from near the mouth of Summers Creek north of Princeton to the Princeton-Coalmont road west of the town. These lenticular units form the basis for the subdivision of the Allenby Formation in the Princeton basin. Although a gap in outcrop of only 8.5 kilometres separates rocks of the Allenby Formation north and south of Whipsaw Creek, there is no detailed stratigraphic continuity across this gap.

In the Tulameen basin, the Allenby Formation contains a lower sedimentary breccia to sandstone transition, a medial section of shale and coal, and an upper sequence of mainly sandstone and granule conglomerate with minor zeolitized rhyolite tephra, that total a 790-metre thickness of sedimentary rocks. The lower transition outcrops in Blakeburn Creek, the 90-metre shale and coal section is sparsely exposed in roadcuts and the 590-metre upper sandstone-conglomerate section is poorly exposed. In spite of a

12-kilometre gap in outcrop from Princeton to Tulameen basin, the detailed stratigraphy of the Princeton basin appears to bridge the gap.

The middle Eocene age of the Allenby Formation rests on more than 50 palynologic macroflora and vertebrate fossil determinations (Appendix A, Table A.1)

SUNDAY CREEK CONGLOMERATE (UNIT Epscg) And Tephra (UNIT EPsct)

A conglomerate and medial rhyolite tephra form the sedimentary fill of the Sunday basin for 7 kilometres from south of Friday Creek to south of Sunday Creek on both sides of Highway 3. The combined thickness of the two units is 350 metres (Section E-F, OF 1987-19). About 320 metres of this thickness is volcanic pebble to cobble conglomerate, minor volcanic wacke and siltstone, and rare micaceous sandstone of the Sunday Creek conglomerate. The underlying grey andesite and dacite flows (EPvd) contribute the dominantly angular to subangular clasts composing the overlying coarsely bedded sediments. The micaceous sandstone occurs only in the stratigraphically highest sediments above the tephra. The best outcrops of the unit are in both forks of Sunday Creek, that provides the name for the units, and in roadcuts along Highway 3.

Sunday Creek tephra is the only zeolitized horizon in the southern portion of the Princeton basin, where it lies within 200 metres of the base of the Allenby Formation. The tephra is mainly a fine (1 to 4 cm) rhyolite lapilli tuff with a vitric-crystal (biotite, feldspar, quartz) matrix and a few percent subangular dacite and andesite clasts up to 5 centimetres in diameter. It is unbedded to crudely bedded, and contains fragments of carbonized wood up to 50 centimetres long. The tephra outcrops over a distance of as much as 500 metres south of the south fork of Sunday Creek in a roadcut that is 5 metres high and on the west side of Highway 3 (Figure 7.2a and Photo 7.3). The only other exposures are in the south fork of Sunday Creek, downstream from Highway 3, where the creek twice intersects the tephra. It has a thickness of 30 metres and an exposed strike length of 1300 metres with both ends passing beneath drift.

HARDWICK SANDSTONE (UNIT EPHhss)

Hardwick sandstone partly fills old river channels on the northwestern edge of the Princeton basin from north of the confluence of Allison and Summers creeks to the Tulameen River. It averages a few hundred metres in thickness, but reaches a maximum thickness of 400 metres in a channel near Allison and Summers creeks (Section M-N, OF 1987-19). Unit Ephss contains some siltstone and shale, but the characteristic rock is a white to cream quartzofeldspathic sandstone that is free of rhyolite ash. Toward the base, the unit loses its quartzofeldspathic composition and whiteness, and becomes a greenish brown lithic sandstone. At the base, unit EPHSS locally includes a rusty brown weathering basal conglomerate, such as that exposed on Highway 5 north of Summers Creek, where angular to subrounded clasts of basement rocks exceed a metre on edge (McMechan, 1983). Of the sparsely scattered outcrops of Hardwick sandstone, slumped roadcuts along the farm road on the north side of Hardwick Creek are typical of the unit. The sandstone is the only unit of the Allenby Formation west of the Asp Creek fault and north of the mouth of Summers Creek, and it probably forms most of the basal basin-fill east of the fault between the mouth of Summers Creek and the Tulameen River where drill hole UP-5 (Carpenter, 1980) intersected 87 metres of Hardwick sandstone overlying Eocene flows (Figure 2.3; Section O-P, OF 1987-19).

In the Tulameen basin, the basal 100 to 150 metres of sediments are part of the Hardwick sandstone. On the west side of the basin, in Blakeburn Creek, the unit grades upwards from an unbedded sedimentary breccia composed of Eocene volcanic clasts, through crudely bedded breccia, to a bedded, feldspar-rich, volcanic-lithic wacke. In addition to the vertical facies change, the volcanic-dominated sediments of the west thin eastward and grade to basal conglomerate and overlying arkosic sandstone.

VERMILION BLUFFS SHALE (UNIT EPVBp)

Vermilion Bluffs shale is the thickest and most extensive shale-rich unit in the Princeton basin. It is the host for the most productive coal seams in the basin (Table 2.1), and for some of the zeolite and bentonite showings (Table 7.1). The unit extends for more than 22 kilometres from north of the mouth of Summers Creek to south of Whipsaw Creek. It fills the basin from east to west and extends westward to the Tulameen basin, but its thickness is highly variable. The unit thins drastically or disappears over basement highs such as the one near the Tulameen River (Section C-E, OF 1987-19,) where it thins from 1000 metres north of the high to 100 metres over the high, and thickens again southwards to about 900 metres near Whipsaw Creek. Widely scattered outcrops show that Vermilion Bluffs shale contains mostly shale, carbonaceous and bentonitic variants and minor thin sandstone layers. The best, but in part an atypical exposure, is at Vermilion Bluffs where uncharacteristic siliceous sinter, siliceous and dolomitic limestone, and silicified diatomaceous sediments form some of the section. The more characteristic unsilicified shale usually does not outcrop but instead underlies slumped topography. Granby strip mine in the Princeton basin and Blakeburn mine in the Tulameen basin expose coal-rich sections of the unit. Bromley Vale tephra and Tailings ash aside, the remaining stratigraphic marker horizons, which allow subdivision of the Allenby Formation, lie within the unit.

A shale tongue or lens within Summers Creek sandstone lies 2 to 3 kilometres south of Princeton where it outcrops along the Similkameen River. Originally named Power Plant shale (Read, 1987b), it consists of shale, carbonaceous and bentonitic variants and layers of quartzofeldspathic grit and coarse sandstone. Because of sparse outcrop, the distribution of the unit west of Highway 3 is unknown and the proportions of shale and sandstone are uncertain but are estimated as probably more shale than sandstone. At showing B6 (OF 1987-19), bentonite layers within the shale have contributed to the only recorded production of bentonite in British Columbia. The tongue attains a maximum thickness of 250 metres along the Similkameen River (Section C-D north of its intersection with Section S-T, OF 1987-19). Based on southerly di-

TABLE 2.1
STRATIGRAPHIC CORRELATION OF COAL SEAMS IN THE PRINCETON BASIN ARRANGED IN DESCENDING STRATIGRAPHIC ORDER

Mine or Prospect	Rock Unit	Coal Zone or Seam	Metres*	Stratigraphic Level
Bethlehem	EAAp	Golden Glow?	-510	400 above top of EAVBp
Bromley Vale #2	EAAp	Golden Glow	-470	360 above top of EAVBp
Golden Glow	EAAp	Golden Glow	-470	360 above top of EAVBp
Bethlehem lower	EAAp	Bromley Vale #1?	-370	260 above top of EAVBp
Bromley Vale #1	EAAp	Bromley Vale #1	-350	240 above top of EAVBp
Burr's	EASCss	unknown	-?	? m above top of EAVBp
Gem	EASCss	Gem	-340	200 above top of EAVBp
Summers Creek	EASCss	Summers Creek	-?	70 above base of EASCss
Pleasant Valley #1	EAVBp	Pleasant Valley	-90	20 below top of EAVBp
Jackson #1	EAVBp	Pleasant Valley	-90	20 below top of EAVBp
Black & Granby strip	EAVBp	Princeton #1	0	110 below top of EAVBp
Taylor #1	EAVBp	Princeton #1	0	110 below top of EAVBp
Pleasant Valley #2	EAVBp	Princeton #1	0	140 below top of EAVBp
Pleasant Valley #4	EAVBp	Princeton #1	0	140 below top of EAVBp
Princeton #1	EAVBp	Princeton #1	0	140 below top of EAVBp
Princeton #2	EAVBp	Princeton #1	0	140 below top of EAVBp
Princeton #3	EAVBp	Princeton #1	0	140 below top of EAVBp
Princeton-Tulameen #1	EAVBp	Princeton #1	0	140 below top of EAVBp
Tulameen #1	EAVBp	Princeton #1	0	140 below top of EAVBp
Tulameen #2	EAVBp	Princeton #1	0	140 below top of EAVBp
Tulameen #3	EAVBp	Princeton #1	0	140 below top of EAVBp
Fairley	EAVBp	unknown	+70#	210# below top of EAVBp
Ashington	EASCss	Ashington	+140	280 below top of EAVBp
China Creek prospect	EASCss	Ashington	+140	280 below top of EAVBp
Blue Flame #1	EAVBp	Blue Flame	+180#	320 below top of EAVBp
Blue Flame #2	EAVBp	Blue Flame	+180#	320 below top of EAVBp
Red Triangle	EACCg	Red Triangle	+310?	450 below top of EAVBp
Deer Valley	EAVBp	unknown	+350?	490 below top of EAVBp
United Empire	EAHss	United Empire	+460?	600 below top of EAVBp

** Distance to the nearest 25 metres above (-) or below (+) Princeton #1 seam.*
-? stratigraphic level above Princeton #1 seam.
+? stratigraphic level below Princeton #1 seam.
 # Because of intercalation of the top of Summers Creek sandstone and the top of Vermillion Bluffs shale, stratigraphic intervals followed by # cannot be compared with any of the other distances.

rected paleocurrents during deposition of the Allenby Formation (Map 2) and a northern source area for the coarse sediments of the formation, I favour an interpretation which makes this shale a tongue of the Vermilion Bluffs shale as shown on Section C-D south of its intersection with Section S-T (Map 1). Vermilion Bluffs shale disappears south of Whipsaw Creek and diminishes to 90 metres in the Tulameen basin.

SNOWPATCH ASH (UNIT EPsa)

Snowpatch ash is the stratigraphically lowest rhyolite ash exposed in the Princeton basin. It lies on the northwest side of the basin astride Asp Creek, and outcrops at 860 metres (2825 feet) elevation 2300 metres up the road to Snowpatch ski area from the Princeton-Tulameen Highway. A roadcut on the south side of the road exposes about 5 metres of yellow ochre weathering, coarse tuffaceous sandstone composed mainly of quartz, feldspar and biotite grains. Although neither the top nor bottom contact is exposed, the zeolitized horizon is probably not much thicker. About 800 metres to the south-southwest, at 945 metres (3100 feet) elevation and east of a powerline, a dip slope exposes a 30-metre width of white-weathering vitric-crystal tuff that is locally zeolitized. The exposed strike length of the tephra horizon is 2400 metres with both ends passing under drift. The ash is crystal rich, only partly zeolitized and not considered to be of economic interest.

CHINA CONGLOMERATE (UNIT EPccg)

China conglomerate is the most extensive marker horizon in the Vermilion Bluffs shale. It extends 11 kilometres from south of the mouth of Summers Creek to south of the Princeton-Tulameen Highway, and is up to 130 metres thick. McMechan (1983, p.15) noted its presence near Asp Creek but did not map its distribution. It is well exposed on the road to Snowpatch ski area, in Asp Creek (formerly China Creek), northwest of Princeton airfield, on Allison Creek west of the trailer park, and on Highway 5 to Merritt. In addition, diamond drilling intersected it in holes PC1 to PC3 (Nicholson, 1981). In Asp Creek, unit EPccg is a fine (5 mm) sedimentary breccia composed of white to red-brown or grey-brown aphanitic volcanic clasts derived from the Nicola and Spences Bridge groups, but free of Eocene rhyolite clasts. Nearby, on the road to Snowpatch ski area, shale accompanies the same sedimentary breccia. To the northeast of Asp Creek, exposures near the airfield show a mixture of breccia and volcanic and quartz-pebble conglomerate which continues to west of the trailer park on Allison Creek. The grain size diminishes northwards and the northernmost exposures on Highway 5 are brownish weathering lithic grit and coarse wacke.

ASP CREEK ASH (UNIT EPca)

In the Princeton basin, Asp Creek ash is the stratigraphically lowest ash that is significantly zeolitized. It is exposed on the highway to Tulameen at the northwest end of the single-lane bridge across the Tulameen River within the Princeton town limits (Photo 7.1). Although Hills (1962, see map p.41) included this outcrop as part of the Princeton ash, backyard exposures show that Asp Creek ash continues westward to Asp Creek where it outcrops in cliffs on the right bank of Asp Creek about 500 metres upstream from its confluence with the Tulameen River and 150 metres north of the Princeton ash (Figure 7.2b and OF 1987-19). The tephra contains scattered plant fragments in a bedded, white ash with intercalated layers of vitric-crystal (biotite, plagioclase, sanidine, quartz) tuff. In Asp Creek, the tephra is 7.3 metres thick, overlies a fine-grained biotite-bearing sandstone tongue of the Summers Creek sandstone and underlies the carbonaceous Vermilion Bluffs shale. The strike length of the tephra is about 1000 metres with both ends covered by drift, but with an eastern extension likely.

PRINCETON ASH (UNIT EPPA)

Princeton ash (Hills, 1962) outcrops on the north bank of a bend in the Tulameen River, 2.1 kilometres upstream from the Princeton-Tulameen road bridge across the river. Additional outcrops are scattered along the north bank for another 400 metres upstream. These outcrops, together with a roadcut on the Princeton- Tulameen road immediately west of Asp Creek and a low outcrop on the east bank of the Similkameen River, yield an exposed strike length of 3 kilometres. Although no outcrop shows both upper and lower contacts, the ash is at least 9 metres thick along the Tulameen River. The medium grey crystal (biotite, hornblende, quartz, andesine) vitric ash is vaguely bedded and contains plant fragments which indicate that it is waterlain. Unlike all the other rhyolite tephra of the basin, Princeton ash is unaltered and zeolite free. It is the highest of three stacked ash lenses which lie in the Vermilion Bluffs shale between two easterly trending paleohighs (Section C-D, OF 1987-19). The northern paleohigh, lying approximately along the Rainbow anticline, and the southern one lying along the Tulameen River, probably controlled the distribution of the waterlain rhyolite ash lenses.

SUMMERS CREEK SANDSTONE (UNIT EPscss)

Summers Creek sandstone is the most extensive sedimentary unit in the Princeton and Tulameen basins. It extends 25 kilometres from the northern edge of the Princeton basin to Lamont Creek in the south, and 15 kilometres westward across the basins. It yields the best outcrops of all units of the Allenby Formation with large exposures scattered along the east bank of Summers Creek, on the south bank of the Tulameen River 3 kilometres upstream from Princeton, and on the east bank of the Similkameen River 5 kilometres upstream from Princeton. Near and south of Princeton, the unit is mainly a quartzofeldspathic grit, granule conglomerate and coarse sandstone with local calcite and quartz cement, but to the north, the rhyolite ash and biotite content increase. Northward along Summers Creek the bedded, tuffaceous and quartzofeldspathic sandstone loses its bedding with an increase in rhyolite ash content, until near the north edge of the basin the rock is a crystal (quartz, feldspar, biotite)-vitric tuff that is locally waterlain. The increase in vitric rhyolite ash whitens the rock and creates the mealy-weathering outcrops encountered along the railroad grade to Jura.

South of Princeton and west of the Similkameen River, outcrops of the Summers Creek sandstone are very sparse as the unit diminishes to less than 300 metres in thickness (Sections C-D and U-V, OF 1987-19). The decrease in thickness results from the southward termination of two basal tongues of Summers Creek sandstone, the lower and upper tongues, in the upper part of the Vermilion Bluffs shale. Extensive diamond drilling by Bethlehem Copper Corporation in the Dalby Creek and Meadows areas (Anderson, 1972; 1976) and a few bedded outcrops are the basis for the extension and distribution of the Summers Creek sandstone, the bounding shale units, and the Asp Creek fault (OF 1987-19). Northeast of the mouth of Whipsaw Creek, the truncation of the Summers Creek sandstone probably results from the unit onlapping the underlying rhyolite (*see* Cedar Formation). This truncation and the lack of detailed stratigraphic continuity southward are evidence that a basement high lies south of Whipsaw and formed a barrier to the southward deposition of Summers Creek sandstone and Vermilion Bluffs shale.

In the Tulameen basin, a few scattered outcrops of quartzofeldspathic sandstone and coarse sandstone to grit with a rhyolite ash component are part of the Summers Creek sandstone. In a few places the ash is dominant and a waterlain, crystal (quartz, biotite, feldspar)-vitric tuff results in which the rhyolite glass has been zeolitized (see Tulameen Bridge occurrency description). The unit reaches a thickness of 590 metres beneath a cap of Miocene basalt flows.

TAILINGS ASH (UNIT EPTA)

Tailings ash is the most extensive zeolitized horizon in the Princeton basin. A series of outcrops, stretching for more than 3.5 kilometres, exposes the gently southward-dipping ash from west of Highway 3 to east of the Similkameen River. A second series of outcrops, spanning only 1.1 kilometres, shows the gently northward dipping unit extending eastward from the Similkameen River. These exposures outline the north and south limbs of the west-trending and gently plunging Tailings syncline. On Highway 3 on the north limb of the syncline, the ash is more than 13 metres thick (Photo 7.2), and on the old Copper Mountain Railway grade on the south limb it is more than 4.2 metres thick (Figure 7.2c). Neither top nor bottom contact is exposed at either location. Roadcuts on Highway 3 expose crystal (biotite, quartz, feldspar)-vitric tuff and lapilli tuff with the rhyolite glass shards completely altered to clinoptilolite cores with montmorillonite rims. On the railway grade, only the crystal-vitric tuff is present.

BROMLEY VALE TEPHRA (UNIT EPBV)

Bromley Vale tephra only outcrops at and upstream from Bromley Vale No. 1 mine adit on Bromley Creek (Figure 7.2d). The easterly flowing creek exposes 9 metres of fine, white to cream-coloured rhyolite breccia overlain by 13 metres of white to light grey vitric-crystal (biotite, feldspar, quartz) bedded tuff with fragments of carbonized wood and leaves, and a thin, dark grey albitized tuff. The 22-metre thickness of tephra has neither top nor bottom contacts exposed, and to the south very thick overburden mantles any possible extension. The tephra does not reappear to the north, perhaps because of truncation by the Asp Creek fault. If the Asp Creek fault has a right-lateral strike-slip displacement of about 1200 metres, then Bromley Vale tephra should correlate with Tailings ash. Sharp's borehole (Rice, 1947) may have intersected the tephra at a depth of 140 metres (460 feet) beneath which a "white clay with dark spots" was logged for 23.2 metres (76 feet).

ASHNOLA SHALE (UNIT EPAP)

Ashnola shale is the highest sedimentary unit in the Princeton basin. Scattered exposures along the Similkameen River extend for 6.2 kilometres downstream from the mouth of Whipsaw Creek, and are best at a distinctive bend 1.8 kilometres downstream, at a place labelled on old maps as `Ashnola'. West of the river, only three outcrops and a number of diamond-drill holes indicate its presence in the core of the Tailings syncline. The unit consists of shale, silty shale and siltstone with minor sandstone layers, and a fine waterlain lapilli tuff on the east bank of the Similkameen River at Ashnola. The abundant shale and silty shale are locally carbonaceous or bentonitic. Ashnola shale reaches a maximum thickness of 550 metres in the core of the Tailings syncline (Section U-V, OF 1987-19).

JURA ANDESITE (UNIT EPJva)

Jura andesite forms a remnant of basaltic andesite flows which lies at the northern edge of the basin east of Summers Creek. The slightly porphyritic hypersthene-augite basaltic andesite flows are vesicular, up to 50 metres thick and cover a few square kilometres. They overlie waterlain tuff of the Summers Creek sandstone (Section A-B, OF 1987-19), but whether they overlie the whole of the Allenby Formation, or just the Summers Creek sandstone is unknown. A K-Ar whole-rock age from this remnant is 49.4 ± 2.0 Ma (Table 3 on OF 1987-19 and Appendix B).

In this study, the `Upper Volcanic' formation of Shaw (1952a) and the `volcanic member' of the Allenby Formation of Hills (1962) and McMechan (1983) have been named the Jura andesite and restricted to only those volcanic rocks which overlie sediments of the Allenby Formation. Of the five areas listed by Shaw as underlain by the `Upper Volcanic' formation only the area at the northern margin of the basin immediately east of Summers Creek meets this criterion. Of the remaining four areas, one on the western margin of the Princeton basin, 1.6 kilometres north of Asp Creek, and a second astride the Tulameen River 3.2 kilometres upstream from the town of Princeton, underlie the Allenby Formation, unconformably overlie the Nicola Group and are part of the Cedar Formation. In part of the first area north of Asp Creek, where the volcanics appear to overlie the Allenby Formation, movement on the Asp Creek fault has set the volcanic rocks east of the fault against, but not over, sediments west of the fault. A third area straddling Highway 5, 2.4 kilometres north of Princeton, contains no evidence of Jura andesite. The fourth and largest area is a more or less continuous belt that extends along the east side of the basin from about 3 kilometres northeast of Princeton southward to Smelter Lakes. Here Shaw (1952a, p. 9) described the `Upper Volcanic' formation as "a group of volcanic rocks that appear to lie with structural discordance on the Allenby Formation, and, farther east, on pre-Tertiary rocks." Because Shaw did not recognize the faulted contact between Eocene sediments and volcanic rocks in this area, and did not realize that movement on the Boundary fault placed the volcanics against the sediments; he mistakenly thought that the volcanics overlay the sediments.

CHILCOTIN GROUP (Mcvb)

In the Tulameen basin, two erosional remnants of flat-lying basalt flows cap the folded sediments of the Allenby Formation. The largest, immediately north of Granite Creek, covers nearly 4 square kilometres and attains a thickness of 150 metres; a second thin one to the northwest is only 0.25 square kilometre. The augite-bearing olivine basalt flows are sparsely vesicular and locally columnar jointed. Church and Brasnet (1983) reported a K-Ar whole-rock radiometric age of 9.0±0.9 Ma (Table 3 on OF 1987-19).

CORRELATION OF COAL SEAMS IN THE PRINCETON BASIN

In the Princeton basin, Fahrni (1945), Shaw (1952a) and McMechan (1983) developed slightly differing correlation schemes for the coal zones. These geologists realized that the thick workable coal seams, though highly variable in thickness, do occur in definable coal-bearing zones, and that broad-scale correlation of these zones is possible (McMechan, 1983). Columnar sections, derived from surface and drilling information at Princeton and at Bromley Vale, were correlated on the basis of number, thickness and spacing of coal seams (Shaw, 1952a; McMechan, 1983), but McMechan noted that the absence of a detailed stratigraphy for the Allenby Formation forced this approach to correlation. In 1952, Shaw did not know that the Asp Creek fault lay between the coal seams of the Princeton and Bromley Vale areas, and in 1983 McMechan did not possess a detailed stratigraphy for the Allenby Formation.

The correlation scheme for the coal seams and zones of the Princeton basin is based on the detailed stratigraphy developed in this study and the stratigraphic thicknesses between the seams and the top of the middle tongue of Vermilion Bluffs shale as measured in plan or cross-sections (OF 1987-19). Shaw's and McMechan's correlation of the Princeton #1 seam in the Princeton area with the Black seam in the Bromley Vale area is corroborated by the positions of the two seams in the detailed stratigraphy of the Allenby Formation. Both seams lie in the Vermilion Bluffs shale about 110 to 140 metres beneath the top of the middle shale tongue (Sections C-D and S-T, OF 1987-19).

The Pleasant Valley seam, exposed in Pleasant Valley No. 1 mine, is in the Vermilion Bluffs shale about 20 metres beneath the top of the middle tongue (Section C-D, OF 1987-19). The stratigraphic interval between the Pleasant Valley seam, at 20 metres and the Princeton #1 seam, at 140 metres beneath the top of the shale, is 120 metres. Hughes (1949, p. A223) estimated the same interval between the Pleasant Valley and Princeton #1 seams as approximately 140 metres (460 feet).

The Ashington mine and seam are in the lower tongue of the Summer Creek sandstone, very close to the Asp Creek ash, at about 320 metres below the top of the middle tongue of the Vermilion Bluffs shale (Section C-D, OF 1987-19), and about 180 metres below the Princeton #1 seam. This position is probably equivalent to the seam exposed at the China (Asp) Creek coal prospect which also lies very close to Asp Creek ash. Although the stratigraphic position of the mine and prospect appears equivalent to that of the Blue Flame seam, the intercalation of the Summers Creek sandstone and the Vermilion Bluffs shale near Princeton spoils the equivalence. As Section B-E (OF 1987-19) shows, the Summer Creek sandstone thins southwards from a thickness of 1000 metres north of Princeton to less than 300 metres north of Whipsaw Creek. The thinning results from the southward termination of the lower and upper tongues of the Summers Creek sandstone in the upper part of the Vermilion Bluffs shale.

The Gem mine and seam are hosted by the upper part of the upper tongue of the Summers Creek sandstone (OF 1987-19) about 200 metres above the top the middle tongue of the Vermilion Bluffs shale. Although the Gem mine is 1 kilometre east of section C- D (OF 1987-19), the stratigraphic position above the Princeton #1 seam and the measured stratigraphic interval (Table 2.1) should be reliable.

Two mines, the United Empire and the Red Triangle, and two prospects, the Summers Creek and the Deer Valley, are located in the northern part of the Princeton basin. The presence of faults and absence of outcrop result in uncertain stratigraphic positions for the seams worked in the two mines and the Deer Valley prospect. The Red Triangle mine is near the bottom of the China conglomerate which is about 450 metres below the top of the middle tongue of the Vermilion Bluffs shale (Section B-D, OF 1987-19). Because the mine is sited 1.7 kilometres east of Section B-D, within a sliver of Boundary fault and close to the edge of the sedimentary basin, measurement of the interval below the Princeton #1 seam is uncertain. However, the mine's position near the base of the China conglomerate indicates that it is stratigraphically lower than the Ashington seam. The Deer Valley prospect is within a thin tongue of the Vermilion Bluffs shale, east of the Boundary fault, but close to the same stratigraphic position as the seam in the Red Triangle mine. The United Empire mine is located near the top of the Hardwick sandstone, and is about 600 metres below the top of the middle tongue of the Vermilion Bluffs shale on Section B-D (OF 1987-19). Although this position is stratigraphically lower than that of the Red Triangle mine, a similar degree of uncertainty in the estimation of the stratigraphic interval exists for the same reasons. The Summers Creek prospect is 70 metres above the base of the Summers Creek sandstone and the underlying rocks of the Nicola Group. Because the middle shale tongue does not extend this far north, the stratigraphic position of the seam relative to the top of the middle shale tongue is indeterminable.

Southwest of Princeton, the Jackson mine and seam are in the Vermilion Bluffs shale very close to the base of the Summers Creek sandstone (OF 1987-19) in a position that is stratigraphically equivalent to the Pleasant Valley seam. This stratigraphic position agrees with Shaw's and McMechan's correlation of the Jackson and Pleasant Valley seams. In addition, Shaw followed Hughes (1948, p.A257) in believing that the seams exposed in the Jackson and Taylor mines are equivalent. However, the Taylor No. 1 seam appears to be about 120 metres below the base of the Summers Creek sandstone (OF 1987-19). This position, stratigraphically equivalent to the Black and Princeton #1 seams, has a large degree of uncertainty because of the assumed position of the base of the Summers Creek sandstone.

In Bromley Creek, the Bromley Vale No.1 and No.2 mines and the Golden Glow prospect exploit seams that are above the Summers Creek sandstone. The Bromley Vale No.1 and the Golden Glow seams are located 350 and 470 metres respectively above the Black seam (Section S-T, OF 1987-19). Because of the equivalence of the Black and Princeton #1 seams, the distances above the top of the Vermilion Bluffs shale are 210 and 350 metres respectively. The stratigraphic position of the Bromley Vale No.1 seam is uncertain, but it probably lies immediately beneath the Bromley Vale tephra.

The Blue Flame seam, at about 320 metres below the top of the Vermilion Bluffs shale (Section D-E, OF 1987-19), indicates a 180-metre southward increase in the distance that the coal seam lies below the top of the shale, agrees with Shaw's observation (1952a, p.16), "that the Blue Flame coal occupies a position several hundred feet stratigraphically below the Princeton-Black coal zone", and negates McMechan's (1983, p.30) equivalence of the Blue Flame to the Princeton-Black seams. The 430-metre stratigraphic interval (Table 2.1) is valid only if no further intercalation develops along the top of Vermilion Bluffs shale between Bromley and Whipsaw creeks.

North of the Blue Flame mine and west of the Asp Creek fault, data from Anderson's (1972) sketch maps of structural contours on the Bethlehem seam yield the position of the seam shown in Section U-V (OF 1987-19). Because the nearest intersections of the top of the Vermilion Bluffs shale are 2 to 2.5 kilometres distant in diamond-drillholes 75-13 and 75-14, a large degree of uncertainty attends the 400-metre distance that the seam lies above the top of the shale. The large discrepancy between the 510-metre distance that the Bethlehem seam lies above Black seam (Table 2.1), and McMechan's (1983, p.30) estimation of 1010 metres results from McMechan's correlations of the Blue Flame and the Black seams, and the Bethlehem lower seam with the Allenby seam. An alternate interpretation is that the lower seam is equivalent to the Bromley Vale #1 seam.

Coal exposed at the Fairley prospect occupies a position in the Vermilion Bluffs shale that is about 210 metres beneath the top of the unit (Section W-X, OF 1987-19) and does not correlate with any other seams. However, because of close proximity to the edge of the sedimentary basin, the position of the base of the Summers Creek sandstone near Fairley prospect is very uncertain.

The coal at Burr's prospect is in the middle to lower part of the Summers Creek sandstone in the core of Allenby anticline (OF 1987-19). Although it is impossible to estimate stratigraphic separations, the seam should lie between the Gem and Bromley Vale seams as shown in Table 2.1.

STRUCTURE

The Princeton basin is the site of a major northerly trending half-graben, bounded on the east by the northerly to north-northeasterly trending Boundary fault, and near the western edge, by the Asp Creek fault. Both faults dip steeply and probably have both strike-slip and dip-slip components of displacement. Folds are upright and open to closed but are irregular in both trend and plunge. The westerly trending portions of the Allenby anticline and Tailings syncline are well defined, but their swing into and extension along the south-southwesterly trend is unexposed and complicated by the Asp Creek fault. Near Whipsaw Creek, north-northwesterly striking faults, and the northerly plunge of the Tailings syncline and Allenby anticline bring rocks of the Nicola Group to surface. A few kilometres to the south, between Kennedy Lake and Deep Gulch Creek, the southerly plunge of the Kennedy Lake syncline, the probable extension of the Tailings syncline, preserves the volcanic-dominated Sunday basin.

The Tulameen basin preserves a portion of a southeasterly plunging syncline which has been truncated on the southeast by the Blakeburn fault.

FOLDS

In the Princeton basin, folds are open and upright but lack continuity as a result of either significant changes in trend or dying out along plunge. Of the four large folds affecting Eocene rocks, the Rainbow Lake anticline (Hills, 1962) and Asp syncline lie north and west of Princeton, and the Allenby anticline (Shaw, 1952a) and Tailings syncline extend for many kilometres south of Princeton (OF 1987-19). North of the Rainbow Lake anticline, gently east-dipping Eocene sediments form a homocline that terminates against the Boundary fault. East of the fault, a sliver of westerly dipping sediments represents the faulted remnant of the other limb of a syncline (Sections M-N and O-P, OF 1987-19). This syncline diverges from the Boundary fault near Jura, extends northward and may be partly responsible for the shape of the northeastern corner of the basin.

In the northern part of the basin, the southeasterly plunging structures are probably a combination of folding and the paleotopography of the basin. The northwest and east margins of the basin show that the Rainbow Lake anticline extends along a belt where the Cedar Formation is preserved beneath the Allenby Formation (OF 1987-19). In the middle of the basin, immediately west of Highway 5, the bottom 16 metres of diamond-drillhole UP-5 intersected amygdaloidal and vesicular, olivine-bearing flows and minor breccias of the Cedar Formation along the hinge of the Rainbow Lake anticline (Figure 2.3) not volcanic rocks of the Nicola Group as mapped in this location by McMechan (1983). North and south of the anticline, the Nicola directly underlies the Allenby Formation.

Statistical analysis of the few bedding attitudes indicates the fold axis for Rainbow Lake anticline trends and plunges 135/12SE (with a standard deviation of ±02). Southwest of the anticline, bedding attitudes on either side of Asp Creek outline the southeasterly plunging Asp syncline which broadens and disappears south of Princeton. Analysis of bedding attitudes (Figure 2.2) yields a fold axis trend and plunge of 139/22SE (±06) which differs from the 160º strike for the subvertical trace of the axial plane shown on OF 1987-19. Near the northwest margin of the basin, Asp Creek fault dextrally displaces the syncline. On the margin, the Allenby Formation directly overlies volcanics of the Nicola Group. Farther southwest, bedding attitudes and the old workings of Pleasant Valley Company's mines outline the southeasterly plunging Pleasant Valley anticline which also broadens and disappears southeastwards. Statistical analysis of bedding attitudes gives a fold axis orientation of 135/15SE (±05) after elimination of the three steepest southeasterly dipping beds (Figure 2.2). Outcrops on the northwest margin of the basin

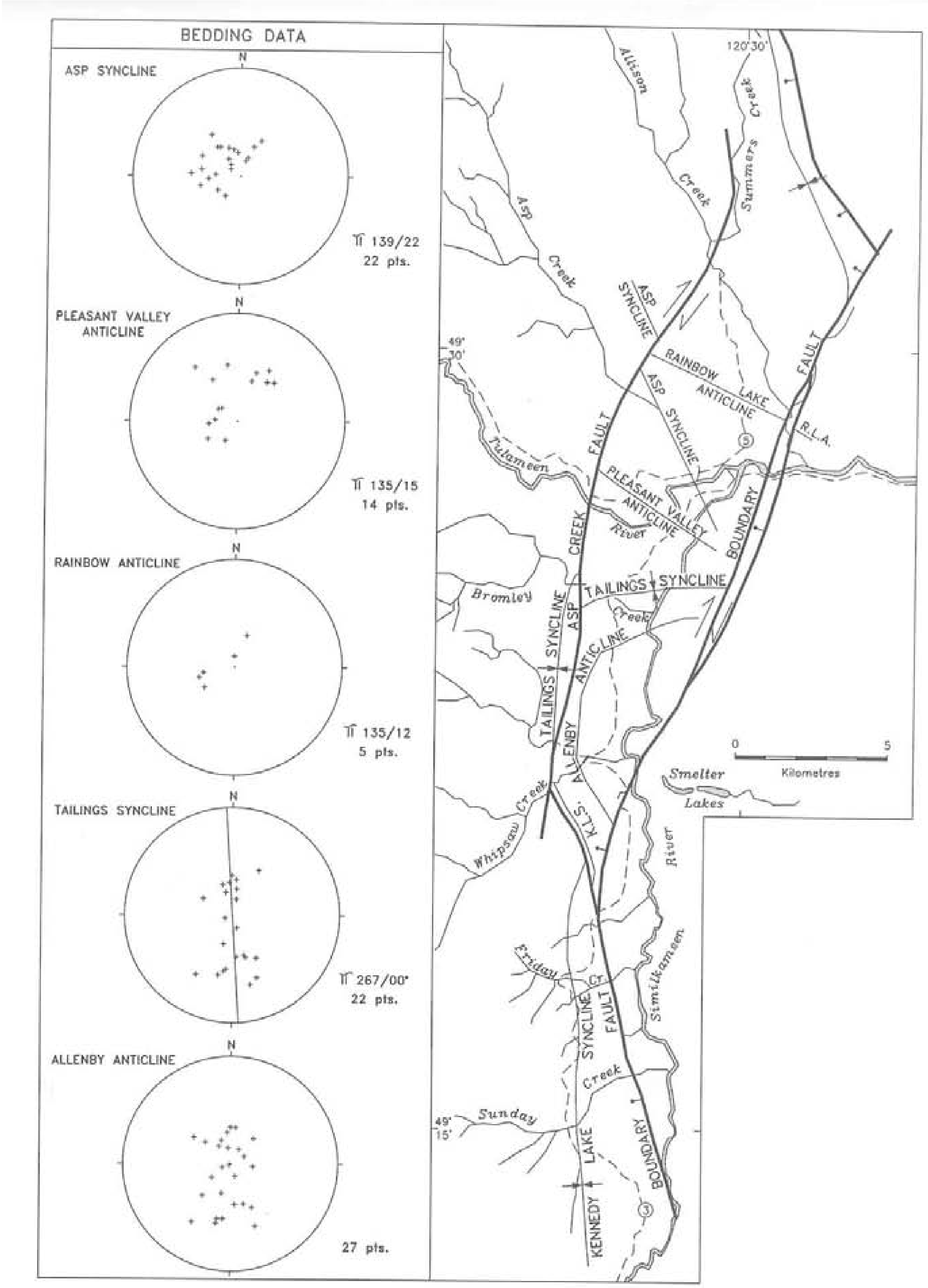

Figure 2.2. Bedding and fold data from the Allenby Formation of the Princeton basin.

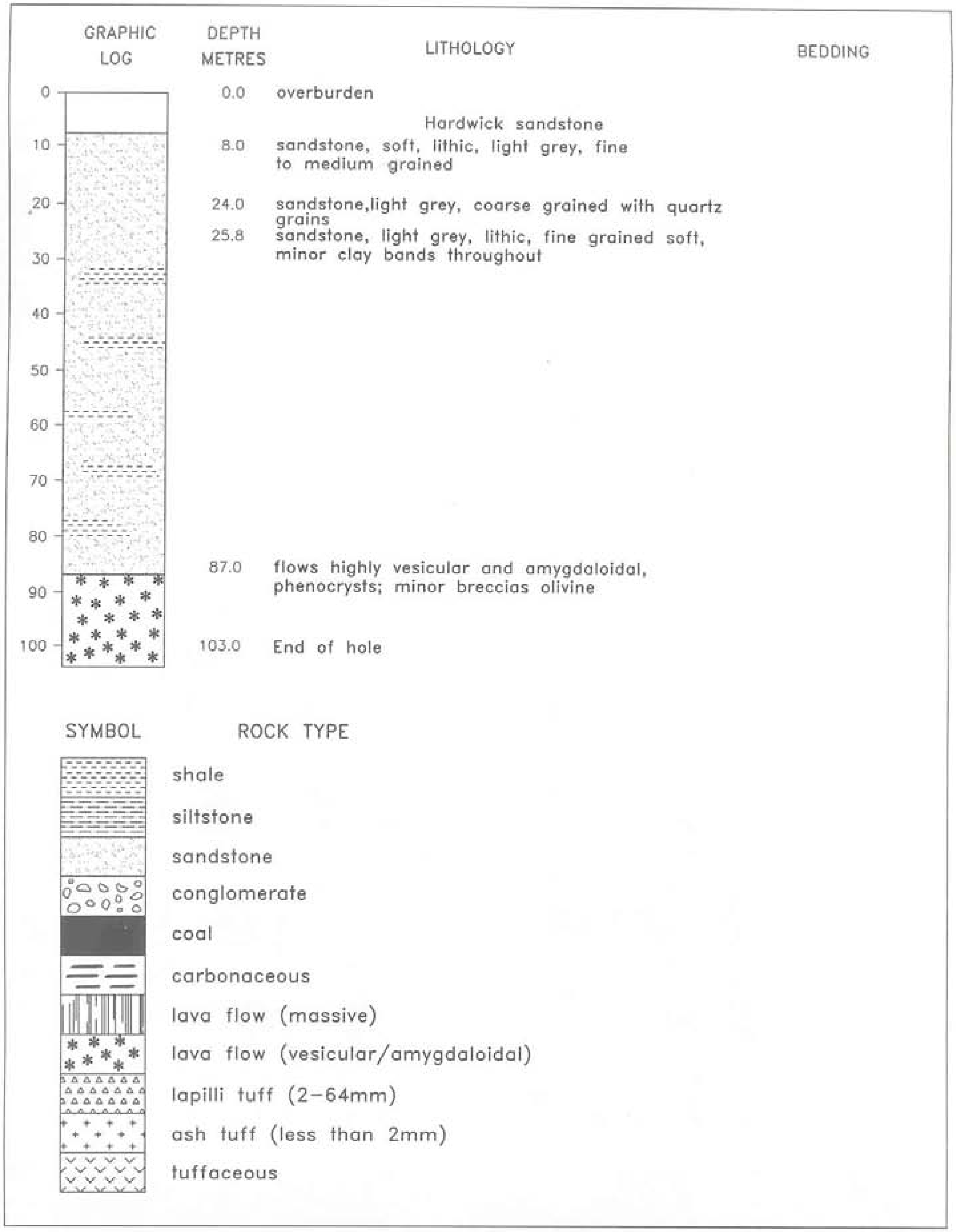

Figure 2.3. Log of vertical rotary-drillhole UP-5, Princeton basin.

show that Cedar Formation underlies the two anticlines, but it is absent in the intervening syncline.

In the Allenby Formation, the distribution of Eocene sedimentary units clearly shows that the Pleasant Valley anticline lies along a paleotopographic high, capped by Eocene volcanic rocks, that apparently prevented the southward distribution of the Hardwick sandstone, Snowpatch ash, China conglomerate, Asp Creek ash and Princeton ash (Section C-D, OF 1987-19). The northern limit of the ash units lies south of a paleotopographic high, capped by Eocene volcanic rocks, along the Rainbow Lake anticline. The intervening Asp syncline, with no underlying Eocene volcanic rocks, lies along a paleotopographic low which contains the ash units and the greatest thicknesses of the Hardwick sandstone, Vermilion Bluffs shale and probably the Summers Creek sandstone.

South of Princeton, the Tailings syncline and Allenby anticline dominate the structure of the Eocene basin for more than 30 kilometres. The shorter of these, the Allenby anticline, extends for 10 kilometres between its terminations on the Boundary fault (OF 1987-19). Although it is clearly defined by bedding attitudes and the distribution of the Ashnola shale on the Similkameen River 6 kilometres south of Princeton, the irregularity of bedding attitudes thwarts determination of the orientation of the fold axis (Figure 2.2). West of the Similkameen River a few northerly striking bedding attitudes show that the fold has changed its trend to south-southwesterly (Section U-V, OF 1987-19), and in the Blue Flame No.2 mine workings, Shaw (1952a, p.22) and Hughes (1955, p. A234) noted that the workings are wrapped around the northwesterly plunging hinge of a gentle anticline. With the change to a northwesterly plunge, the Allenby anticline broadens, disappears southwards and perhaps does not reach the Boundary fault.

Near the Similkameen River, about 5 kilometres south of Princeton, bedding attitudes and the distribution of the Summers Creek sandstone, Tailings ash, and Ashnola shale, define the west-trending Tailings syncline (Figure 2.2 and Section C-D, OF 1987-19). East of the Similkameen River, a statistical analysis of the bedding indicates that the orientation of the fold axis is 267/flat. West of the Similkameen River, projection of the syncline mimics that of the adjacent Allenby anticline and fulfills the restriction that the axial plane must lie east of the Summers Creek sandstone intersected in diamond-drill holes 75-13 and 75-14 (Anderson, 1976). Furthermore, in the vertical diamond-drill holes 71-12 and 76-15 (Anderson ,1972, 1976), the depth of intersection of a distinctive sandstone layer in the Ashnola shale, and bedding that is perpendicular to the core axis, indicate horizontal bedding atitudes which are consistent with proximity to the fold hinge as shown in Section U-V (OF 1987-19). South of Whipsaw Creek, a splay from the Boundary fault subparallels the syncline and complicates its southward projection. In this area, bedding attitudes in the Nicola Group define the Kennedy Lake syncline (Preto, 1972, p. 51). Not until Sunday Creek, do bedding attitudes in the Eocene Sunday Creek conglomerate and tephra outline the open, gentle northerly plunging Kennedy Lake syncline.

FAULTS

Two major northerly striking faults affect the Princeton basin. The Boundary fault (Preto, 1972) defines most of the eastern margin of the basin, and the Asp Creek fault, part of the western margin of the basin. Near Smelter Lakes, the Boundary fault veers to the north-northeast and lies close to the boundary between Eocene and older rocks. The dip of the fault has been defined in two places: one a short distance south of Deep Gulch Creek and immediately east of Highway 3, where drilling defined a 45° to 60° westerly dip (Preto, 1972, p.57); the second in an exposure on the east bank of Allison Creek, south of the United Empire mine, where the attitude of the fault is 350/68SW with dip-slip slickensides and a fault drag that is consistent with normal displacement. McMechan (1983, p.34) inferred a displacement in the order of 1400 metres. Along the east side of the basin, the Boundary fault is probably a zone of faults as described by Preto for the area south of Smelter Lakes. West of Allison Creek, a splay seems necessary to resolve structural and stratigraphic inconsistencies.

The Asp Creek fault is a north-northeasterly striking structure which lies mainly within the Eocene basin and only locally forms the faulted edge on its western side. The Asp Creek fault of this study coincides with McMechan's Asp Creek fault (1983, p.34) only where he defined it in the Tulameen River about 4 kilometres west of Princeton. From Tulameen River it strikes north-northeasterly to a roadcut between Hardwick and Asp creeks where an exposed subparallel fault has an attitude of 051/72SE with horizontal slickensides. The fault continues north-northeasterly along Summers Creek west of diamond-drill holes PC-4 and PC-5 (Nicholson, 1981; Section A-B, OF 1987-19). Six kilometres south of Tulameen River, near Tracey Lake, drill intersections of fault zones and sandstones are reconciled by a southward extension of the Asp Creek fault along the trace of an unnamed fault shown by Anderson (1972). Because the continuity in the old workings of the Blue Flame No.1 mine precludes a projection of the fault east of the mine portal, the fault probably passes to the west where the lack of development workings could be the result of the fault termination of the seam against the Asp Creek fault.

CHAPTER 3 GEOLOGY OF THE MERRITT BASIN

INTRODUCTION

In contrast to the areally extensive Eocene rocks exposed at Princeton to Tulameen, Hat Creek and along the Fraser River, the Merritt basin (92I/1 & 92I/2) is preserved in four widely separated fault blocks stretching 50 kilometres from the Fig Lake graben (Thorkelson, 1989) on the southwest to Quilchena Creek in the east (Figure 1.1).

Geological data from Ells (1905a, 1905b), White (1947), Preto (1979), McMillan (1978, 1981), Monger and McMillan (1989), Read (1987a) and numerous assessment reports have been used extensively in the preparation of Map 3.

STRATIFIED ROCKS

The Merritt basin locally contains erosional remnants of Eocene volcanic rocks that underlie a cover of the Eocene Coldwater Formation that is up to 1200 metres thick and consists of sandstone and pebble conglomerate of unit EPcss, and shale and minor coal of unit EPcp. Northerly trending, normal faults segment the basin into four parts (Figure 3.1): an eastern segment underlying the northern part of Quilchena Valley, a central portion around and east of Merritt, a western part underlying the southern end of Guichon Valley to Lower Nicola and beyond, and in the Fig Lake graben exposed along the Coldwater River near Kingsvale south of the mapped area.

PRINCETON GROUP

Cockfield (1948), Ewing (1981b), Monger and McMillan (1984) and Thorkelson (1989) included the Eocene volcanic and sedimentary rocks of the Merritt basin with the Kamloops Group. Later, Monger and McMillan (1989) correlated the volcanic rocks of the basin with the Princeton Group. Based on similarities in the lithology of the volcanic and overlying sedimentary rocks of the Merritt basin with the stratified rocks in the Princeton basin, Read (1988d) correlated the volcanic rocks of the Merritt basin with the Cedar Formation of the Princeton Group and the sediments of the Coldwater Formation with those of the Allenby Formation. Hills (1965, p.28) provided the data for the correlation of the sediments with those of the Princeton basin when he noted that:

> (a) the sandstones at Princeton, Merritt, Nicola-Mamit (Guichon Creek) and Quilchena are arkosic, and at all locations, except Coalmont, the arkoses are very pure with more than 90% of the detritus being of granitic origin.
>
> (b) the sediments of the Coldwater Formation in the Merritt basin belong to the uppermost and possibly the upper part of the middle of three palynological zones present in the Princeton and Tulameen basins, whereas the tuffaceous sediments of the Tranquille Formation of the Kamloops Group belong to only the lower zone which is not represented in the Merritt basin.

Correlation of the Eocene rocks of the Merritt basin with those of the Princeton Group is strongly supported by lithology and palynology; Cockfield's (1948), Ewing's (1981b), and Thorkelson's (1989) suggested correlation with the Kamloops Group is not.

Controversy exists as to whether the Eocene volcanic rocks in the Merritt basin overlie or underlie the Eocene sedimentary rocks. Cockfield (1948) stated, and Monger and McMillan (1984, 1989) implied, that the volcanics overlie the sediments. This conclusion was based on the presumed relationships between the Eocene volcanics and sediments southwest of Merritt. Detailed drilling (Sumicol Consultants Co. Ltd., 1970; Gilmar, 1980) and surface mapping (Read, 1988d) indicated that the last defined fold immediately northeast of the Eocene volcanics is a northwesterly trending syncline. As a result, the Eocene volcanics probably underlie the sediments on the southwest limb of this structure. This is the stratigraphic order of the Eocene stratigraphy exposed in the Fig Lake graben (Thorkelson, 1989).

CEDAR FORMATION (Units EPvd, EPvr and EPv)

Southwest of Merritt, medium grey, aphanitic dacite flows (EPvd) and rhyolite lapilli tuff and flows (Epvr) rest unconformably on maroon-grey plagiphyric andesite flows and pyroclastic rocks of the Nicola Group (uTav). At 810 metres (2650 feet) elevation southwest of Merritt, exploration trenches and pits show that Eocene shale and coal immediately overlie the rhyolite at UTM coordinates FL0656480 mE and FL5551360 mN (OF 1988-15).

At the south end of Guichon Creek, radiometrically dated felsic to intermediate flows and volcanic breccias (EPv) nonconformably overlie the Guichon Creek batholith and the Nicola Group, and underlie the Eocene sediments which extend northward up Guichon Valley. Farther south in the Fig Lake graben, radiometrically dated hornblende-phyric dacite flows and pyroclastic rocks are up to 500 metres thick, underlie Eocene sediments and form the basal unit of the graben fill.

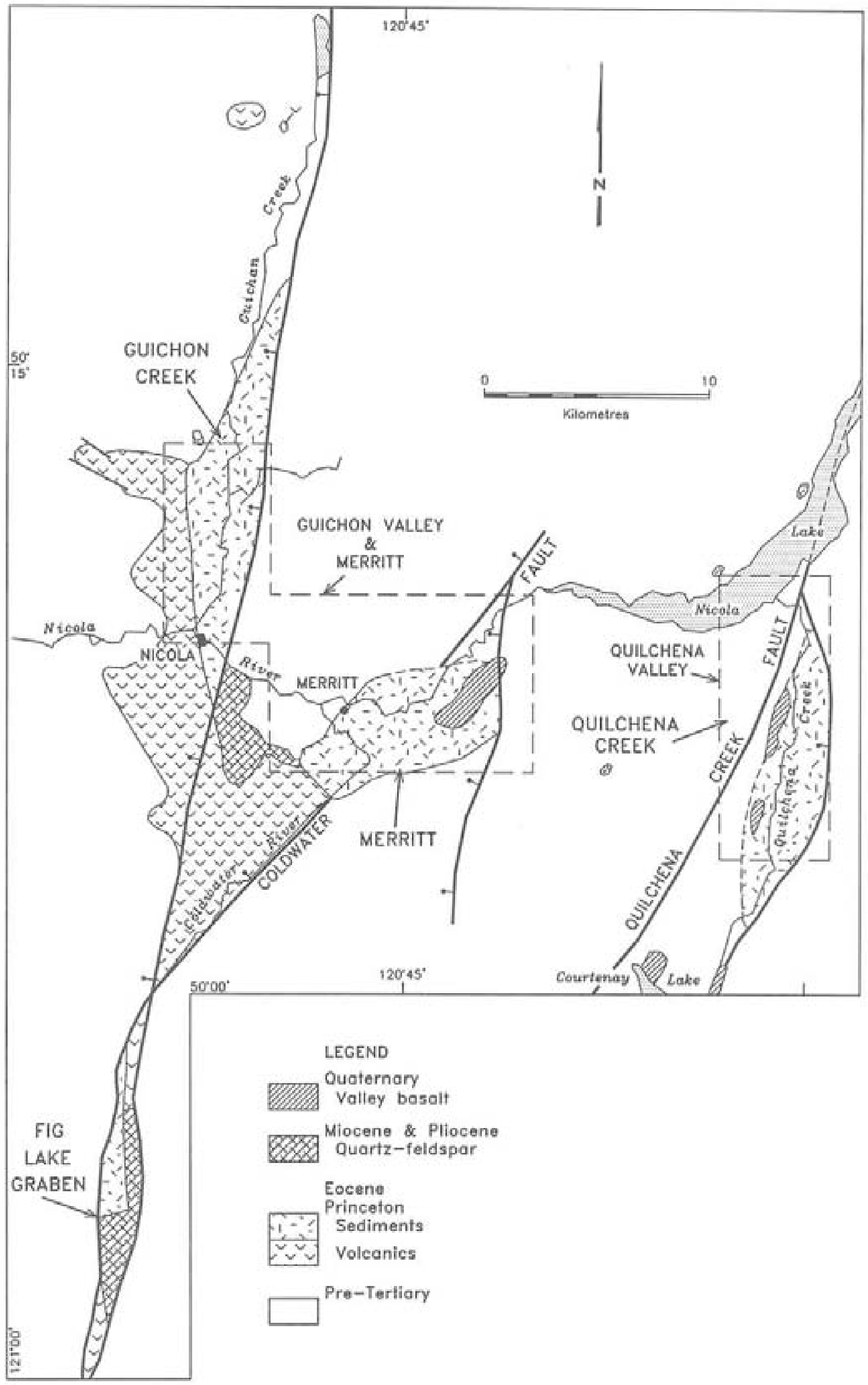

Figure 3.1. Simplified geological map of Merritt basin showing the Fig Lake graben, Guichon Creek, Merrit and Quilchena Creek segments of the basin, the bounding normal faults and the outlines of mapped areas.

COLDWATER FORMATION (Units EPcss, EPcp and EPc)

In Quilchena Valley, sandstone and pebble conglomerate, minor shale and rare coal and bentonite seams form a gentle easterly dipping wedge of Eocene sediments that lie unconformably upon the Nicola volcanics and Triassic or Jurassic intrusions. The sediments attain a minimum thickness of 1100 metres before truncation on the east along the Triangle Ranch fault (Section E-F, OF 1988-15).

Near Merritt, folded sandstone and shale with minor, but formerly productive coal seams, unconformably overlie the Nicola Group and locally the Eocene volcanics. Several thin shale-coal intervals of unit EPcp) are present in the dominant arkosic sandstone and grit host (EPcss). Southwest of Merritt, drilling indicates that the preserved sediments are only 300 metres thick. In Hamilton Creek, where deformation is less intense, bore hole X#1 penetrated 387 metres of gently dipping Eocene sediments.

In Guichon Valley, a gentle northeasterly dipping sequence of sandstone and shale with rare coal and bentonite seams, possibly totalling 1200 metres in thickness (Section A-B, OF 1988-15), apparently overlies Eocene volcanic rocks. A few outcrops and bulldozer trenches several kilometres north of Lower Nicola show that the sandstone (EPcss) and shale-siltstone (EPcp) units are of subequal thickness.

Farther south in the Fig Lake graben, polymictic conglomerate and sandstone attain a total thickness in excess of 2000 metres (Thorkelson, 1989). The conglomerate contains well-rounded to subrounded pebbles and cobbles of mainly volcanic and granitic detritus, and Eocene hornblende-phyric dacite clasts are also present. The sediments were deposited by northward-flowing currents.

The Middle Eocene age of the Coldwater Formation is based on palynology, macroflora and insect collections from 15 localities (Appendix A, Table A2).

"VALLEY BASALT" (UNIT PRvb)

Fresh, vesicular olivine basalt flows (PRvb) of Pleistocene age form remnants along the Nicola and Quilchena valleys. Elevations of the bases of the remnants decrease from 1070 metres (3500 feet) north of Courtney Lake to 640 metres (2100 feet) in the Nicola Valley northeast of Hamilton Creek. The flows probably originated north of Courtney Lake and flowed down the Quilchena Valley into the Nicola Valley.

STRUCTURE

FAULTS

Northerly trending, normal faults segment the basin into four parts. From east to west, the faults are: in the Quilchena Valley, the Triangle Ranch fault on the east and the Quilchena Creek fault on the west bound a downfaulted block that preserves 1100 metres of easterly dipping Eocene sediments; near Merritt, the Normandale fault forms the eastern limit of folded Eocene sediments; along and south of the Guichon Valley, the Guichon Creek fault forms the eastern limit of an easterly tilted Eocene succession that is more than 1500 metres thick; and in the southwest, the Fig and Kingsvale faults form the western and eastern limits respectively of the north-trending Fig Lake graben which is filled with 2500 metres of Eocene rocks (Thorkelson, 1989). The thicknesses of Eocene rocks preserved in the downfaulted blocks indicate large normal components of fault movement which range from a maximum of at least 4.5 kilometres in the Fig Lake graben (Thorkelson, 1989) to about 2.5 kilometres for the Guichon Creek fault (Section A-B, OF 1988-15), approximately 1.5 kilometres for the Triangle Ranch fault on the east side of the Quilchena Valley (Section E-F, OF 1988-15), to a low of a kilometre for the Normandale fault on the east side of Merritt (Section C-D, OF 1988-15). Although fault movement indicators are lacking and the dip of the faults is unknown, the gentle eastward dip of Eocene rocks in Guichon and Quilchena valleys suggests that the Guichon Creek and Triangle Ranch faults are west-dipping, listric and normal.

The Coldwater fault is a southwesterly striking splay of the Clapperton fault system (Moore and Pettipas, 1990) that bounds the northwest side of the Nicola horst north of Nicola Lake. Contradictory senses of fault movement have been proposed or implied for the Coldwater fault. Monger (1985) depicted the fault as normal with the northwest side down, and Moore and Pettipas (1990) showed it as a splay from the Eocene Clapperton fault system that is estimated to have several kilometres of Eocene or younger normal displacement with the northwest side down, but Thorkelson (1989) suggested that it is a left-lateral strike-slip fault. Within the loose contraints imposed by the lack of Eocene sedimentary outcrops near Merritt, the distribution of the Coldwater Formation indicates that the Coldwater fault may not truncate the formation. A majority of K-Ar radiometric ages for biotite and hornblende from the plutonic rocks of the Nicola horst yield a Paleocene to Early Eocene cooling age for the Nicola batholith (Monger 1989b). These cooling ages would allow normal displacement along the Coldwater fault to precede deposition of the Coldwater Formation.

FOLDS

As Ells (1905a), White (1947) and Cockfield (1948) observed, the Eocene sediments form southeasterly trending, open to tight folds south of Merritt. Later diamond drilling by Sumicol Consultants Co. Ltd. (1970) and Crows Nest Resources Ltd. (Gilmar and Sharman, 1981) substantiates this orientation and extends the affected area. Southwest of Merritt, the folds are probably doubly plunging and preserve the Coldwater Formation in fold depressions. The tight folding has obscured the stratigraphic relationship between the Eocene volcanic and sedimentary rocks. However, an interpretation of the drilling indicates that the southwesternmost Eocene sediments southwest of Merritt occupy the core of a northeasterly overturned syncline, which is flanked farther to the southwest by stratigraphically lower Eocene volcanic rocks.

In the Fig Lake graben, Guichon and Quilchena valleys, Eocene rocks are unfolded but dip gently to moderately eastward as a result of displacement along west-dipping, listric normal faults.

CHAPTER 4 GEOLOGY OF THE ARROWSTONE HILLS

INTRODUCTION

The Arrowstone Hills lie between the Bonaparte and Deadman rivers north of the Thompson River (Maps 4 and 5). The deeply incised river valleys range from 450 to 900 metres (1500 to 3000 feet) in elevation with good outcrop along the valley sides, and in the Deadman Valley extensive landslides. Above 900 to 1050 metres (3000 to 3500 feet) is a rolling upland with few exposures except in roadcuts. The few peaks rising above 1525 metres (5000 feet) show bedrock along the ridges. Of the Tertiary rocks that underlie most of the area, the Eocene volcanics and Miocene basalt flows are adequately exposed, but the Miocene sediments and tephra are mostly covered.

Up to 2000 metres of Eocene volcanic rocks of the Kamloops Group fill a broad northwesterly trending syncline that lies between the Bonaparte and Deadman rivers. The Deadman River fault cuts across the northeastern limb and the Bonaparte fault may truncate the southwestern limb. The Tertiary rocks lie on a faulted basement composed of the Cache Creek Complex along the Bonaparte Valley on the west edge, and the Nicola Group, Ashcroft Formation, Thuya batholith and Silverquick formation along and north of the Deadman Valley on the east. The basal Eocene unconformity is very irregular and at the southwest end of the Arrowstone Hills, has a paleorelief of nearly 600 metres.

The study area straddles part of the southern edge of an area of thousands of square kilometres of Miocene basalt flows which extends from the Thompson and North Thompson rivers on the south and east respectively, to the western edge of the Interior Plateau, and northwestward into the Chilcotin-Nechako basin. Up to 850 metres of Miocene rocks lie on a paleosurface, much like the present topography of deeply incised valleys separated by rolling uplands, with a relief ranging up to 600 metres. Unlike the present south to southwesterly drainage direction, the Miocene drainage was generally northwestward.

In the southern part of the area (92I/14, 15), the regional mapping of Monger and McMillan (1984, 1989) in the Ashcroft area revised the earlier regional work of Duffell and McTaggart (1952), and incorporated the detailed studies of Travers (1978), Shannon (1982), and Frebold and Tipper (1969). McMillan (1978) investigated Cenozoic and older rocks south of the Thompson River and Ewing (1981b) mapped the Eocene volcanic and sedimentary succession north of McAbee. Campbell and Tipper (1971) mapped the northern part of the study area (92P/2, 3) covered by the Bonaparte Lake map sheet.

STRATIFIED ROCKS

Along the Bonaparte River, the basement to the Tertiary stratified rocks is the Cache Creek Complex consisting of greenstone (PTv), a mélange containing blocks of chert, limestone and greenstone in a phyllite matrix (PTtpx), minor serpentinite (us) and, near Scottie Creek, limestone of the Marble Canyon Formation (PTc). On the north side of the Thompson River, and east of an unnamed pre-Eocene fault, the Tertiary rocks rest on massive grey shale (lmJA) of the Lower and Middle Jurassic Ashcroft Formation and locally diorite of the Guichon Creek batholith (TJdi) up to about Battle Creek. East of Battle Creek and northward along the Deadman River valley, basic volcanics (uTAwv) of the Middle and Upper Triassic Nicola Group underlie the Eocene rocks. East of a line drawn from near the mouth of Gorge Creek to and beyond the west end of Upper Loon Lake, the Nicola basement supports Miocene rocks; Eocene rocks are absent. The younger stratified rocks, including a sliver of the mid-Cretaceous clastic rocks of the informally named Silverquick formation (luKs) unconformably overlie this basement.

SILVERQUICK FORMATION (luKs)

Roadcuts on the east side of the southern half of Mowich Lake and northern half of Snohoosh Lake, and on the Brigade Creek road just above its junction with the Deadman Valley road, expose grey and locally red shale and siltstone interbedded with a coarse sandstone. East of Chartrand Lake, diamond-drill hole 88-2 (Figure 4.1) intersects the same sediments with weathered granitic clasts in the sandstone. The unit is preserved as thin remnants, no more than a few hundred metres in thickness, which unconformably overlie the Nicola Group and nonconformably rest on small granitic intrusions. In the map area, the formation erodes so easily that wherever it exists it forms the basement to Miocene drainage channels. Only the overlying Miocene basalt flows have protected the unit from complete removal. The Albian age (F6, OF 1989-21;Table A.1, Appendix A) for the unit and a similarity in lithology to the Albian and Cenomanian sediments at and near Hat Creek and southeast of Merritt, and others at the head of Drynoch slide, indicate that the unit was widespread but now is preserved only locally.

KAMLOOPS GROUP

Middle Eocene volcanic rocks up to 2000 metres in thickness underlie the southern half of Arrowstone Hills. Thin volcanogenic sedimentary lenses and lithologically distinctive volcanic rocks occur only at or near the base of the group along the southern edge of the hills from north of

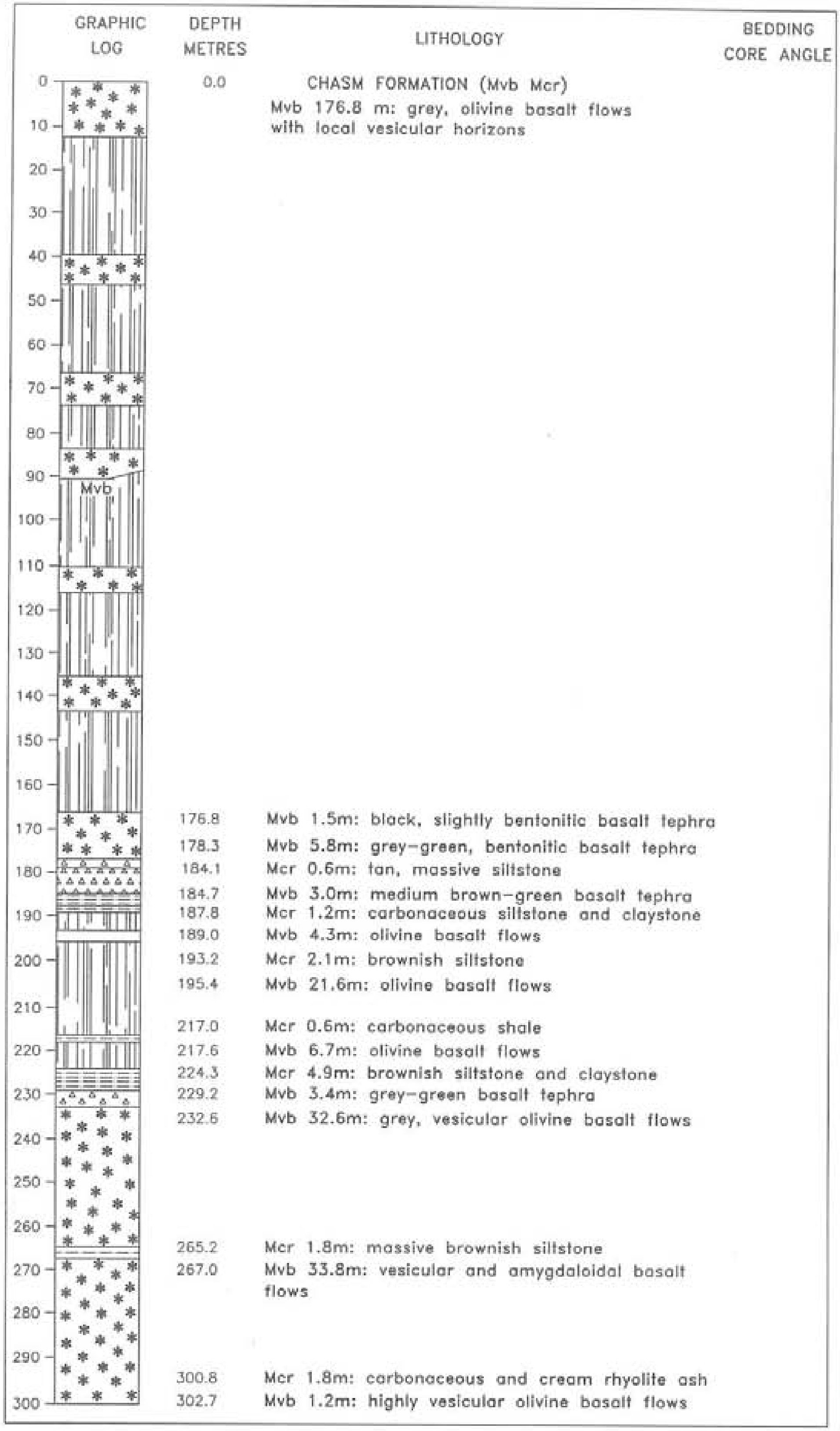

Figure 4.1 Log of vertical diamond-drill hole 88-2 Chartrand Lake (for graphic log symbols *see* Figure 2.3).

the village of Cache Creek to as far east as Barricade Creek. Elsewhere sediments are absent and the volcanic rocks are exclusively aphanitic andesite and dacite. All of the volcanic and lenticular sedimentary rocks of the area are included in the Dewdrop Flats Formationas as redefined by Ewing (1982) in the Kamloops area immediately to the east.

SKULL HILL FORMATION

The formation underlies the south end of the Arrowstone Hills, and narrows northward to 25 kilometres of the formation north of Loon Lake, Miocene flows cover all but an inlier around Fly Creek. Beneath the Miocene, Eocene flows are preserved west of a north-northwesterly trending line starting just east of Split Rock, passing about a kilometre east of Gorge Creek, crossing the west end of Upper Loon Lake and continuing northward at least 3 kilometres east of Fly Creek. The lack of Eocene to the east probably results from nondeposition, post-Eocene uplift and erosion, or both. The greatest lithologic diversity is at the southern end of the large area underlain by the Dewdrop Flats Formation. Among the first rocks of theDewdrop Flats Formation are felsic volcanics, waterlain tephra and hypabyssal intrusions. Similar stratified rocks are included in a lithologically diverse lens of sediments and volcanics north of McAbee. Northward, aphanitic dacite and andesite comprise the formation.

RHYOLITE FLOWS, BRECCIA AND HYPABYSSAL INTRUSIONS (Unit Ef) AND RHYOLITE TUFF (UNIT Etf)

Within the map area and south of Ashcroft, the earliest Eocene rocks are rhyolite flows, hypabyssal felsite dikes and porphyritic rhyolite and rhyodacite dikes and plugs. On the north side of the village of Cache Creek, biotite-quartz-feldspar rhyolite dikes intrude rhyolite flows and tephra. These rhyolites were probably 300 metres below the Eocene surface and are the subvolcanic remnants of an eruptive centre (Section A-A', OF 1988-30). East of the village of Cache Creek, white felsite dikes intrude the dark grey shale of the Ashcroft Formation but not the Dewdrop Flats Formation. In the Trachyte Hills, 12 kilometres west of the village, rhyolite underlies a roughly circular area 2 kilometres in diameter and either lies on or intrudes mid-Cretaceous sediments. A body of porphyritic (biotite, hornblende, quartz, feldspar) rhyolite 6 kilometres long, which Drysdale (1914) called the `Ashcroft rhyolite porphyry', outcrops south-southeast of Ashcroft and 13 kilometres from Cache Creek. Although long believed to be an extrusive part of the Kamloops Group (Drysdale, 1914, p.141; Duffell and McTaggart, 1952, p.67; Monger and McMillan, 1989), the rhyolite locally has vertical or outward-dipping contacts and shale of the Ashcroft Formation, within a metre of the porphyry, is contact metamorphosed. All of these occurrences of rhyolite are probably intrusive into pre-Eocene but not Eocene rocks, suggesting that rhyolite was the earliest phase of volcanism in this area of the Kamloops Group.

White, crystal-rich (biotite, hornblende, quartz, feldspar) vitric tuff (Etf) locally forms thin basal lenses up to 15 metres thick, which immediately overlie the pre-Eocene basement from 1.5 kilometres southeast of Carquile to 1.5 kilometres east of Battle Creek (Photo 7.4). The tuffs are the extrusive remnants of the hypabyssal rhyolite intrusions. Where the lenses are waterlain, they are zeolitized by a heulandite-clinoptilolite of intermediate composition.

SUCCESSION AT MCABEE (UNITS Evd, Evdm, Ecg and Eptf)

The lower parts of the southern slopes of the Cache Creek Hills expose a diverse sequence of volcanic rocks that surrounds a west and an east sedimentary lens that are each up to 100 metres thick (Photo 4.1). Although the succession is atypical of the Dewdrop Flats Formation in the map area, its description follows because the succession contains zeolitized rocks and differs from Ewing's (1981b) observations on the stratigraphy and importance of faults in the same rocks. Beneath both the west and east sedimentary lenses are grey, aphanitic andesite flows (Evd) with vesicular margins and some interflow breccia. Although less than 50 metres thick and locally absent beneath the lenses, the unit thickens rapidly away from them to more than 500 metres. A lens of grey, porphyritic (plagioclase, hornblende) andesite flows (Evdm) characterized by columnar jointing, underlies and spans the interval between the two lenses. Near the mouth of Battle Creek, the lowest part of the eastern sedimentary lens, a diorite cobble or boulder conglomerate (Ecg), nonconformably overlies the northern margin of Guichon Creek batholith near the base of an Eocene hill that is over 400 metres high. In the upper part of the conglomerate, volcanic detritus dominates and the clast size diminishes. Although the elevations of the base and top of the flat-lying unit indicate a thickness of nearly 200 metres, the unit is probably thinner and represents a veneer plastered against the side of an Eocene hill. Tuffaceous sandstone, siltstone and shale of unit Eptf form the 40-metre-thick western lens (Photos 4.1 and 7.5) and the upper 70 metres or less of the eastern lens. Most of the sediments are cream weathering, tuffaceous, well bedded and commonly contain plant debris. Within a few metres of the top of unit Eptf, lenses of rhyolite vitric ash represent the stratigraphically highest rhyolite of the early phase of acid volcanism. An x-ray diffraction investigation of samples taken at 1-metre intervals of thickness across unit Eptf in both lenses shows that the crystal portion of the tuffaceous sediments consists of quartz, feldspar, biotite and hornblende, and the vitric ash portion is altered mostly to cristobalite and a zeolite of the heulandite-clinoptilolite series, and locally to carbonate with montmorillonite or kaolinite. Where strongly altered to cristobalite, the rocks are hard, porcellanous and, except for a low specific gravity, are similar to chert. Rocks containing montmorillonite are buff and mealy weathering, and mainly form the western end of the western lens. The volcanic rocks overlying the succession at McAbee are widespread and described later.

SUCCESSION NEAR SPLIT ROCK (UNIT Ebx)

The Deadman Valley between Criss and Gorge creeks, and the lower few kilometres of the creeks, expose sedi-

Photo 4.1 On the lower southern slopes of the Cache Creek Hills (FM0626600 mE, FM 5629900 mN), looking west towards the middle of the western sedimentary lens north of McAbee with the McAbee zeolite showing (Z4) in the middle of the white ridge on the right side. The low, platy jointed cliff under the powerlines is aphanitic andesite and dacite flows (Evd) intercalated with cream-coloured tuffaceous shale and siltstone (Eptf) that dips gently northward beneath the upper brown cliffs of breccia (Evdx).

Photo 4.2. A view to the east side of the Deadman River valley south of Gorge Creek to low rounded hills composed of bentonite-rich tephra of unit Evdx at Split Rock showing. The white slopes in the left-centre are underlain by Eocene quartzofeldspathic sandstone and granitic pebble conglomerate forested slopes which overlies a steep dipping paleoslope of volcanics of the Nicola Group (uTnv) exposed on the upper forested slopes.

mentary and possible sedimentary rocks. In Criss Creek south of Split Rock, a small sedimentary lens at the base of the Eocene rocks contains fossils (F9, Map 4). The bentonite localities in the Deadman Valley occur in poorly bedded andesite-dacite ash and lapilli tuff (Evdx) close to the basal unconformity (Photo 4.2). Along the western side of Deadman Valley, cliffs up to 200 metres high expose crudely bedded, light-weathering rhyodacite and dark dacite or andesite breccia and lithic tuff lenses of unit Ebx (Photo 4.3). With the exception of the fossiliferous lens, the remaining occurrences may be only in part waterlain. The earlier suggestion (Read, 1988a) that the sediments at McAbee and the occurrences here may be connected is repeated, but in the absence of additional mapping between the two areas, it remains very speculative.

DACITE AND ANDESITE (UNITS Evd and Evdx)

Grey, aphanitic andesite and dacite flows and breccia compose more than 90% of the Eocene volcanic rocks exposed in the Arrowstone Hills (Photo 4.4). Taking into account that a significant area underlain by Eocene volcanics remains unmapped south of Loon Lake, the best exposures are in Loon Valley from west of Loon Lake to the west end of Upper Loon Lake. Along the western side of the Arrowstone Hills, aphanitic andesite and dacite breccia up to 1000 metres in thickness forms the basal unit of the Dewdrop Flats Formation (Section B-B', OF 1989-21). The basal breccia starts southeast of Carquile in an area of high relief on the basal unconformity, crosses Scottie and Loon creeks, and disappears under the Miocene cover on the north side of the Bonaparte River. Along the eastern side of this zone, the breccia interfingers with aphanitic flows that underlie the central part of the Eocene belt. Outcrops on the north side of Loon Lake show that breccia underlies the flows, but at the south end of the hills, across the watercourse of Cache Creek, the flows extend to the basement in an area with more than 400 metres of relief on the sub-Eocene unconformity. Along the eastern side of the Eocene belt, basal breccia up to several hundred metres in thickness reappears. A whole-rock radiometric age from a large breccia clast in unit Evdx yields an age of 50.9 ± 1.8 Ma (Appendix B).

BASALT (UNIT Evb) AND PORPHYRITIC (PLAGIOCLASE) ANDESITE (UNIT Evdf)

In the map area, dark grey aphanitic basalt flows (Evb) are rare in the Dewdrop Flats Formation and only form a few flows totalling less than 100 metres in thickness. They outcrop on the eastern side of the map area within a few hundred metres of the base of the formation where the basal breccia (Evdx) passes upward into the flows (Evd) around Cultus Lake and Charette Creek. A second occurrence of thin basalt flows on the east side of Fly Creek is similar to those of the nearby Miocene Chilcotin Group that previously they have been included within the Miocene (Campbell and Tipper, 1971±and only as a result of a whole-rock radiometric age of 52.1 ± 1.8 Ma (Appendix B, Table B.1) are they now known to be Eocene.

Dark grey vesicular and sparsely porphyritic (plagioclase) andesite and(?) basalt flows and interflow breccia, and widespread breccia comprise unit Evdf. The breccia forms much of the Cache Creek Hills and grades downwards into nonporphyritic breccia. Farther to the east in the 100 to 200-metre cliffs along the west side of the Deadman Valley, less than 100 metres of porphyritic (plagioclase) andesite flows and interflow breccia surround the crudely bedded breccia of unit Ebx.

Photo 4.3 A view northward up the Deadman River valley towards Gorge Creek showing the cliffs of white rhyodacite breccia (Ebx) with the darker slopes beneath exposing aphanitic andesite and dacite breccia (Evdx). The dark peak to the right, on the skyline, exposes Mio-Deadman channel filled with flat-lying basalt flows of the Chasm Formation and the underlying Deadman River Formation poorly exposed in the light area below and to the left of the peak.

Photo 4.4. In Battle Creek just downstream from Tsotin Creek, coarsely bedded aphanitic andesite and dacite volcanic breccia typical of unit Evdx.

CHILCOTIN GROUP

The basalt flows of the Chilcotin Group cover most of the older rocks from the mouth of Gorge Creek on the south, across to the north side of Loon Lake and west to Fiftyseven Creek. Several kilometres north of Gorge Creek, the southern limit of the Miocene strikes eastward across the Deadman Valley and continues beyond the map area. Erosional remnants of the Miocene extend a further 15 kilometres down the Deadman Valley from Gorge Creek, and 23 kilometres down the east side of the Bonaparte Valley from Fiftyseven Creek. The Miocene succession consists of up to 350 metres of fluviatile rhyolite ash and fine tuffaceous sediments underlying a minimum thickness of 500 metres of olivine basalt flows. East of Chartrand Lake, the core from diamond-drill holes 88-1 and 88-2 indicates that the basalt flows and sediments are intercalated over a thickness of 150 metres (Figure 4.1). All of these rocks belong to the Chilcotin Group, which Mathews (1989) defined as consisting of Neogene basalts and intercalated sedimentary and pyroclastic strata in south-central British Columbia. The rhyolite ash and fluviatile and lacustrine sediments, up to the first appearance of basalt, belong to the Deadman River Formation (Mvr) of Campbell and Tipper (1971), and the overlying olivine basalt flows (Mvb) and intercalated rhyolite ash and locally diatomaceous sediments (Mcr) belong to the newly proposed Chasm Formation (Read, 1989b).

DEADMAN RIVER FORMATION (UNIT Mvr)

The Deadman River Formation outcrops in a few roadcuts, slide scarps and stream bottoms on the western side of the map area, along sections of the Bonaparte River, and in Loon and Scottie creeks. On the east side of the map area, it forms parts of the valley walls of the Deadman River (Photo 4.5) and the north-trending valley containing Young Lake. White to buff-weathering, unbedded rhyolite ash and lapilli tuff dominate, and white locally diatomaceous, sandstone, siltstone and shale occur near the top of the sequence. Although there are only a few exposures of carbonaceous shale and siltstone near the top, the two drill holes near Chartrand Lake show carbonaceous layers up to a few metres in thickness are scattered throughout the formation. Campbell and Tipper (1971) suggested that diatomaceous layers up to 4 metres in thickness occur near the bottom of the succession in the Deadman Valley, but in Loon Creek, diatomaceous earth outcrops near the base and at the top. In Loon Creek, pebble conglomerate and sandstone form a minor but well-exposed part of the formation. Because less than 1% of the area underlain by the formation is exposed, drill logs yield the only complete section of the formation (Figure 4.1). However, even these are incomplete because neither of the two holes has diatomaceous earth, a rock type present in some outcrops.

Most of the sediments are fluviatile and fill the lower parts of the deeply incised, steep-walled valleys which are similar to the present valleys of the Deadman and Bonaparte rivers and Chasm Creek. Local debris-flows from the steep valley walls form some of the fill.

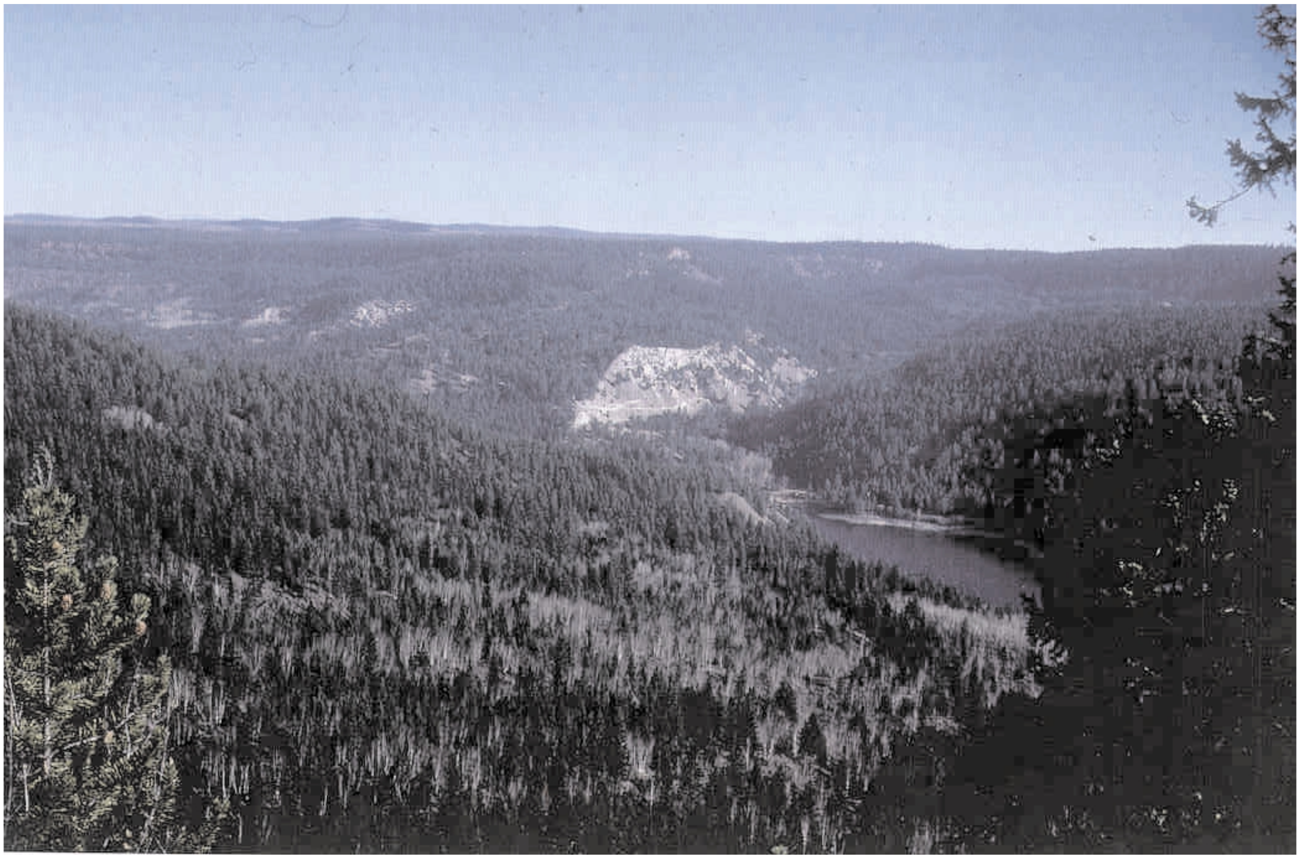

Photo 4.5. A view eastward across Snohoosh Lake to the mouth of Sherwood Creek where a zig-zag cut and cliffs expose white rhyolite tephra (Mvr) of the Deadman River Formation at Sherwood Creek showing (A2) in Mio-Snohoosh Channel. A 20 to 50-metre-high rim of cliffs exposes the overlying basalt flows that are the source of the basalt-block slides on the hummocky topography of both the near and far slopes.

Rhyolite eruptive centres are probably present in the map area. The Deadman River Formation contains layers of massive rhyolite lapilli tuff up to 118 metres thick containing angular clasts up to at least 1 centimetre on edge (Figure 4.1). Undoubtedly the large thicknesses of tephra result from the redeposition of the tephra into the drainage system. However, the 1-centimetre size of the angular clasts and up to 20 metres depth of rhyolite tephra covering at least once of the Miocene interfluves between Criss Creek and Deadman River favour a nearby eruptive centre that the extensive overlying basalt flows may have covered. Bevier (1983) suggested that the thin, felsic air-fall tephra separating a few of the basalt flows were possibly derived from concomitant but unrelated calc-alkaline arc volcanoes to the southwest. However, these few air-fall tephra layers in the Chasm Formation are insignificant compared to the similar rhyolite tephra found in the underlying Deadman River Formation.

CHASM FORMATION (UNITS Mvb and Mcr)

The Chasm Formation typically forms a chain of cliffs up to 50 metres in height at the top of the present valley sides. The late glacial to postglacial channel of Chasm Creek, ringed by cliffs of 100 metres or more, exposes up to a dozen olivine basalt flows ranging in thickness from 1 to 15 metres (Photo 4.6). Only near the margins are the flows vesicular or amygdaloidal with zeolites as the common filling. Away from the margins, most of the flows are medium to dark grey with prominent olivine and plagioclase. The outcrops are blocky to columnar jointed, and lack platy jointing or flow layering. These outcrop characteristics usually distinguish the Miocene olivine basalt flows from the typically grey, aphanitic and platy jointed flows of the Eocene Kamloops Group. In addition, Miocene volcanic breccias are very localized in contrast to the widespread distribution of breccias in the Eocene. Near the base of the formation, some Miocene basalt flows have a weak platy jointing and contain ultramafic nodules such as those near the mouth of Fly Creek, or olivine xenocrysts as in basal flows near Moose Creek. Drillholes east of Chartrand Lake show that the lower 150 metres of the formation consists of olivine basalt flows with intercalations of rhyolite ash, siltstone, shale and carbonaceous sediments ranging from 2 to 9 metres in thickness (Figure 4.1). The base of the Chasm Formation is set at the first appearance of olivine basalt and thus the formation includes the overlying silicic tephra and locally diatomaceous shale and siltstone layers of unit (Mcr) that here and there separate the olivine basalt flows.

In the valleys of the Bonaparte and Deadman rivers and Loon Creek, the succession of flat-lying olivine basalt flows is close to 500 metres thick. Such a thickness probably contains dozens of flows and is many times the average

Photo 4.6. A view northward along the postglacial channel of The Chasm which exposes several basalt flows of the Chasm Formation (Mvb) at its type locality.

thickness of 67 metres which Bevier (1983) calculated for the Chilcotin Group. The thickest section of 141 metres was measured by Bevier on the north side of Deadman River, north of its confluence with Gorge Creek. The section measured is in the Mio-Deadman channel which at this point is 2 kilometres wide and has a fill that is 440 metres thick (Photo 4.7). Because the lower and deeply incised portions of the Miocene channels were already filled by the Deadman River Formation, the voluminous basalt flows of the Chasm Formation filled the upper third or less of the channels and then spread extensively over the rolling upland surface of the Miocene interfluves. Only peaks rising above 1400 metres (4600 feet) remained uncovered.

Eruptive centres for the basalt are apparently absent within the area. Although a few thin olivine diabase sills occur within the flows, no coarse olivine dolerite plugs, similar to those described by Farquharson (1965), are exposed. Tin Cup Mountain at 1295 metres (4250 feet) and 10 kilometres north of the area, and Skoatl Point at 1640 metres (5382 feet) about 25 kilometres to the east, are the closest known basalt centres. Although Skoatl Point has not been dated, a whole-rock radiometric age of 15.5$\pm$0.5 Ma from nearby Cannine Lake (Mathews, 1989) indicates that the eruptive centre at Skoatl Point may be too old to be a source for flows in the map area which all are in the range of 8.2±0.3 Ma to 10.4±0.4 Ma based on six samples (Appendix B, Tables B.4 and B.5). Only the undated vent on Tin Cup Mountain remains a viable source.

MIOCENE DRAINAGE

In contrast to the westerly to southerly drainage direction of the present streams, Miocene drainage was dominantly northerly to westerly with some south-flowing tributaries (Figure 4.2). As a result of only rare current direction indicators in the Deadman River Formation, the data used to determine current direction are open to interpretation because they assume that the Miocene remained essentially untilted, unfolded and unfaulted in the map area.

In two areas, current indicators yield conflicting results. Within cliffs of conglomerate in the Mio-Bonaparte channel on the south side of Loon Creek, four observations of pebble imbrication indicate northerly flow. South of the confluence of Chasm Creek and Bonaparte River (FM0610300 mE, FM5665700 mN) pebble imbrication at one locality indicates a southerly flow.

Within the Arrowstone Hills, the angle of intersection of Miocene channels and the differences in elevations along their bases indicate that most of the Miocene channels drained to the north and west. In the Mio-Bonaparte channel, pebble imbrication, and a northward decrease in the elevation of the channel, prove north-northwestward

Photo 4.7. A view northward from near the confluence of Gorge Creek and Deadman River to a cross-section of the Mio-Deadman channel which is filled by 220 metres of rhyolite ash, sediments and minor diatomaceous earth of the Deadman River Formation (Mvr) and 175 metres of basalt flows of the Chasm Formation (Mvb). Gorge Creek showing (D1) is marked.

flow in a channel that is subparallel to, but about 4 kilometres east of the Bonaparte River. Near Scottie Creek, the southernmost erosional remnants of the channel fill are up to 100 metres thick, a few kilometres long and extend down to the 900-metre (2950 feet) level. To the north of Loon Creek crosses the channel, it is 5 kilometres wide and more than 400 metres deep, with a fill of more than 365 metres of rhyolite ash, conglomerate and diatomaceous earth (Figure 4.2). The channel is more than 2 kilometres wide along the bottom of Loon Creek at 720 metres (2350 feet) elevation which indicates that the channel depth not only exceeds 400 metres but may approach 500 metres. Between Fiftyseven and Chasm creeks, the Bonaparte River crosses the 3 to 4-kilometre-wide channel which is 2 kilometres wide on the valley floor at 695 metres (2275 feet) elevation.

The Deadman Valley contains exposures of parts of five Miocene channels which from south to north are Mio-Deadman, Mio-Snohoosh, Mio-Falls, Mio-Hamilton and Mio-Coal. Within the map area, erosional remnants of basalt flows outline the southern extent of the north-flowing Mio-Deadman channel sited along the Deadman River. The largest of these is a remnant of basalt flows 330 metres thick that extends down to 1030 metres (3375 feet) elevation on the west side of the Deadman Valley south of Charette Creek. The channel is clearly defined north of the confluence of Gorge Creek and Deadman River where it is 2 kilometres wide, 440 metres deep and bottoms at 885 metres (2900 feet) elevation. Its northern extension under the basalt flows is picked up in diamond-drill hole 88-2 (Figure 4.1) where the basement lies at 811 metres (2659 feet) elevation and indicates that the channel has dropped at least 105 metres.

Three of the remaining Miocene channels clearly drain southwards. Of these Mio-Coal Creek is a small channel filled with tephra with the bottom exposed at 1035 metres (3400 feet) elevation in Coal Creek. A few kilometres to the south-southwest it joins Mio-Hamilton channel at 945 metres (3100 feet) elevation at an angle of 30°. Mio-Hamilton channel is 0.5 kilometre wide where it crosses Hamilton Creek at 930 metres (3050 feet) elevation. Drilling through the Chilcotin Group between Deadman River and Enright Lake defines the southerly oriented Mio-Falls channel with a bottom at least as low as 980 metres (3215 feet) elevation. To the south, the falls on the Deadman River partly expose the easily eroded rhyolite tephra filling of Mio-Falls channel beneath a basalt cap. At the falls, the channel is a kilometre wide, has a fill of nearly 200 metres and the bottom of the channel, which is at least as low as 875 metres (2875 feet) elevation, indicates that Mio-Falls channel drained southward.

The north-flowing Mio-Deadman and south-flowing Mio-Coal Creek, Mio-Falls and Mio-Hamilton channels meet Mio-Snohoosh channel under a thick cover of basalt

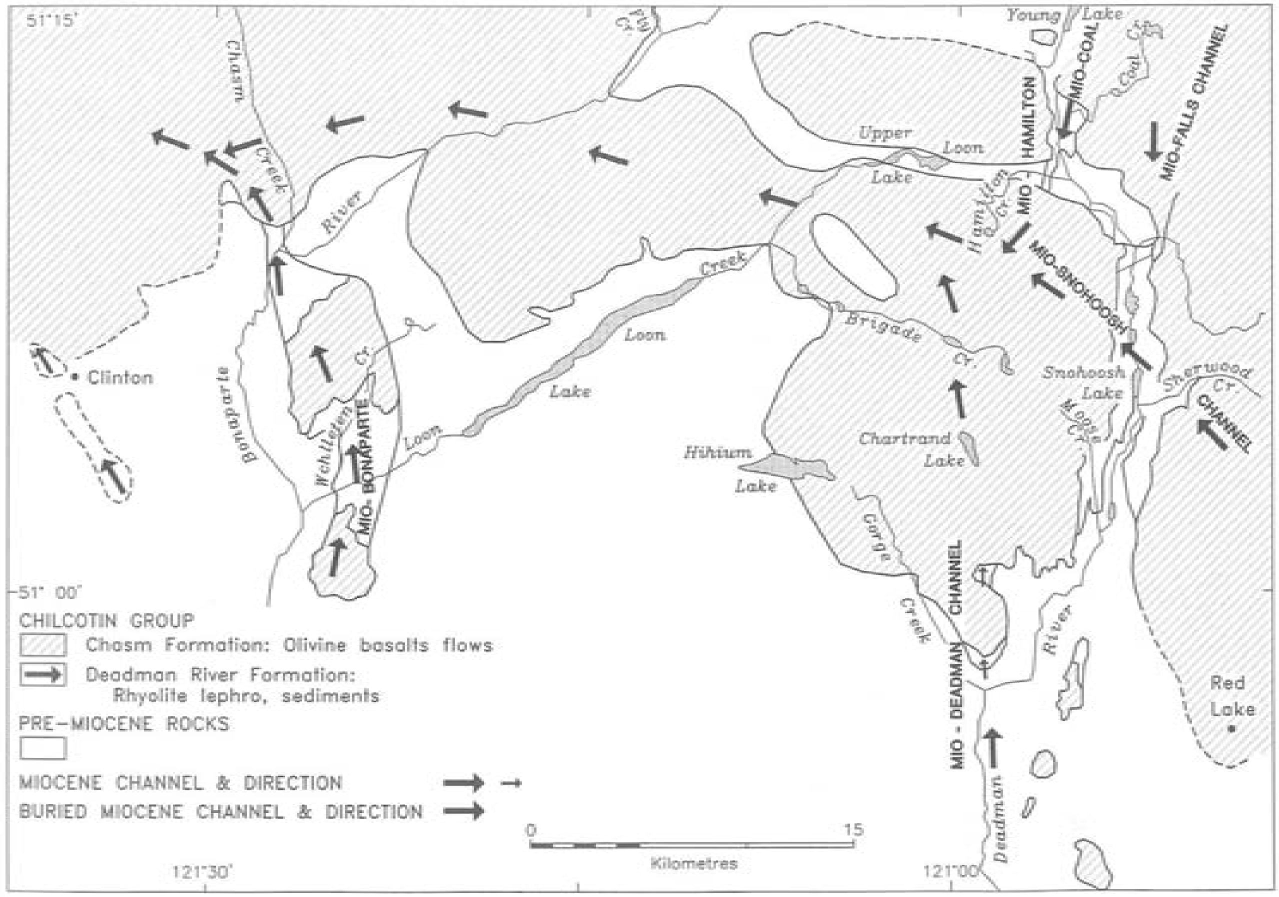

Figure 4.2. Simplified geological map showing the distribution and flow directions of Miocene drainage channels between Deadman and Bonaparte rivers.

flows between the heads of Hamilton and Brigade creeks, and from this confluence probably flowed westward. In the Deadman Valley floor between the north end of Snohoosh Lake and the south end of Vidette Lake, rhyolite tephra fills the northwesterly trending Mio-Snohoosh channel which is at least 3 kilometres wide and contains 300 metres of fill down to at least (825 metres (2700 feet) elevation. To the west, the distribution of the Chilcotin Group permits the Miocene drainage system to flow westward. In Loon Creek, between Loon and Upper Loon lakes, the base of the basalt flows is less than 930 metres (3050 feet) elevation, indicating, but not requiring the base of the channel fill to be at least 100 metres lower. Farther west in the Bonaparte Valley upstream from Chasm Creek, the base of the basalt flows is less than 725 metres (2375 feet) elevation. It is through these low spots on Loon Creek and Bonaparte River that the Miocene drainage probably flowed to the west and met the north-flowing Mio-Bonaparte channel now under a thick cover of basalt flows near The Chasm. Regional mapping by Campbell and Tipper (1971) showed that the elevation of the base of the Miocene increases east of the Deadman Valley which precludes an eastward drainage of any Miocene channel towards the North Thompson River.

STRUCTURE

The post-Eocene structure of the area involves some fault reactivation with minor displacement, and very open folding. Mesozoic deformation involved folding, faulting and refolding of the Cache Creek Group prior to the deposition of Eocene rocks (west end of Section A-A', OF 1988-30). The Bonaparte fault immediately underlies the western edge of the Kamloops Group. In the Cache Creek Group the fault zone is sheared, slickensided and marked by lenses of serpentinite. This severity of deformation is absent in the Eocene rocks, and in view of the probable eastward dip of the unconformity, a post-Eocene fault is unnecessary. The north-northwesterly striking Deadman River fault lies near the eastern margin of the Eocene rocks. Near the confluence of Deadman River and Criss Creek, the sub-Eocene unconformity has an apparent right-lateral movement of 3 kilometres. The suggested motion relies on a subparallel fault with slickensides plunging 19° northerly which cuts Eocene rocks 400 metres away in Gorge Creek.

The stratigraphic boundaries, and attitudes of crude bedding and flow layering, indicate that the Eocene rocks occupy a very open, upright syncline between the Bonaparte and Deadman River faults.

Miocene faulting is probably absent within the map area. Within extensive outcrops, several kilometres in The Chasm, flows do not deviate from horizontal, and faults are absent The basal surface of deposition of the Miocene differs from that described by Mathews (1989, p.977) as near-horizontal over long stretches of river-cut valleys which indicates the prior existence of extensive near-horizontal erosion surfaces with low relief (less than 100 m), probably developed close to a common base level. In the Arrowstone Hills, the Miocene topography was similar to the present topography in which a sharply and deeply incised drainage system dissects a rolling upland surface with valleys up to 500 metres deep and 4 kilometres wide. To distinguish a sub-Miocene unconformity that later has been tectonically disturbed from a sub-Miocene unconformity with a rugged Miocene paleotopography will be difficult. Making the distinction would resolve whether or not there has been Late to post-Miocene deformation. About 20 kilometres east of the map area, Mathews (1989) favoured post-lava doming to explain the distribution of Miocene lavas in the Porcupine Hills. In the study area, the delineation of a rugged Miocene paleotopography suggests that the distribution of Miocene lavas in the Porcupine Hills may result from a rugged paleotopography, not deformation.

CHAPTER 5 UPPER HAT CREEK VALLEY

INTRODUCTION

Although the Hat Creek valley (92I/12, 13, 14) is the most poorly exposed area of Tertiary sediments in southern British Columbia, its stratigraphy and structure are well known because of of more than 50 000 metres of diamond drilling, 7500 metres of rotary drilling, 173 test pits, and detailed magnetometer and gravity surveys. These data are contained in numerous private reports by Golder Associates and B.C. Hydro.

A significant thickness of coal-bearing Tertiary strata in the upper Hat Creek valley has been known for over a century (Dawson, 1879a, 1896). MacKay (1926) was the first to detail the unusually thick coal seams penetrated by drilling. These data were incorporated in the regional mapping of Duffell and McTaggart (1952), and Monger and McMillan (1984). In 1974, B.C. Hydro started extensive drilling, test pitting and geophysical investigations of the coal resources to support the establishment of a thermal power plant. Church (1977) presented the first detailed geological map of the area, and determined the structure and stratigraphy based on surface observations and drilling results to the end of 1975. B.C. Hydro's investigations ended in 1982, and this report results from a remapping of surface exposures, augmented by all drilling, test pitting and geophysical data, and the incorporation of 167 palynology determinations, of which 36 are new, into the proposed stratigraphy and structure (OF 1990-23).

At Hat Creek, Cretaceous sediments and Tertiary stratified rocks unconformably overlie a basement composed of upper Paleozoic and Triassic Cache Creek Group and Lower Cretaceous volcanics of the Spences Bridge Group that form the slopes of upper Hat Creek valley. Over 1600 metres of Eocene and(?) Oligocene sediments, up to a few hundred metres of Middle Eocene volcanics, and as many as 400 metres of mid-Cretaceous sediments subcrop beneath 100 metres or less of overburden that mantles most of the valley floor. These rocks form two northerly trending synclines separated by a locally faulted anticline. Northerly oriented strike-slip faults with minor dip-slip components have offset the folds by as much as 5000 metres. The Cretaceous and Tertiary rocks, including Miocene basalt flows, compose bedrock slide blocks of Quaternary age that are up to 4000 metres long. They have moved as much as 2500 metres from either valley wall towards the present valley axis.

STRATIFIED ROCKS

Basement to the Cretaceous sediments and Tertiary stratified rocks is light grey to white limestone of the cliff-forming Marble Canyon Formation (PTRc). Grey phyllite and siliceous phyllite (PTRp), and greenstone (PTrv) of the Cache Creek Group underlie a subdued topography with little exposure. Porphyritic and amygdaloidal dacite, andesite and rare basalt flows (unit lKsBv) comprise the Spences Bridge Group that outcrops on the west and south sides of the valley. The younger stratified rocks unconformably overlie this basement.

SILVERQUICK FORMATION (luKsp, luKcg, and luKs)

Widely scattered exposures of buff-weathering, friable sandstone, grey siltstone and chert-rich pebble conglomerate form a 0.5 to 1.5-kilometre-wide zone of mid- Cretaceous rocks that extends 16 kilometres along the east side of the valley. The zone is widest near Ambusten Creek where it may contain more than a 400-metre thickness of sediments, but it pinches out and disappears 7 kilometres southward near Bedard Lake. The best exposures are at the north end of the zone where a section 700 metres long outcrops in the unnamed creek that drains Harry Lake. Elsewhere the unit forms a few low, rounded, rusty buff, friable sandstone and siltstone outcrops in gullies on the ridges between Hat and Ambusten to Cashmere creeks, and in the Trachyte Hills. On the west side of the valley, the unit only subcrops in a south-trending zone about 3.5 kilometres long which passes beside Finney Lake.

The few outcrops are fine to coarse arkosic sandstone and rounded chert±volcanic-pebble conglomerate. Although most of the exposures in the valley are buff weathering, outside the valley, minor red shale and siltstone horizons characterize the unit. Individual outcrops and local groups of outcrops can be subdivided into conglomerate±sandstone of unit luKcg, and sandstone-siltstone-shale of unit luKsp, but the outcrops are so few that these units cannot be projected beneath the extensive overburden and here only an undivided sedimentary unit luKs is recognized. Because the unit has so few exposures, the log from diamond-drillhole 78-869 illustrates the typical lithology of the unit (Figure 5.1). The hole intersected a minimum thickness of 200 metres of mixed sandstone, conglomerate, siltstone, shale and coaly zones, with neither the top nor bottom contacts exposed, and it shows that siltstone and shale form about a third of the unit.

The western area underlain by the unit is an erosional remnant on the western limb of the Hat Creek syncline, and the eastern area outlines the White Rock anticline and Bedard syncline.

On the east side of the valley, the unit assuredly lies unconformably on the Cache Creek Group, but as a result of no exposure on the west side of the valley, and no drillhole penetrating the basal contact, it has a less certain relationship to the Spences Bridge Group. The choice of a probable unconformable relationship to the Spences Bridge Group

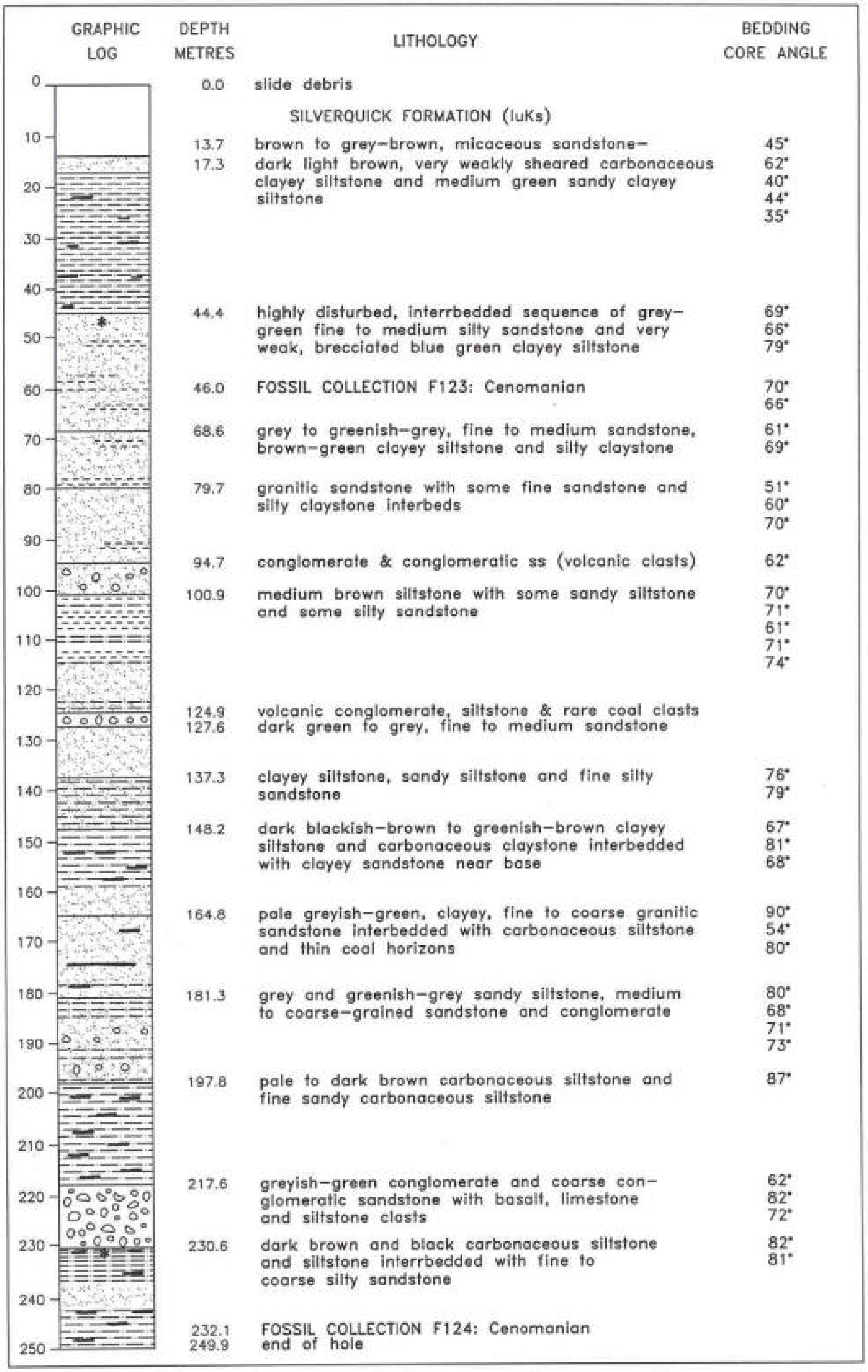

Figure 5.1. Log of vertical diamond-drill hole 78-869, Hat Creek (for graphic log symbols *see* Figure 2.3).

takes into account the Cenomanian age for parts of the unit in contrast to the Late Albian age of the Spences Bridge Group (Thorkelson and Rouse, 1989), and the fact that correlatives of this unit overlie the Nicola Group, with no intervening Spences Bridge Group, in the Deadman Valley (OF 1989-21), the Spences Bridge Group at Drynoch Slide (Monger and McMillan, 1989) and the Cache Creek Group in Pavilion Creek valley (Mortimer, 1987). Southward along Hat Creek valley, the sub-Eocene unconformity cuts stratigraphically downward and bevels off the mid-Cretaceous sediments which are then absent for 35 kilometres southward before they reappear overlying the volcanics of the Spences Bridge Group in a fault wedge near the head of Drynoch Slide (Monger and McMillan, 1989).

Eighteen palynological determinations (Table A.6, Appendix A) firmly establish the age of the unit as late Albian and Cenomanian with one collection ranging to possibly as young as Santonian. These ages indicate that the unit is synchronous with and younger than the nearby volcanic rocks of the Spences Bridge Group. The mid-Cretaceous sediments are contemporaneous with and lithologically similar to the Silverquick formation informally used by Garver (1989) 90 kilometres to the northwest in Tyaughton Creek on the west side of the Fraser River fault system. In Churn Creek 100 kilometres to the north-northwest and on the west side, Hickson et al. (1991a) correlated Late Albian to Cenomanian sediments with the Silverquick formation. Removal of approximately 100 kilometres of right-lateral strike-slip displacement across the Fraser River fault system brings the Churn Creek sediments to within 25 kilometres of the mid-Cretaceous sediments on the opposite side of the fault system in Upper Hat Creek valley.

Because the mid-Cretaceous sediments are so similar to those of the Eocene, they have commonly been included as part of the Eocene. Northeast of Hat Creek, Shannon's work (1982) indicated that a south-southeasterly trending fault-bounded zone of sediments ending in the Trachyte Hills is mid-Cretaceous and not Eocene as previously thought (Höy, 1975).

KAMLOOPS GROUP

At Hat Creek, Middle Eocene volcanic rocks and overlying Middle Eocene and younger sediments subcrop on the valley floor and parts of the lower valley walls for 22 kilometres along the north-trending portion of the valley. Here and there the walls expose the volcanics, but the sediments form only a dozen or so outcrops along the valley floor and most information on their distribution comes from extensive diamond and rotary drilling and test pitting. The Eocene succession consists of a volcanic-dominated sequence up to 300 metres in thickness overlain by more than 1600 metres of fluviatile and lucustrine sediments. It belongs to the Kamloops Group with the lower volcanic portion assigned to the Dewdrop Flats Formation and the upper sedimentary part to an unnamed formation.

DEWDROP FLATS FORMATION

Of all the Tertiary units, the Dewdrop Flats Formation is best exposed. It underlies a low ridge 15 kilometres in length along the east side of the valley, and a second one 5 kilometres long on the west side. The formation consists of rhyolite tephra of unit Evrx and locally flows of unit Evr above and below dacite and andesite flows (Evd) and breccias of unit Evdx along the east side of Hat Creek valley. With the exception of an uncertain outcrop of rhyolite tuff, only dacite and andesite extend to the west side of the valley between Houth Meadows and Anderson Creek.

RHYOLITE (UNITS Evr and Evrx)

Beneath the andesite and dacite, the rhyolite consists of flows (Evr) and tephra (Evrx). The thickest section of more than 50 metres of massive rhyolite flows outcrops in a gully on the southeast side of the Hat Creek valley adjacent to Hat Creek Indian Reservation No. 1. A few kilometres to the south, the flows lens out and rhyolite tephra continue and thicken southward to more than 100 metres in Medicine Creek. In the creek bottom, and along ridges and gullies to the north, are excellent exposures of white-weathering rhyolite lapilli tuff with an ash matrix. Dacite and andesite clasts are locally present, and here and there an increase in clast size produces breccia. Drilling near the creek has intersected lenses of white to buff tuffaceous siltstone and sandstone within the rhyolite tephra (Figure 5.2). Near the head of White Rock Creek, flow-layered rhyolite forms a cap 30 metres thick. To the south near Bedard Lake, tephra forms a lens of ash and lapilli tuff up to 60 metres thick.

Intercalated with and above the andesite and dacite, the rhyolite ranges from ash to breccia. It underlies a zone of very sparse outcrops extending southwards along the east side of the Hat Creek valley as far as White Rock Creek. The best outcrops, in a Quaternary slide block, expose rhyolite flows and bedded tephra within a few kilometres of White Rock Creek. Drill holes piercing the slide block pass through a maximum thickness of 100 metres of rhyolite.

Capping the Trachyte Hills northeast of Hat Creek valley, is a remnant of cream-weathering, aphyric to sparsely porphyritic (quartz and feldspar) rhyolite 150 metres thick. The massive rhyolite, which underlies an area over 2 kilometres in diameter, lacks flow layering even at its margins. It probably represents a partly eroded lava dome (Church, 1977) that marks the eruptive centre for the rhyolite preserved in the Hat Creek valley.

In thin section, rhyolite flows contain about 20% oligoclase (An20), biotite and sparse quartz phenocrysts set in a matrix of oligoclase and glass. Sanidine, anticipated from whole-rock analyses and descriptions published by Church (1977), is absent. X-ray diffractograms of the rhyolite tephra indicate that calcite and montmorillonite are ubiquitous alteration minerals, illite occurs locally, and zeolites are absent.

Radiometric dating of biotite phenocrysts in the rhyolite flows of the Quaternary slide block (Appendix B, Table B.6) yields a K-Ar age of 51.2 1.4 Ma (Church et al., 1979) which is consistent with three of the seven palynological

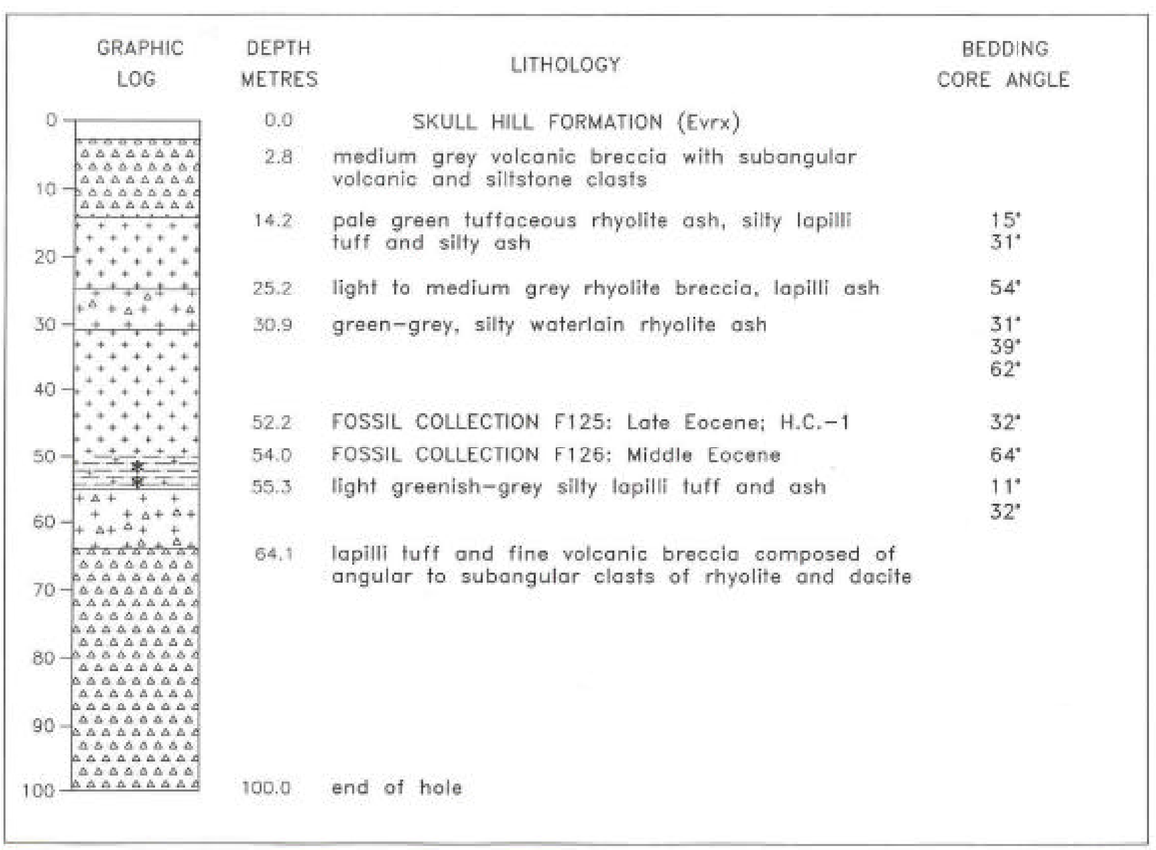

Figure 5.2. Log of vertical diamond-drill hole 77-830, Hat Creek (for graphic log symbols *see* Figure 2.3).

age determinations derived from waterlain tuffaceous sediments in the rhyolite tephra (Table 2, OF 1990-23). The extent to which contamination by drilling affects the palynologic age determinations, is unknown.

DACITE AND ANDESITE (Units Evd and Evdx)

On the east side of the valley, dacite and andesite flows (Evd) and breccias (Evdx) range from 200 to 300 metres in thickness and lie mostly within the rhyolite. They underlie a strip up to 600 metres wide which extends 10 kilometres from Hat Creek Indian Reservation No. 1 on the north to beyond Ambusten Creek on the south. Within this length, the flow-layered and platy-jointed flows diminish southwards with the incoming of breccia. To the south, near White Rock Creek, extensive breccia underlies flows in the Quaternary slide blocks. In the southern exposures west of Bedard Lake, flows form most of the 150-metre section. The best exposures of the flow-layered and platy jointed aphanitic flows are along an unmarked road that climbs the east valley escarpment about a kilometre north of Medicine Creek. The creek exposes a section of oxidized and unoxidized breccia and the southern terminus of an interfingering flow, and cliffs on the ridge west of Ambusten Creek show crudely bedded debris flows.

On the west side of the valley, two thick lenses of andesite and dacite form the lowest Eocene unit from Houth Meadows 6 kilometres southwards to Anderson Creek. Exposures, particularly those south of Finney Lake, indicate a minimum thickness of 300 metres of crudely layered breccia. Some drill holes indicate up to a 50-metre thickness of flows, but none outcrops.

The volcanic rocks range in colour from shades of grey to red, are mainly aphyric, and locally some of the flows are vesicular or amygdaloidal. Porphyritic variants are sparsely so with up to 15% of mainly labradorite (An54-62), some augite, and rare hypersthene phenocrysts. The more common aphyric flows and breccias consist of mostly trachytic andesine (An42-48) microlaths, some slender augite and rare hypersthene prisms all set in an altered glassy matrix. Amygdules are filled with saponite, quartz, chalcedony, calcite and probably heulandite. A few have thin coatings of opaline silica. Whole-rock analyses by Church (1977) indicate that andesite and dacite flows are present, but these dominantly aphyric rocks are indistinguishable in the field.

A K-Ar whole-rock date from dacite flows in the northeast corner of the Hat Creek valley yields a mid-Eocene age of 44.7±1.8 Ma (Church *et al.*, 1979) (Appendix B, Table B.6). On the west side of the valley, palynological age determinations from immediately adjacent sediments support the mid-Eocene radiometric age. In drillholes 74-47 (F127; Figure 5.3) and 78-849 (F4), 2 and 3 metres respectively above the andesite and dacite breccia, the sediments are Middle Eocene (Appendix A, Table A.6).

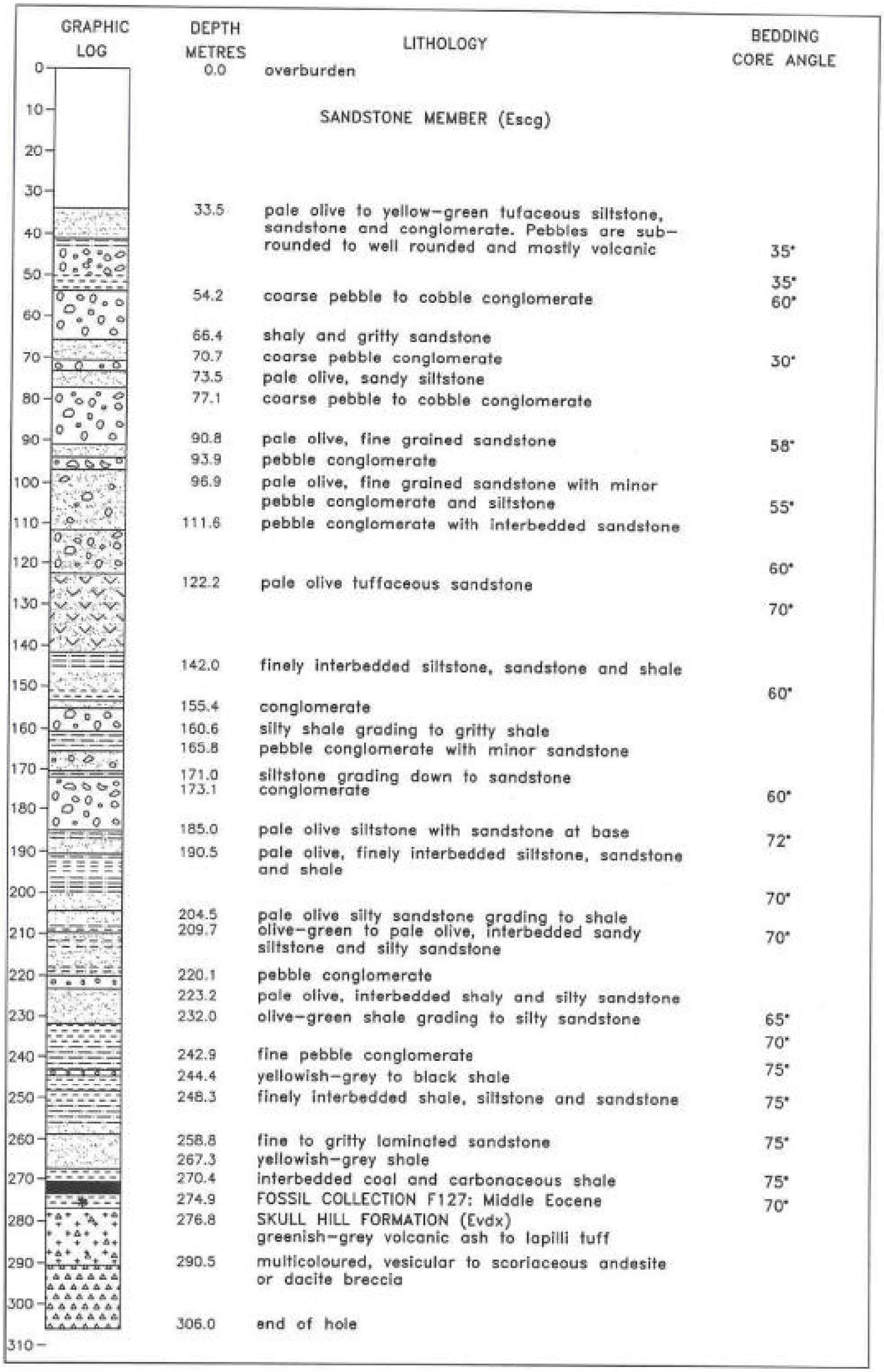

Figure 5.3. Log of vertical diamond-drill hole 74-47, Hat Creek (for graphic log symbols *see* Figure 2.3).

In the northeast and east parts of the area, Middle Eocene volcanic rocks lie with slight unconformity on mid-Cretaceous sediments which wedge out southwards at the south end of the Bedard syncline. On the west side of the valley, they overlie mid-Cretaceous sediments to within a few kilometres south of Finney Lake where they sit directly on the Spences Bridge Group. Nearby, Middle Eocene sediments rest on Middle Eocene volcanic rocks on an erosional surface which north of Finney Lake completely truncates the Middle Eocene volcanic rocks. These relationships differ significantly from those reported by Church (1977) who thought that the Middle Eocene volcanic rocks overlie the Eocene sediments. His conclusions were based on volcanic-over-sediment relationships across the base of the Quaternary slide block at White Rock Creek, and 10 kilometres north of the map area where Eocene volcanic rocks overlie sediments which were then thought to be Eocene but are now known to be mid-Cretaceous.

UNNAMED FORMATION OF MIDDLE TO UPPER EOCENE AND(?) YOUNGER SEDIMENTS

The Eocene and(?) Lower Oligocene sediments overlying the Dewdrop Flats Formation form three distinct members: a lower sandstone-conglomerate-siltstone sequence informally named the sandstone member; coal-bearing and intervening strata of the middle Hat Creek Member; and an upper massive siltstone and claystone of the informally named claystone member. Because there are less than a dozen exposures of these sediments, most of the information on lithology and distribution comes from examination of drill core.

SANDSTONE MEMBER (Escg)

The sandstone member lies only west of the Finney fault where it is exposed in four small roadcuts along the western side of the valley. Only drill core (Figure 5.3) shows that the member consists of mainly quartz-feldspar-rich sandstone, locally micaceous, and granitic and volcanic pebble to cobble conglomerate, with lesser amounts of siltstone, shale and carbonaceous layers with an aggregate thickness of approximately 400 metres. The member has a basal limestone breccia where it overlies the Marble Canyon Formation at the north end of the valley. Along most of the west side of the valley, it overlies the Spences Bridge Group, but west of Aleece Lake it lies on mid-Cretaceous sediments, and north and south of the lake it rests on the Dewdrop Flats Formation. Where the underlying rock unit is volcanic, the base of the member is set at the first appearance of clastic sediments (Figure 5.3), but where the member overlies the mid-Cretaceous sediments, the rock units are so alike that they cannot be distinguished on lithologic criteria. The variety of underlying units implies that there is an unconformity at the base of the sandstone member. About half of the 34 palynological collections from this member contain distinctive palynomorphs typical of the Middle Eocene of British Columbia. The remainder do not and these collections may be of early Late Eocene age (Appendix A, Table A.6).

HAT CREEK MEMBER (EHc)

The Hat Creek Member is exposed in four outcrops along and adjacent to Hat Creek, of which the best is in a large trench between Aleece Lake and the creek. Extensive drilling shows that the member subcrops in the core of the White Rock anticline immediately west of the Hat Creek fault where it forms the No. 2 coal deposit, and immediately west of the north end of the Finney fault where it outlines the faulted Hat Creek and Bedard synclines in the No. 1 coal deposit. The member contains up to four coal seams, each ranging in thickness from 60 to 180 metres, and thin intervening bentonitic and kaolinitic shale, siltstone, sandstone and conglomerate sequences which total an aggregate thickness of 550 metres. The four coal seams are designated as Zone A at the top to Zone D at the base and these together with the intervening and bounding rocks are included in the section cut by diamond-drill hole 74-44 (Figure 5.4). At the large trench, the member has been baked by pyrometamorphism (Church et al., 1979), caused by the bearing of nearby coal seams and the regional lignite to sub-lignite rank of the coal has been raised to sub-bituminous. The base of the member is set at the bottom of the lowest, thick coal-bearing sequence, and the top of the member at the top of the highest substantial coal-bearing zone. The 82 palynological collections from this member yield a provisional age range of Late Eocene and(?) Early Oligocene (Appendix A, Table A.6). They also indicate that the coal seams belong to distinctive palynozones and do not result from the tectonic stacking of a lesser number of seams. The occurrences of palynozones 6 and 7 in both the Hat Creek and sandstone members, and palynozones 1 and 2 in the Hat Creek and claystone members show that the three members are conformable.

CLAYSTONE MEMBER (Ep)

The better of the two exposures of the claystone member is a slumped roadcut 1.5 kilometres west of the hamlet of Upper Hat Creek. Drilling indicates that the member subcrops west of the Finney fault in the core of the south-plunging Hat Creek syncline, and to the east in the fault block bounded by the Hat Creek fault. The member consists of more than 600 metres of massive bentonitic claystone and siltstone, and the log of diamond-drill hole 74-44 shows the monotonous lithology characteristic of the member. The base of the member is set at the first appearance of carbonaceous shale or coal (Figure 5.4). The 26 palynological collections made from this member yield a provisional age range of Late Eocene and(?) Early Oligocene (Table 2, OF 1990-23).

CHILCOTIN GROUP (Mvb)

Two remnants of horizontal olivine basalt flows (Mvb) lie between 1355 and 1435 metres (4450 and 4700 feet) elevation in the Trachyte Hills at the northeastern corner of the map area. An uncertain outcrop is at 1495 metres (4900 feet) elevation southwest of the hamlet of Upper Hat Creek. All other occurrences of olivine basalt flows in the valley are probably transported either by glaciers or as Quaternary slide blocks. One such occurrence contains the younger and more reliable of the two whole-rock K-Ar ages of 14.5 ±0.5

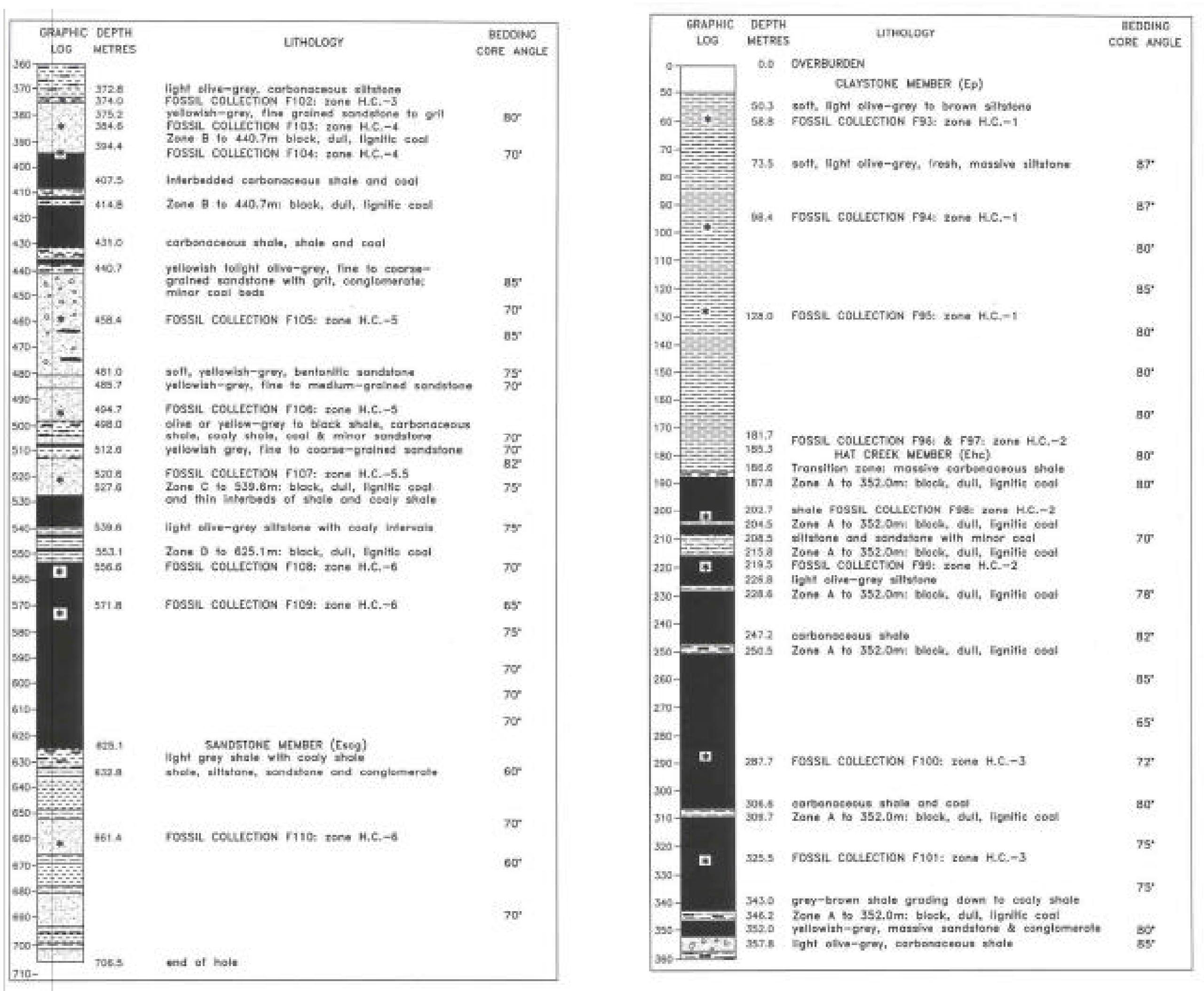

Figure 5.4. Log of diamond-drill hole 74-44 (-60° @ 2700), Hat Creek (for graphic log symbols *see* Figure 2.3).

Ma (Church, 1977) determined for this unit (Appendix B, Table B.6

STRUCTURE

In the map area, post-Eocene folding formed the northerly trending Bedard and Hat Creek synclines and intervening White Rock anticline. P. McCullough, H. Kim and K. Penner of B.C. Hydro determined this structural configuration during the drilling of the No. 1 deposit. In general, the folds are upright and open in the competent Marble Canyon Formation, but tighten and overturn to the west as they pass into the incompetent Tertiary sediments. At the south end of the Bedard syncline, the top of the massive Marble Canyon Formation outlines a northerly plunging, upright and open fold, but north of the Finney fault, in the claystone member, the same fold plunges southerly, and is tight and overturned to the west. The White Rock anticline is upright and open at its south end in massive limestone. Northward, between the Hat Creek and Finney faults, it becomes upright and closed. North of the Finney fault, the steep easterly dipping Ambusten Creek reverse fault replaces the anticline. Little is known of the southerly plunging Hat Creek syncline south of the No. 1 deposit. East of the Finney fault, the position of the axial surface is based on the rise to the west of the base of the claystone member from 932 metres (3057′) in hole 75-76 and to 1014 metres (3326 feet) in hole 75-59. The southern extension of the fold west of the Finney fault is weakly constrained by sparse outcrop and a few bedding attitudes.

Two important strike-slip faults, Finney and Hat Creek, cut the folds and form a crescent-shaped fault sliver that is 23 kilometres long. Displacement of the steeply dipping axial surfaces of the folds, particularly the White Rock anticline, across the Hat Creek fault yields a left-lateral displacement of 9 kilometres, and across the Finney fault a right-lateral displacement of 4 kilometres. Because the position of the axial trace of the Bedard syncline to the west of the two faults lies on the northward projection of its trace from east of the faults, the two faults form a fault wedge that moved relatively southward. Based on drilling data, the two faults dip moderately to steeply westward in the north, but to the south Finney fault probably passes through vertical and dips steeply to the east near diamond-drill hole 75-72. The widespread appearance of the claystone member subcropping in the intervening fault wedge indicates that the wedge has dropped as much as a kilometre, and that the Hat Creek fault has a normal component and the Finney fault a reverse component in the north and normal component in the south. The Ambusten Creek fault dips steeply eastward and its offset of the base of the Hat Creek Member indicates that it is a reverse fault with a dip-slip component of a few hundred metres. Drilling of the No. 1 deposit has penetrated many other faults with displacements in the order of a few hundred metres. At the north end of the map area, the 2.5 kilometre-offset of Finney fault on the Hat

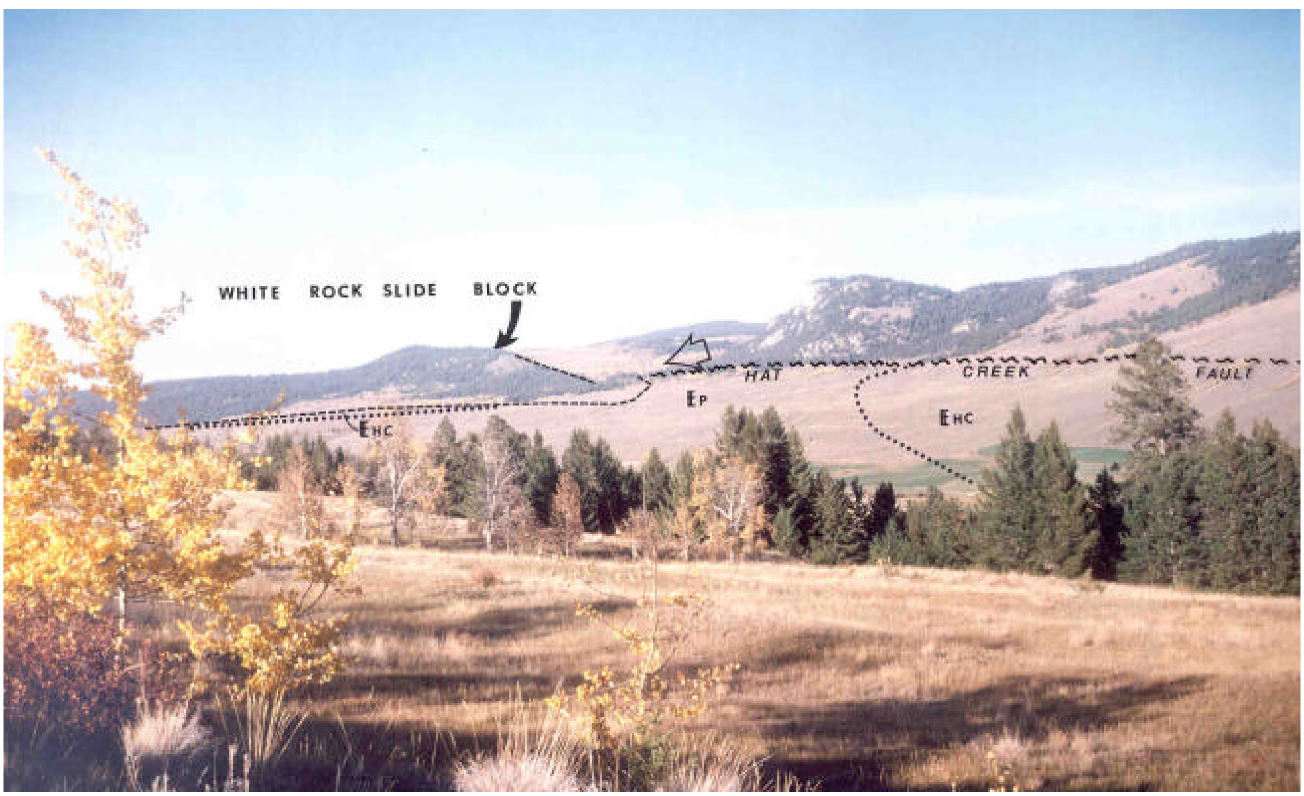

Photo 5.1. A view northward along Upper Hat Creek valley to White Rock slide block, composed of Middle Eocene volcanics which slid westward along bentonitic horizons in the folded and structurally underlying sediments of the Hat Creek and claystone members.

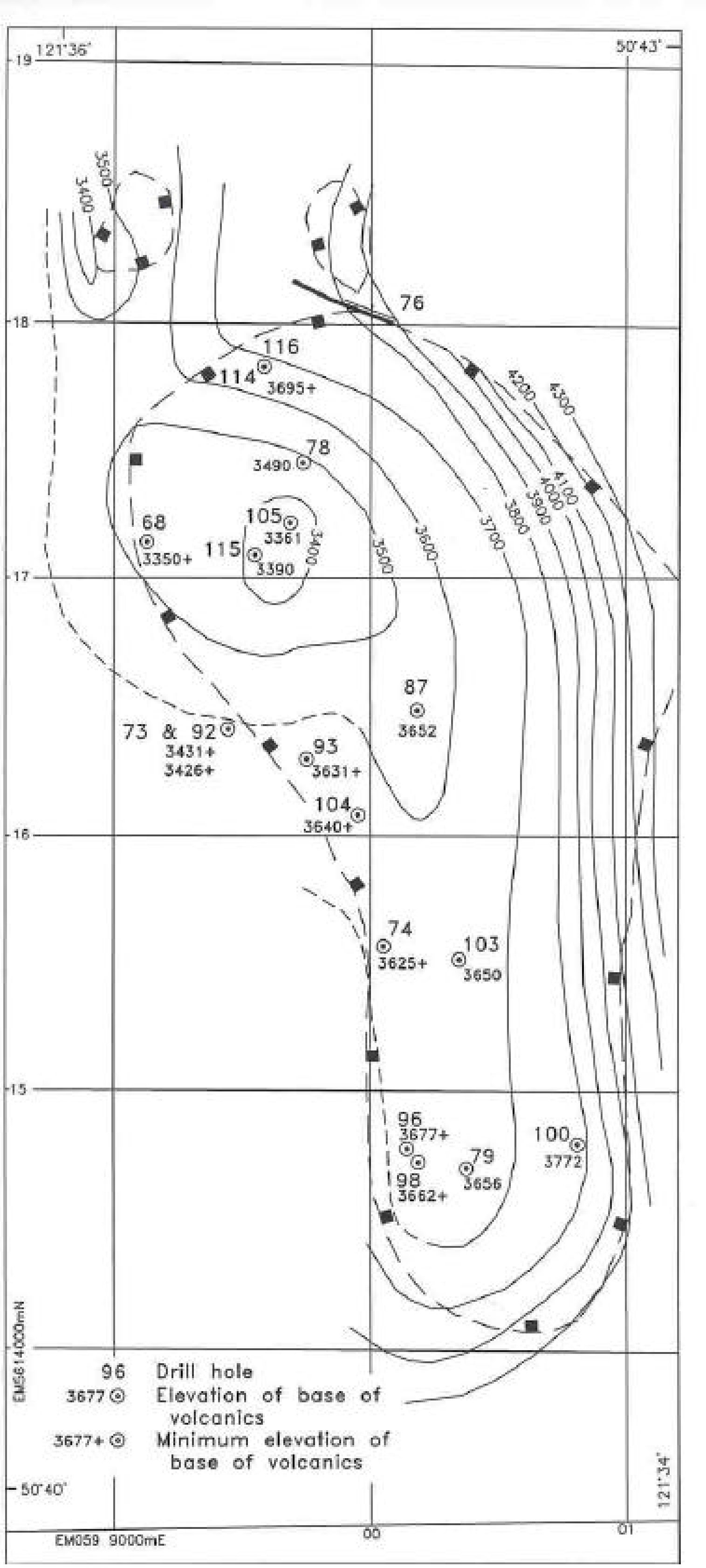

Figure 5.5. A structural contour map of the base of White Rock slide block showing the elevations (in feet) of the drill-hole piercing points.

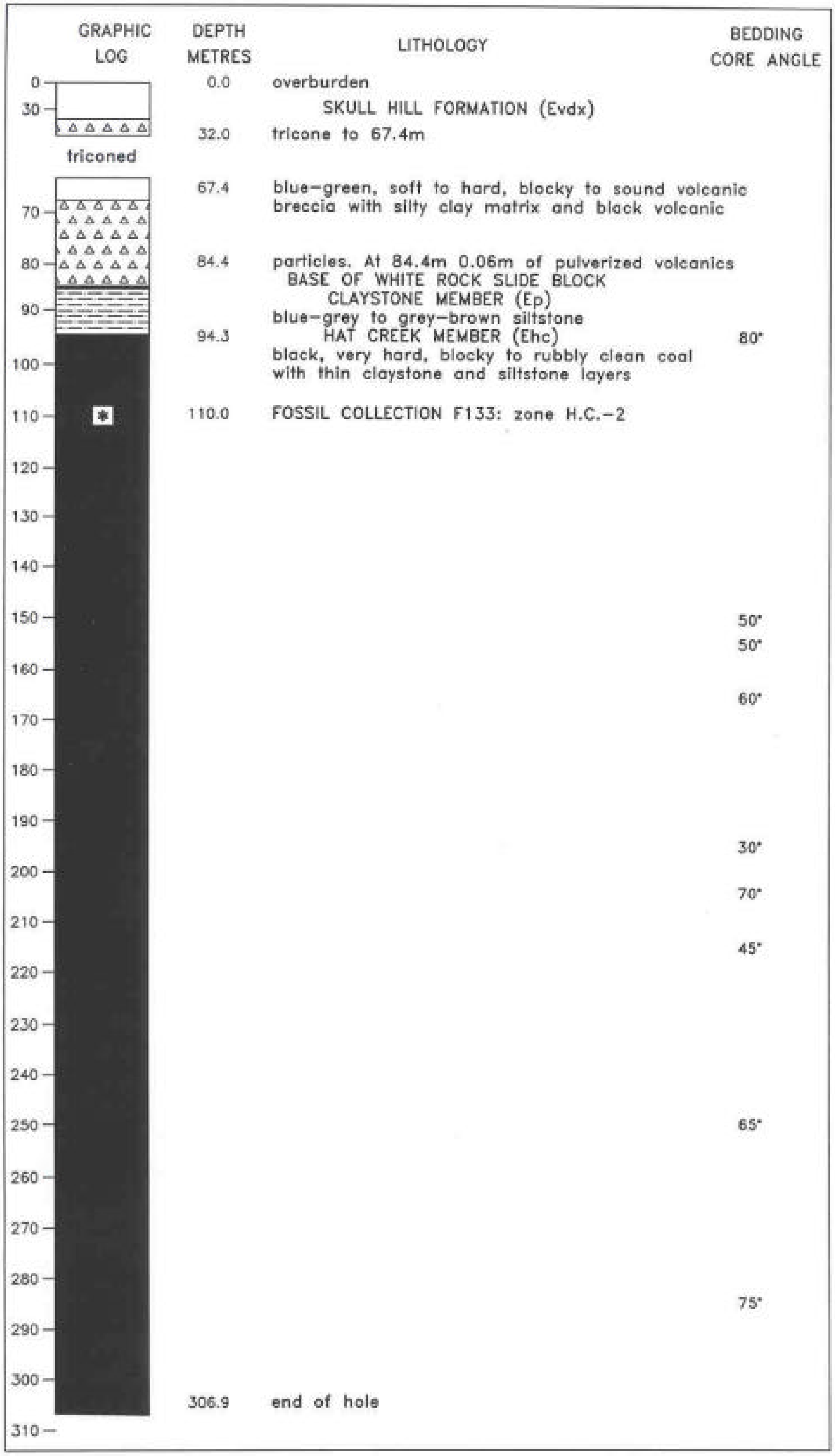

Figure 5.6. Log of vertical diamond-drill hole 76-115, Hat Creek (for graphic log symbols *see* Figure 2.3).

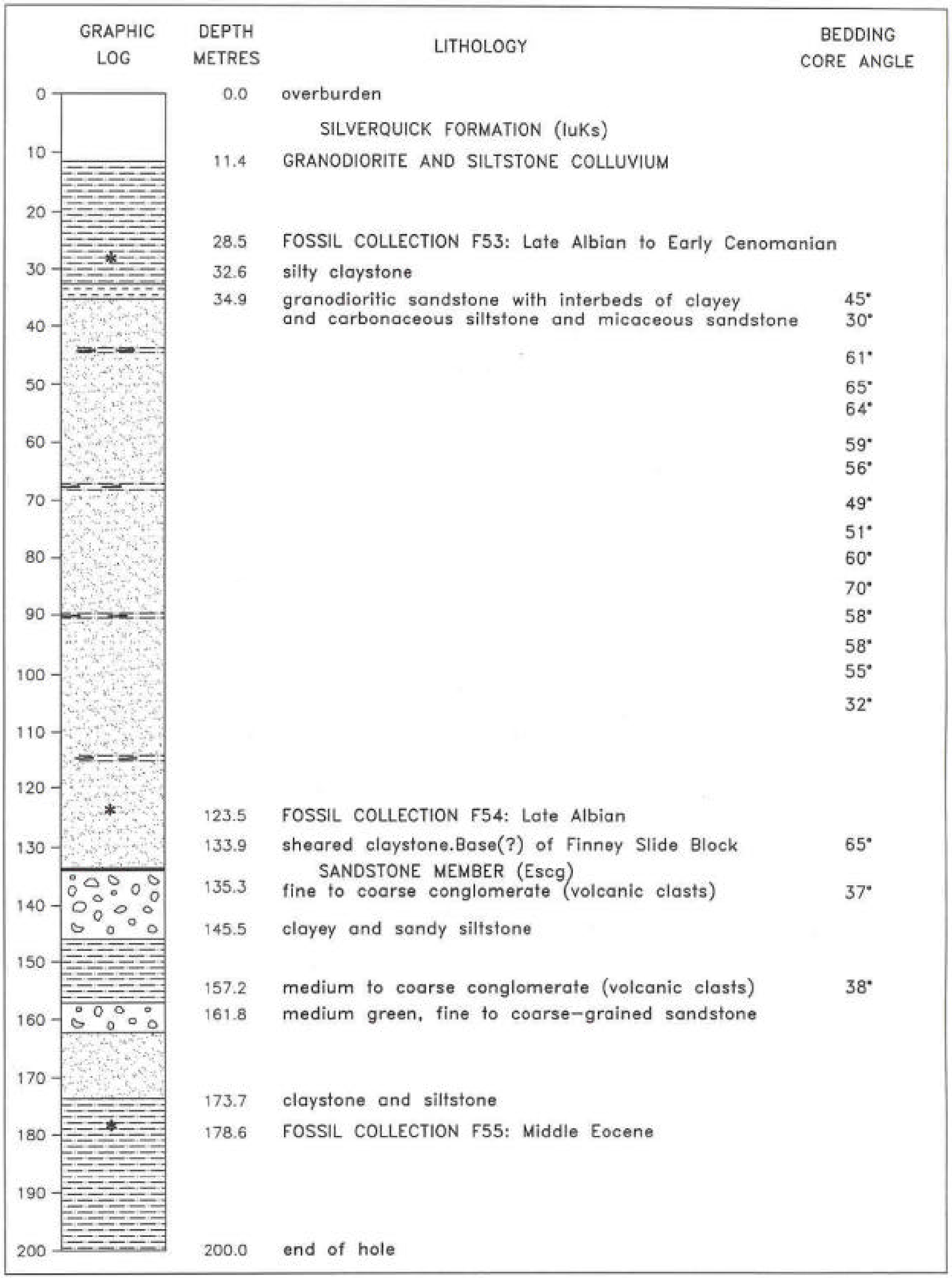

Figure 5.7. Log of vertical diamond-drill hole 78-868, Hat Creek (for graphic log symbols *see* Figure 2.3.).

Creek fault is conjectural, but is necessitated by the northward continuation of the Dewdrop Flats Formation east of the Hat Creek fault. The offset fault pattern implies that some of the movement on the Hat Creek fault is after completion of the movement on the Finney fault.

The development of north-northwesterly oriented folds, probably during the Oligocene, preceded that of the northerly trending faults with dominantly a strike-slip component. At the No. 1 deposit, the distance between the axial surfaces of the Bedard and Hat Creek synclines is 600 metres, but 18 kilometres south it has increased to about 9 kilometres. The increase in the wavelength of the folds is primarily the result of noncylindrical folds propogating from a point near the northern edge of the map area but some may result from an increased east-west shortening toward the north. The north-northwesterly orientation of the folds and the southerly displacement of the fault wedge implies an east-west shortening in the order of 1.5 to 2 kilometres at the latitude of the No. 1 deposit, compared to zero shortening 18 kilometres farther south. A structural environment involving some east-west shortening conflicts with the northerly oriented graben suggested by Church (1977). The basis for Church's interpretation is: the northerly oriented faults are dip-slip tensional faults, and they are offset by conjugate shear faults striking northeasterly and northwesterly. Church used these three fault sets to orient a stress ellipse with a north-south maximum compressive stress axis. Recent drilling and mapping do not corroborate the detailed faults and fault sets that are the basin for the graben model proposed by Church, 1977.

The preservation of a northerly oriented belt of Eocene and(?) younger volcanic and sedimentary rocks at Hat Creek results from the folding and faulting of a more extensive sheet. The overall fold is a northerly trending syncline which preserves mid-Cretaceous and younger rocks west of the Finney fault and east of the Hat Creek fault. Depression of the intervening fault block protected the remainder of the Eocene and(?) younger rocks. The Eocene and(?) younger sedimentary units do not thin toward the edges of their areas of outcrop and subcrop which implies that the deposition of these units was not controlled by, or restricted to, a local graben. The thinning of the mid-Cretaceous sediments away from the centre of the map area probably results from pre-Middle Eocene uplift and erosion.

BEDROCK SLIDE BLOCKS

Three major slide blocks, Finney, White Rock and Phil, consist of slices of bedrock up to 200 metres in thickness. Of the three, White Rock is the largest, best exposed and penetrated by the most drill holes (Photo 5.1). The slide block is 4000 metres long, up to 200 metres thick, and 13 drill holes define the shape of its base (Figure 5.5). Assuming that the three satellitic blocks were separated from the main slice by erosion, then the originally rectangular slide block measured at least 4800 metres by 2500 metres and covered 12 square kilometres. The rhyolite and dacite flows and tephra composing the slide block are unique to the east side of the valley at this latitude and indicate that the slide block moved about 2000 metres downhill from the east valley-wall. A few diamond-drill holes, such as 76-115 (Figure 5.6), penetrate a thin pulverized to thick rubbly zone of the Dewdrop Flats Formation intervening between the overlying radiometrically dated Middle Eocene flows of the slide block and the underlying palynologically dated claystone or Hat Creek members of Late Eocene and(?) Early Oligocene age. On the west side of the valley, the Finney slide block involves a bedrock slice of andesite and dacite breccia and underlying mid-Cretaceous sediments which measures about 3000 metres by 1500 metres. In diamond-drillholes 78-861 and 78-868, sufficient palynological determinations, collections F53 to F55 and F111 to F113 respectively, show that Middle Eocene volcanic rocks and dated mid-Cretaceous sediments overlie dated Middle Eocene sediments. Although the logs for these holes, such as diamond-drill hole 78-868 (Figure 5.7), do not record faults between the mid-Cretaceous sediments and lower Middle Eocene sediments, the bentonitic nature of the sediments probably camouflages the basal surface of the slide block. Farther south, the Phil slide block probably consists entirely of volcanic rocks of the Spences Bridge Group. Its shape, 2000-metre length and 1000-metre width are based on a single exposure, and the size and shape of a spatially associated ground magnetometer anomaly (B.C. Hydro, 1980, Photo 10).

CHAPTER 6 GEOLOGY OF THE FRASER RIVER - LILLOOET TO GANG RANCH

INTRODUCTION

The northerly trending Fraser River (92I/11, 12; 92O/I, 8, 9; 92P/4) fault system and northwesterly striking Yalakom and subparallel faults slice the Eocene and older rocks into elongate fault blocks ranging to more than 50 kilometres in length (Figure 6.1). Previous geological investigations by Duffell and McTaggart (1952), Trettin (1961), Tipper (1978), Monger and McMillan (1984), and Mathews and Rouse (1984) have shown differing distributions of the Eocene rocks which are the subject of this investigation. Consequently, rocks shown as Eocene in any of the previous work were examined and assessed for industrial minerals. Significant areas of rocks previously mapped as Eocene are now re-assigned to the Lower Cretaceous Spences Bridge Group. One such area lies upstream from Lillooet along the Fraser River between the Slok Creek and Fraser faults to as far north as the Hungry Valley fault (Map 7). Because of the difficulty in distinguishing Eocene from Lower Cretaceous volcanics, four new radiometric dates augment those reported by Mathews and Rouse (1984) and, together with field criteria, form the basis for separating Eocene from Lower Cretaceous volcanic rocks. In the field, Lower Cretaceous volcanics are selectively amygdaloidal, complexly jointed and veined, in contrast with the typically vesicular, simply jointed and unveined Eocene rocks. The distinction between Eocene and Lower Cretaceous volcanic rocks is important because all the occurrences of industrial minerals are in Eocene rocks.

East of Lillooet, two major faults, the eastern Fraser fault and the western Hungry Valley - Slok Creek fault divide the rocks into eastern and western blocks separated by a middle wedge that widens northward. The eastern block and middle wedge have a similar stratigraphy in contrast with the western block which lacks Eocene rocks and Lower Cretaceous volcanics. South of Gang Ranch, Cretaceous and Eocene rocks exclusively outcrop in the middle wedge, whereas upper Paleozoic and lower Mesozoic rocks of the Cache Creek Group mainly form the eastern block. A description of the stratigraphy of the eastern block and middle wedge precedes that of the western block.

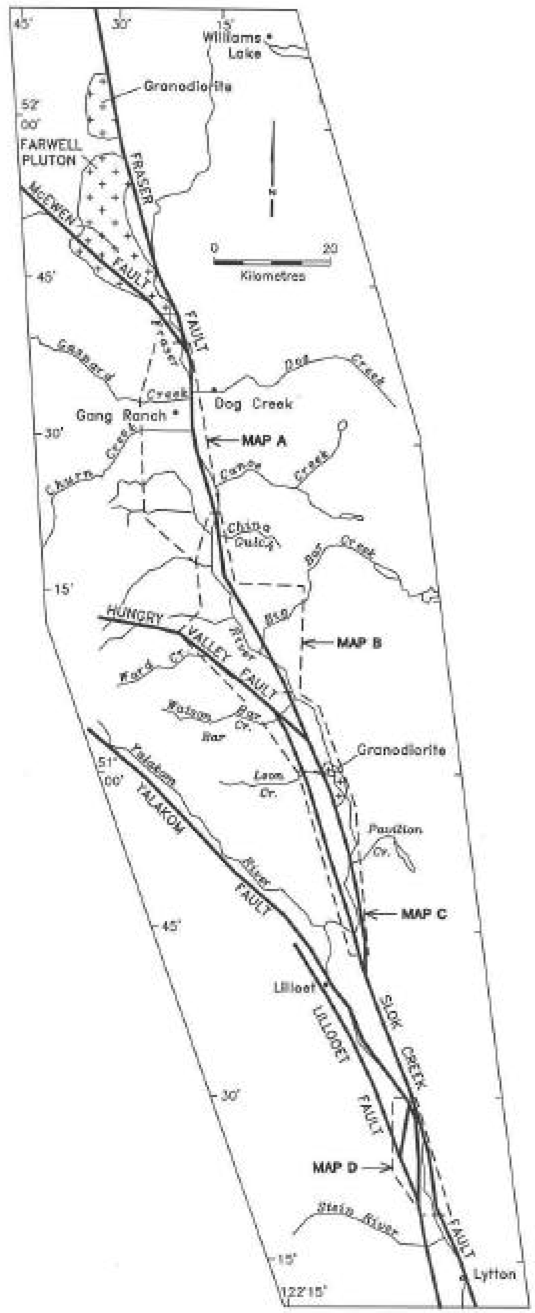

Figure 6.1. Regional map showing strands of the Fraser River fault sysem. Yalakom and subparallel faults, and the distribution of granodiorite plutons across the Fraser fault.

STRATIFIED ROCKS OF THE EASTERN AND MIDDLE BLOCKS

CACHE CREEK COMPLEX (UNITS PTtp PTv)

The Cache Creek Group (Monger and MacMillan, 1984) consists of eastern and western belts separated by the massive limestone of the Marble Canyon Formation which forms most of the central belt. In the map area, the western belt contains grey phyllite, varicoloured ribbon chert, siltstone, greywacke, and minor limestone and greenstone in a sediment-dominated subdivision (unit PTtp), and greenstone with minor chert and grey phyllite in a volcanic-dominated subdivision (unit PTv). The western belt corresponds to Trettin's (1961) Pavilion Group and the sedimentary and volcanic subdivisions to his Divisions I and II respectively. From a few kilometres north of the mouth of Fountain Creek to beyond the northern limit of mapping, the western belt of the Cache Creek Group forms the east wall of the Fraser fault (Map 7). On the west side of the fault, the southernmost outcrops of the western belt are in Word Creek, 105 kilometres northward along the fault trace from the southernmost exposures on the east side of the fault. Although Tipper (1978) separated the stratified rocks in Word Creek from the Cache Creek Group east of the Fraser fault, the presence of widespread ribbon chert favours their correlation with the western belt or the Bridge River Complex (Hickson *et al.*, 1991a). Of the three belts of the Cache Creek Group, the western belt is preferentially intruded by postkinematic plutons, of which Tiffin Creek stock (lJdi) is radiometrically dated as Late Jurassic, but the rest (gd) are undated.

SPENCES BRIDGE GROUP (UNITS lKsB and lKsBs)

Although grey to maroon, plagiphyric andesite and dacite(?) flows and breccia (unit lKsBv) represent the Spences Bridge Group within the map area, Trettin (1961) included the volcaniclastic sediments (unit lKsBs) lying east of the mouth of Fountain Creek and beyond the map area (Map 7). In the middle block near Glen Fraser, the Fraser River exposes an anticlinal core of argillite, sandstone and conglomerate beneath radiometrically dated volcanic rocks of the Spences Bridge Group. The sediments probably represent part of the faulted transition from the sediments of the Jackass Mountain Group to the west, which do not contain flows or volcanic breccias, and the contemporaneously deposited but volcanic-dominated Spences Bridge Group to the east.

On the east side of the Fraser fault, the northern exposure of the Spences Bridge Group lies a few kilometres north of the mouth of Fountain Creek, but on the west side of the fault, the Spences Bridge Group forms the western wall for another 30 kilometres northward to 6 kilometres southeast of Watson Bar Creek. At this point, the Fraser fault intersects the Hungry Valley fault, and north of the intersection, a few hundred metres or more of Eocene rocks intervene between the Fraser fault and rocks of the Spences Bridge Group such as opposite the mouth of Lone Cabin Creek.

Because previous workers have given conflicting correlations and age assignments to rocks in the middle block between the mouth of Fountain and Watson Bar creeks, four new radiometric age determinations (Appendix B) confirm the distribution of Eocene and Cretaceous rocks shown in Map 7. The new dating also indicates the reliability of the qualitative field criteria used to distinguish the rock units..

EOCENE VOLCANIC AND SEDIMENTARY ROCKS (UNITS Evd, Evdx, Evr, Eva, Evax, Etfs, Ecg and Ep)

The Eocene succession consists of more than 1500 metres of volcanic rocks which locally underlie 200 to 400 metres of conglomerate and other sediments. With the exception of a fault sliver east of the Fraser fault near the mouth of Pavilion Creek, all other Eocene rocks lie in the middle block. Although Mathews and Rouse (1984) correlated the Eocene rocks near and south of the Gang Ranch with the contemporaneous Kamloops Group, the rhyolite and dacite-rich composition of much of the succession differs from the common andesite and basalt composition of the volcanic rocks of the Kamloops Group in the type area.

East of the Fraser fault, Swiss-cheese weathering cliffs of aphanitic grey breccia, bentonitic brown andesite and white rhyolite lapilli tuff and minor flows comprise unit Evdx of dated Middle Eocene age. The rocks form a westerly dipping succession locally preserved east of its truncation along the Fraser fault.

West of the Fraser fault, the Eocene succession consists mainly of varicoloured aphanitic volcanics ranging from andesite to rhyolite flows, breccia and tuff and local tuffaceous sediments all underlying a sedimentary sequence consisting of a distinctive volcanic conglomerate (unit Ecg) and bentonitic siltstone and shale (unit Ep). The Eocene rocks form a gently east-dipping homocline that steepens to nearly vertical here and there next to the Fraser fault.

The largest volume of Eocene volcanic rocks is aphanitic andesite and dacite flows (unit Evd) accompanied by lesser quantities of grey, brown and maroon-weathering tephra (unit Evdx) which are locally waterlain and poorly bedded. They form a faulted remnant 200 metres thick and 5 kilometres long on the east bank of the Fraser River north of the mouth of Fountain Creek. Northward in the middle block, Eocene volcanics do not reappear again until the northeast side of the Hungry Valley fault as a result of the fault movement, only Eocene volcanics are exposed in the block. North of the fault, the lower part of French Bar Creek cuts through about 1000 metres of these flows that include some plagiphyric variants typical of Black Dome Mountain to the northwest. North of the fault, the flows usually have the platy jointing or flow layering which indicates that the Eocene volcanics form a gently east-dipping homocline truncated on the east by the Fraser fault.

Medium grey, chocolate-brown and maroon-red aphyric andesite and dacite tephra and thin flows of unit Evdx are intercalated with the rhyolite units and the tuffaceous sediments of unit Etfs. Because bentonitic ash is present in the tephra, the unit is characterized by steep, varicoloured slopes of low, crumbly outcrop usually splashed with a few lenses of white-weathering rhyolite.

Rhyolite units Evr, Eva and Evax are common throughout the volcanic succession only on the east side of the middle block where they are intercalated with grey, brown and maroon andesite and dacite breccia (unit Evdx). All of these rock units diminish westward at the expense of widespread grey aphanitic dacite and some andesite flows (unit Evd).

Of the felsic rock units, unit Evr is the most restricted. It forms a subhorizontal sheet of porphyritic (quartz, sanidine), columnar-jointed rhyolite, up to a few hundred metres in thickness, which underlies the ridge close to the four-wheel-drive road connecting Watson Bar and Ward creeks. The other occurrence is a subvertical felsite up to 800 metres thick and more than 4000 metres long which lies immediately east of the mouth of Fountain Creek between the Slok Creek and Fraser faults. Within a hundred metres of the northeast portal of the British Columbia Railway tunnel, some of the irregular joint surfaces in the pinkish felsite are coated with silky white, coalescent rosettes of dawsonite [NaAl(CO3)(OH)2] up to 3 millimetres in diameter (Photo 6.1). This first occurrence of dawsonite in British Columbia was verified by x-ray diffraction, optical properties and an SEM analysis. In the oil shale of the Green River Formation of the Piceance Creek basin in Colorado, dawsonite crystallized in voids from carbonate-rich solutions which circulated to depth after a period of intense evaporation (Smith and Milton, 1966). Similar climatic conditions may have existed during the Eocene in British Columbia (Rouse, 1977; Rouse and Mathews, 1988) and the nearby Fraser and Slok Creek faults would permit deep circulation of carbonate-rich waters. Because dawsonite accompanies oil shale in the Piceance Creek basin, it is considered an industrial mineral and is a potential source of acid-leachable alumina (Haas and Atwood, 1975); in British Columbia it is at present a mineralogical curosity.

Photo 6.1. Silky white coalescent rosettes of dawsonite formed along joints in felsite of unit Evr exposed immediately northeast of a tunnel on the British Columbia Railway east of the mouth of Fountain Creek.

Glassy and locally perlitic rhyolite flows (unit Eva) with sparse biotite, hornblende, augite and plagioclase phenocrysts form flow-layered sequences up to a few hundred metres thick and a few kilometres long between Watson Bar and Churn creeks (Photo 6.2). The rocks range in colour from pale green and flesh through grey to dark grey. Chemical analyses show them to be rhyolite with the perlite from the Frenier deposit restricted to some of the highly siliceous rhyolites (Tables 6.1 and 7.20, Figure 7.3). Spatially associated with the flows are white-weathering, locally bedded and zeolitized rhyolite tuffs and, here and there, breccia lenses of unit Evax. Although some of the rhyolite tephra lenses are immediately underneath the Eocene sediments in Churn Creek (Mathews and Rouse, 1984), others are at deeper levels.

The tuffaceous sediments of unit Etfs range from a lithic grit, sandstone or siltstone composed of varicoloured andesite and dacite detritus to an ashy white quartz sandstone derived from rhyolite (Photo 6.3). The sediments, particularly those rich in andesite and dacite detritus, are bentonitic and are hosts for some of the bentonite showings. Some of the volcanic-poor siltstones contain palynomorphs yielding an age determination of younger than mid-Paleocene (Appendix A), and organic debris with high vitrinite reflectance values of 1.07, 1.31 and 1.43 (Mathews and Rouse, 1984). The tuffaceous sediments form a northwest-trending lens truncated on the south by the Hungry Valley fault near Watson Bar Creek, and surrounded and probably overlain by Eocene volcanic rocks in all other directions. The tuffaceous sediments have a minimum thickness of 200 metres with the base not exposed. Attitudes of the sediments and surrounding volcanic rocks are consistent with the sediments occupying the core of a northeasterly overturned, northwesterly trending, doubly plunging anticline. The tuffaceous sediments underlie the thick conglomerate- bearing sedimentary succession at the top of the Eocene, but whether they lie at the base of, or within the Eocene volcanic succession, is unknown.

At the north end of the map area, north of Gang Ranch, porphyritic (hornblende±plagioclase±biotite) dacite flows of unit Evdm form most of the section (Hickson *et al.*,

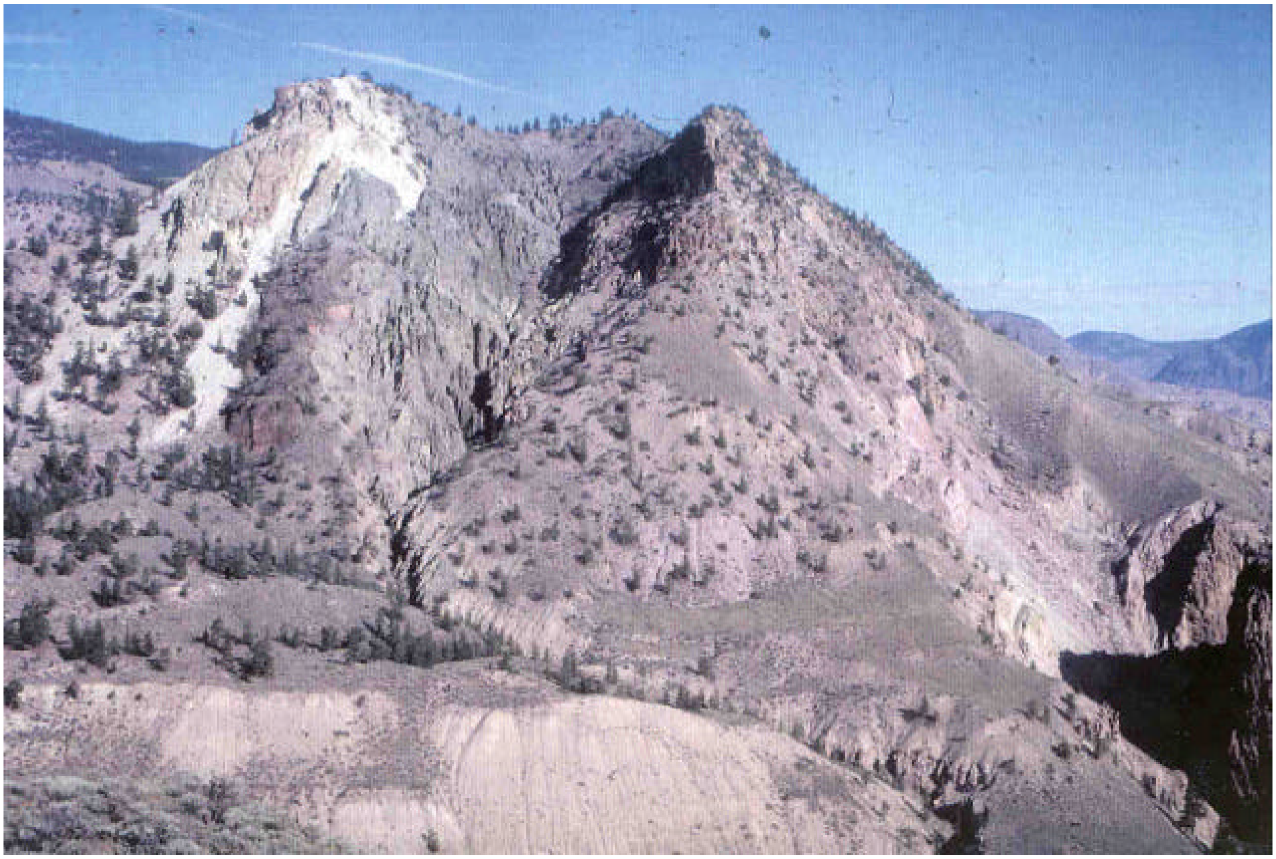

Photo 6.2. A view to the north side of the lower part of Watson Bar Creek exposing the subvertical Eocene volcanics of the middle block. From left to right there are white-weathering rhyolite flows and tephra of unit Eva on the lefthand ridge, grey tephra and thin intercalated flows of dacite and andesite of unit Evdx in the central valley to the skyline and porphyritic (feldspar, quartz, hornblende), glassy rhyolite flows of unit Eva exposed along the righthand ridge and foreground on the right.

1991a). Although these distinctive hornblende-porphyritic dacite flows and minor tephra extend south of Churn Creek (Mathews and Rouse, 1984), they apparently thin rapidly southwards and terminate in the middle of the thick volcanic succession.

For 45 kilometres northwestward from Big Bar Creek to Gaspard Creek, Eocene sediments form the western wall of the Fraser fault. The lowest sedimentary unit is a subangular to subrounded pebble to cobble conglomerate rich in volcanic clasts (Photo 6.4). The conglomerate and interbedded volcanic sandstone and grit are up to 250 metres thick. About 100 metres of bentonitic sandstone and siltstone overlying the conglomerate outcrop only in Crows Bar and Churn creeks.

STRATIFIED ROCKS OF THE WESTERN BLOCK

JACKASS MOUNTAIN GROUP

An undetermined but great thickness of interbedded greywacke, siltstone and conglomerate, that is rich in volcanic detritus, forms the Lower Cretaceous Jackass Mountain Group (lKJM) of the western block. Because the group is devoid of industrial minerals, it formed the western limit of mapping.

CHILCOTIN GROUP

The Chilcotin Group consists of fluviatile and locally lacustrine sediments and rhyolite tephra of the Fraser Bend Formation which underlies the widespread olivine basalt flows that characterize the Chilcotin Group (Photo 6.5). Erosional remnants of the group, up to 450 metres thick, lie scattered along the Fraser River for 85 kilometres from south of Leon Creek to the north end of the map area.

FRASER BEND FORMATION (UNIT MFBs)

Near Gang Ranch, mostly pebble and cobble conglomerate and interbedded grit and sandstone and minor rhyolite ash form a very poorly exposed channel filling beneath the basalt flows. The sediments are characteristically friable and ochre to rusty weathering. Near the base, the conglomerate clasts include many subrounded to rounded pebbles and cobbles of buff, pink, light grey or cream quartzite. In most places the sediments are only a few tens of metres thick, but on the west bank of the Fraser River between Word and Churn creeks, they thicken to 350 metres, and on

TABLE 6.1
CHEMICAL ANALYSES OF EOCENE VOLCANIC ROCKS: GANG RANCH TO WARD CREEK, BRITISH COLUMBIA

Rock Unit		**Unit Evd**				**Unit Evt**		
Sample #	**25-4**	**27-1**	**35-1**	**44-3**	**44-4**	**8-2**	**30-3**	**43-3**
SiO_2	68.09	67.18	61.75	70.61	68.56	64.50	63.07	64.25
TiO_2	1.01	0.44	0.61	0.33	0.40	0.52	0.68	0.66
Al_2O_3	14.23	15.82	11.90	15.33	15.74	16.03	15.51	16.20
Fe_2O_3 *	4.82	2.89	4.54	1.34	3.11	3.77	4.95	4.05
CaO	2.44	3.11	4.80	2.34	2.76	3.92	4.31	4.09
MnO	0.08	0.03	0.07	0.02	0.01	0.05	0.14	0.05
MgO	0.93	1.18	3.64	lt 0.35	lt 0.35	2.09	2.63	2.99
Na_2O	4.32	3.99	3.72	4.42	4.20	3.65	3.81	4.15
K_2O	3.52	3.37	2.53	3.21	3.53	3.53	2.80	2.76
P_2O_5	0.22	0.15	0.20	0.11	0.13	0.18	0.16	0.20
H_2O+105^o**	0.59	1.04	1.68	0.84	0.75	2.01	1.22	0.68
TOTALS	100.25	99.20	99.72	98.90	99.54	100.25	99.28	100.08

Rock Unit				**Unit Eva**				
Sample #	ST-1B	ST-3	ST-3	ST-6T	ST-6T	ST-7	ST-7	ST11/3
SiO_2	72.97	71.44	71.69	73.76	73.59	78.27	78.31	74.44
TiO_2	0.07	0.13	0.13	0.07	0.07	0.07	0.07	0.07
Al_2O_3	11.98	12.58	12.64	11.98	11.98	12.41	12.49	11.73
Fe_2O_3*	0.76	1.33	1.36	0.84	0.82	1.02	1.03	0.80
CaO	0.96	1.35	1.36	1.15	1.13	0.42	0.42	0.77
MnO	0.03	0.03	0.03	0.04	0.04	0.02	0.01	0.04
MgO	0.17	0.43	0.37	0.33	0.36	0.28	0.32	0.23
Na_2O	2.56	2.47	2.42	2.24	2.24	3.36	3.28	2.50
K_2O	4.84	4.06	4.05	4.36	4.35	4.93	4.94	5.01
P_2O_5	0.01	0.02	0.02	0.01	0.00	0.02	0.02	0.01
H_2O+105^o**	5.14	5.70	5.70	5.49	5.49	0.70	0.70	4.64
TOTALS	99.49	99.54	99.77	100.27	100.07	101.50	101.59	100.24

Rock Unit				**Unit Eva**			
Sample #	**18-9**	**37-11C**	**C529E**	**C530A**	**538I**	**C541**	**C541C**
Showing			**G3**	**G2**	**G1**	**G1**	**G1**
SiO_2	78.52	74.11	69.21	68.34	67.61	67.52	67.82
TiO_2	0.12	0.18	0.25	0.25	0.33	0.35	0.34
Al_2O_3	10.54	13.24	13.45	13.42	14.31	14.28	14.51
Fe_2O_3*	1.29	1.47	2.84	2.71	2.81	2.85	2.84
CaO	0.46	0.70	1.05	1.22	2.44	2.53	2.47
MnO	0.01	0.02	0.09	0.10	0.06	0.06	0.05
MgO	lt 0.35	lt 0.35	0.19	0.25	0.83	0.88	0.91
Na_2O	2.99	3.50	4.19	3.90	3.30	3.49	3.42
K_2O	4.39	5.18	3.66	3.62	3.41	3.26	3.27
P_2O_5	0.04	0.04	0.03	0.03	0.09	0.09	0.09
H_2O+105^o	0.95	0.94	4.88	5.59	3.76	4.74	4.05
TOTALS	99.66	99.73	99.84	99.43	98.94	100.04	99.77

** H_2O+105^o = combined water
* Total Fe given as Fe_2O_3
Sources of analyses: ST series, Trupia 1989; C series, this study; the remaining series, Green 1990.

Photo 6.3. A view westward up Ward Creek to gently north dipping, ashy white quartz sandstone, and grey bentonitic dacite-rich sediments and tephra of unit Etfs exposed at the North Ward Creek bentonite showing (centre of photograph).

Photo 6.4. A view to the east side of the Fraser River from the north side of French Bar Creek showing gently easterly dipping Eocene conglomerate and interbedded sandstone of unit Ecg faulted against bentonite-bearing sediments and tephra of unit Evdx which underlie most of the high terrace. The Fraser fault lies near the back edge of the terrace and truncates the Cache Creek Group. The French Bar bentonite showing (B8) lies at the head of a gully occupied by a block slide of conglomerate that descended 500 metres to the Fraser River.

the east bank opposite the mouth of Word Creek, the base descends to 520 metres (1700 feet) elevation (Hickson *et al.*, 1991a). North of Gang Ranch, rhyolite tephra and diatomaceous earth form part of the succession. Pebble imbrication measured in a roadcut of conglomerate 2 kilometres northeast of Empire Valley Ranch and in conglomerate outcrops north of the lower part of Gaspard Creek indicates deposition from a northerly flowing river (Green, 1990; Mathews and Rouse, 1984). Based on palynology from two fossil localities near Gang Ranch (Map 7), the fluviatile and rhyolite-tuff-bearing sediments are latest Early to Middle Miocene (Mathews and Rouse, 1984).

CHASM FORMATION (UNIT Mvb, Pvb and MPvb)

A series of erosional remnants of basalt flows veneer parts of the Fraser valley walls for 60 kilometres from south of Leon Creek to Grinder Creek. South of Leon Creek, a 20 square kilometre area of unfaulted olivine basalt flows, containing up to a 100-metre thickness of flows, spans the west, middle and east fault blocks. The base of the flows is

Photo 6.5. A view to cliffs of Plio-Pleistocene basalt flows of the Chilcotin Group on the east side of the Fraser River opposite Gang Ranch. In the left middleground, low cliffs expose fluviatile sediments of the underlying Fraser Bend Formation.

about 1250 metres (4125 feet) elevation. From Leon to Watson Bar creeks, three small erosional remnants lie along the west valley wall of the Fraser River between 1160 and 1280 metres (3800 and 4200 feet) elevation. The bases of five outliers along the lower part of Big Bar Creek range from 1040 to 1175 metres (3400 to 3850 feet) elevation. To the north, the base of the flows descends slightly to 1030 metres (3375 feet) in elevation for the remnant opposite the mouth of Lone Cabin Creek, and 975 metres (3200 feet) elevation (Green, 1989) for the outlier north of Grinder Creek along the Fraser River, . The elevation of the base of flows descends northward from 1250 metres (4125 feet) south of Leon Creek to 975 metres (3200 feet) at Grinder Creek. The regular northward decrease in elevation implies that the flow remnants may be part of a north-tilted, or more probably a northward-draining valley-fill of basalt flows.

Whole-rock radiometric dating of the basalt flows yields two age populations of which the older spans 10.0±0.3 to 11.2±0.4 Ma (Late Miocene) and the younger, 0.78±0.08 to 2.2±0.3 Ma (Late Pliocene to Pleistocene). Because olivine basalt flows of both ages are petrographically and chemically indistinguishable, the basalts are designated as unit Mvb where the rocks have a Miocene radiometric age, unit Pvb where the rocks have a Pleistocene or Late Pliocene age and unit MPvb where the rocks are undated. Within the map area, unit Mvb lies east of the Fraser River and unit Pvb along the Fraser River. Miocene flows reappear northwest of the map-area along the Chilcotin River a few tens of kilometres upstream from its confluence with the Fraser. Because both the Plio-Pleistocene and Miocene flows are indistinguishable in the field, and at the present level of geological mapping are physically continuous with the Late Miocene basalt flows of the Chasm Formation 50 kilometres to the east, the basalt flows of both ages have been correlated with the Chasm Formation.

As noted by Lay (1940, 1941), Tipper (1971), and Mathews and Rouse (1984), the Fraser River has occupied approximately the same course since at least Miocene time, but certainly has not retained the same direction of flow. Both Lay (1940, p.3) and Tipper (1968, p.5) suggested that the northward-flowing Fraser was captured by the Chilcotin River or a tributary that apparently worked headward from the present mouth of the Chilcotin River and intersected the northward drainage of the Fraser River. However, pebble imbrication in Fraser Bend sediments south of the present mouth of the Chilcotin River (Mathews and Rouse 1984, p.1143; Green 1990, p.26; Hickson *et al.*, 1991a, p.214) indicates that Miocene drainage south of the mouth of the Chilcotin River was northward, not southward as would be anticipated in the stream-capture hypothesis. The northward decrease in the elevation of the base of Plio-Pleistocene flow remnants implies that the northward drainage direction remained until after deposition of the youngest radiometrically dated flows at 0.78±0.08 Ma (Appendix B, Table).

FRASER RIVER FAULT SYSTEM: AGE AND MAGNITUDE OF DISPLACEMENT

Subhorizontal slickensides on the Fraser and Slok Creek faults indicate that the last movements were strike-slip. On the west, the Fraser fault truncates the zircon-dated mid-Permian (Friedman and van der Heyden, 1992; Read, 1993). Farwell Pluton near and north of the month of Chilcotin River and a lithologically similar, zircon-dated portion of Late Permian age (250±5 Ma) of the Mount Lytton Complex north of Lytton. Because of the lithologic similarity of the pluton and complex and the rarity of 250 to 260 Ma plutons in this part of the Cordillera, Friedman and van der Heyden, 1992) correlated the two plutons and measured a 135 to 160 kilometres dextral strike-slip displacement. On the west side of the fault, mid-Cretaceous sediments of the Silverquick Formation underlie the lower course of Churn Creek. On the east side of the fault, mid-Cretaceous chert pebble conglomerate and red clastics have been correlated by Monger and McMillan, 1989) to the Pasayaten Group. These fault slivers of sediment may also correlate to the 150 kilometre distant Silverquick Formation in Churn Creek.

Although the southern limit of Eocene rocks on both sides of Fraser fault shows little difference, post-Eocene strike-slip faulting, with a dip-slip component, in Upper Hat Creek along faults subparallel to the Fraser fault implies post-Eocene faulting along Fraser fault. In Upper Hat Creek, Hat Creek and Finney faults cut the folded Upper Eocene and(?) Lower Oligocene claystone and Hat Creek members with structures developed in a regime of transcurrent rather than tensional faulting.

Eocene rocks and Lower Cretaceous volcanics are absent west of the Slok Creek fault where the Lower Cretaceous strata are sediments of the Jackass Mountain Group. The distribution of rock units across the Slok Creek fault implies post-Eocene movement which is probably dextral strike-slip but is of unknown magnitude. The Slok Creek and Fraser faults join southeast of Lillooet. Because the rock unit distribution south of the junction is similar to that across the Slok Creek fault north of the junction, namely Jackass Mountain Group without Eocene rock units underlies the western block and Spences Bridge and other rock units comprised the eastern block, Slok Creek fault continues south of its junction with the Fraser fault.

CHAPTER 7 INDUSTRIAL MINERALS IN THE CENOZOIC ROCKS OF SOUTHERN BRITISH COLUMBIA

INTRODUCTION

This chapter focuses on the occurrences of industrial minerals in the Eocene and Miocene to Pleistocene rocks deposited in the Tertiary basins and river systems of British Columbia's southern interior west of the metamorphic core complexes (Figure 1.1). The areas of Eocene rocks are the Princeton, Sunday and Tulameen basins, also Merritt basin, Hat Creek basin, McAbee to Deadman River area, and along the Fraser River from Lillooet to the Chilcotin River. To assess the industrial mineral potential of Miocene to Pleistocene rocks, the sediments of the Miocene to Pleistocene drainage system were investigated in the area between the Bonaparte and Deadman rivers north of the Thompson River and in the Fraser River near Gang Ranch. The three main criteria used to select the areas south of latitude 52°N are:

- Presence of significant volumes of sediments in the volcanic-dominated stratigraphy of these ages.
- Proximity to major transportation routes.
- Presence of previously discovered occurrences of industrial minerals.

Although volcanics dominate the Eocene rocks of the Princeton and Kamloops groups and the Miocene to Pleistocene stratigraphy of the Chilcotin Group, most of the industrial mineral showings of zeolites, swelling and nonswelling clays, and diatomaceous earth occur within or adjacent to volcanogenic sediments of these ages. Only Eocene volcanics near the Fraser River contain a sufficient component of glassy rhyolite for occurrences of perlite and volcanic glass; elsewhere, Eocene volcanic rocks are typically more basic and these industrial minerals are absent.

Because industrial minerals present in Cenozoic rocks have low densities, typically in the range 2.2 to 2.7, their transportation to market is a major production cost. With the potential market concentrated in southern British Columbia, all the areas studied south of latitude 52°N are close to major highways or railroads.

In the areas of Eocene sediments, bentonite is widespread, zeolites are restricted to the Princeton, Sunday and Tulameen basins, near McAbee and along the Fraser River between Lillooet to Gang Ranch, and kaolinite is limited to the Hat Creek and Princeton basins. Perlite and volcanic glass are restricted to Eocene volcanic rocks west of the Fraser River. In the Miocene sediments beneath the basalt flows of the Chilcotin Group, waterlain rhyolite ash is widespread and thick, and diatomaceous earth is widespread but accessible only where the present drainage of the Deadman, Bonaparte and Fraser rivers and their tributaries has exposed the Miocene drainage channels.

Of the areas studied, the Eocene rocks of the Princeton basin include the thickest and most continuous zeolitized tephra units. These consistently contain the most clinoptilolite-rich composition of the heulandite-clinoptilolite solid solution series with the highest cation exchange capacity (CEC) (Table 7.2 and Figure 7.1). In fact, Marcille's (1989) cation exchange capacity measurements on samples from the Tailings RR showing (Z7, OF 1987-19) in the Princeton basin overlap the CECs of the PDZ-140 and PDZ-150 products of the Mud Hills operation near Barstow, California. Of the bentonites analyzed in southern British Columbia, those from the Split Rock showing (B2, OF 1988-30) in the Deadman River valley and from showings in the Ashnola shale in the Princeton basin contain the highest exchangeable monovalent cations (Tables 7.2 and 7.10). The values from these two areas lie within the range of bentonite from the Cheto deposit in Arizona, but are well outside the range of the sodium-bentonite from the Clay Spur deposit in Wyoming (Figure 7.1). The Princeton basin contains many showings of zeolites and bentonite and is well served by major transportation routes. Besides Princeton, Hat Creek has a bentonite potential, but in the other areas the lack of drilling and trenching curtails an assessment. Recently discovered and previously known occurrences of diatomaceous earth in the Miocene rocks near Clinton lie closer to major roads and a railway than the producer at Red Lake.

PRINCETON, SUNDAY AND TULAMEEN BASINS (92H/9 to 10)

All the industrial mineral occurrences of the Princeton, Sunday and Tulameen basins (Table 7.1) are in the Eocene sediments of the Allenby Formation (OF 1987-19). Only those sediments which have a significant intermediate to felsic ash component are suitable for the development of zeolite, bentonite and kaolinite concentrations. Prior to this investigation, the Princeton basin contained the only bedded zeolite deposit (showing Z4) known in southern British Columbia (Hora and Kwong, 1984), and among several bentonite occurrences (McMechan, 1983), the only bentonite deposit with production records (showing B6). As a result of this study, the Princeton and Tulameen basins are now known to contain the most widespread zeolite-bearing rocks in southern British Columbia, numerous bentonite occurrences and a kaolinite locality.

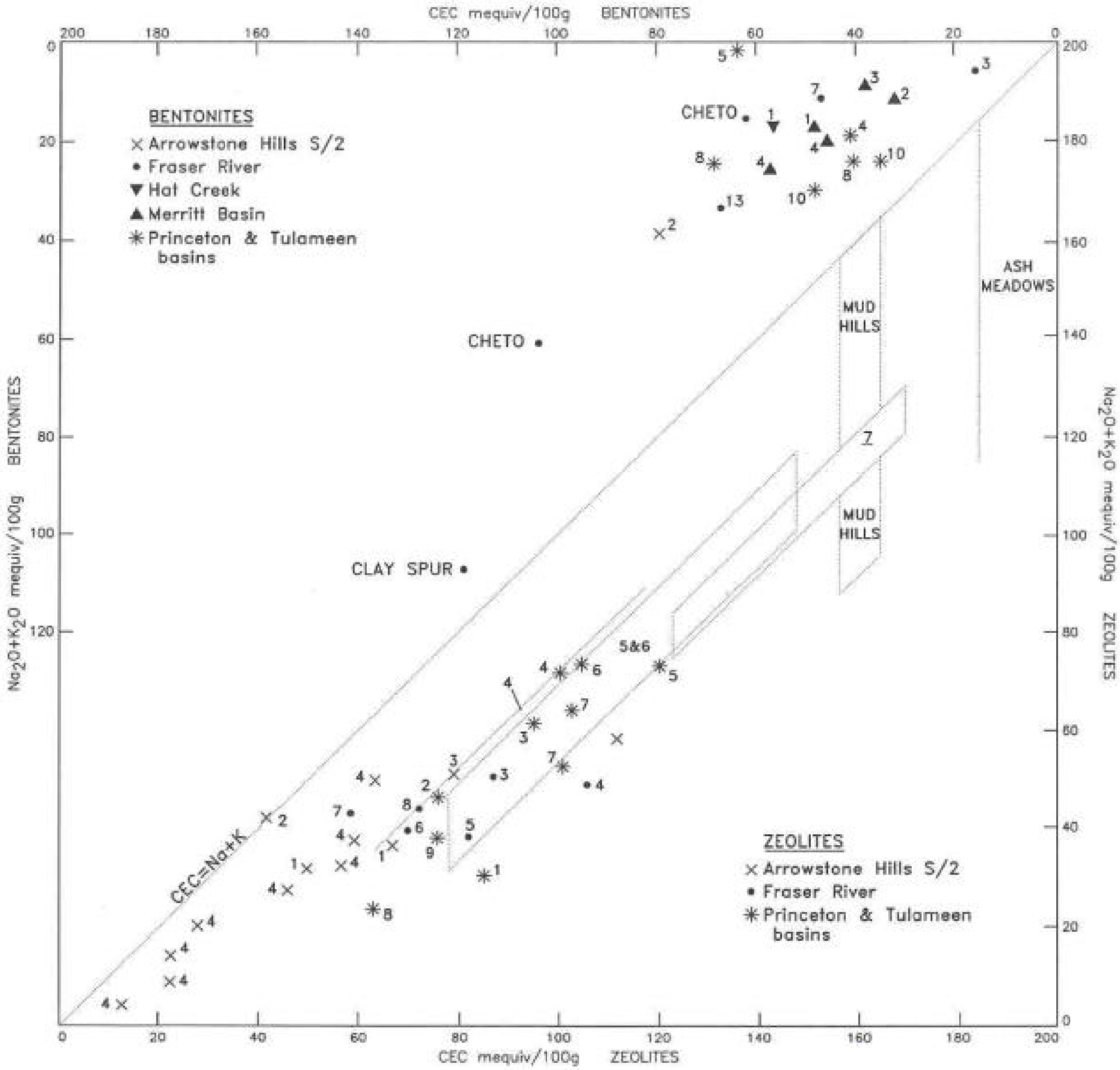

Figure 7.1. Plot of cation exchange capacity (CEC) against monovalent exchangeable cations (Na+K) for analyzed zeolites and bentonites from southern British Columbia compared with data from operating zeolite and bentonite deposits in the western United States. The numbered data points correspond to the number of the zeolite or bentonite showing in the map area denoted by the shape of the symbol. The inclined and vertical lines and parallelograms result from a lack of analyses of monovalent exchangeable cations. Their probable range has been assumed so that the CEC data can be plotted on the diagram. Sources of zeolite data; point data, this study; parallelograms and line oriented at 45° to axes, Marcille's data (1989) from Princeton basin; parallelogram and line oriented vertically, Griffiths (1987). Sources of bentonite data: numbered point data, this study; named point data Grim and Güven (1978).

TABLE 7.1
INDUSTRIAL MINERALS IN THE PRINCETON AND TULAMEEN BASINS

Loc #	Property	Commodity	Rock Unit	Status	Location Easting	Location Northing	Cert	MINFILE Number
TULAMEEN BASIN:								
B1	Hamilton Hill	Bentonite	EAVBp	Showing	FK0661610	FK5485900	1	092HNE187
B2	Blakeburn	Bentonite	EAVBp	Showing	FK0663340	FK5483760	1	092HSE157
Z1	Fraser Gulch	Zeolite	EASCss	Showing	FK0663320	FK5486720	1	092HNE188
PRINCETON BASIN:								
B3	Princeton Coll.	Bentonite	EAVBp	Showing	FK0681500	FK5480930	2	092HSE158
B4	Gem	Bentonite	EASCss	Showing	FK0680000	FK5480180	1	092HSE159
B5	L987	Bentonite	EAVBp	Showing	FK0676370	FK5479280	1	092HSE160
B6	Princeton Prop.	Bentonite	EAVBp	OPAPR	FK0680170	FK5479580	2	092HSE151
B7	Princeton Prop.	Bentonite	EAVBp	Showing	FK0681020	FK5479220	3	092HSE151
B8	Copper Mtn. RR.	Bentonite	EAAp	Showing	FK0679080	FK5475650	1	092HSE161
B9	L3959	Bentonite	EAAp	Showing	FK0678570	FK5474260	3	092HSE162
B10	Ashnola	Bentonite	EAAp	Showing	FK0678570	FK5472330	1	092HSE163
K1	Fairley Kaolinite	Kaolinite	EAVr	Showing	FK0677240	FK5471680	1	092HSE171
Z2	Tulameen Bridge	Zeolite	EACa	Showing	FK0680410	FK5481740	1	092HSE164
Z3	Asp Creek	Zeolite	EACa	Showing	FK0679530	FK5481600	1	092HSE164
Z4	Highway #3	Zeolite	EAta	Showing	FK0677480	FK5477570	1	092HSE165
Z5	Bromley Vale	Zeolite	EABv	Showing	FK0674530	FK5477030	1	092HSE166
Z6	Bromley Vale	Zeolite	EABv	Showing	FK0674500	FK5476910	1	092HSE166
Z7	Tailings RR	Zeolite	EAta	Showing	FK0679830	FK5476740	1	092HSE167
Z8	Sunday Creek	Zeolite	EASCt	Showing	FK0675950	FK5457870	1	092HSE168
Z9	Sunday Creek	Zeolite	EASCt	Showing	FK0675910	FK5457690	1	092HSE168

With the exception of the zeolite showings Z8 and Z9 in Sunday Creek tephra, all of the industrial mineral localities in the Princeton basin lie within 8 kilometres of the Canadian Pacific Railway which passes through Princeton. In the Tulameen basin, all the occurrences are within 6 kilometres of the Canadian Pacific Railway at Tulameen or Coalmont.

ZEOLITES AND THEIR OCCURRENCES

Rhyolite ash and vitric-crystal tuff are the hosts to the zeolite occurrences in the Princeton, Sunday and Tulameen basins. The zeolite is clinoptilolite which replaces original glass shards in waterlain vitric-crystal (biotite, plagioclase, sanidine, quartz) tuff and rhyolite glass in lapilli tuff lenses of the Allenby Formation. Four of the zeolitized horizons have been sampled in detail at approximately 0.9-metre intervals across their exposed thicknesses at selected localities. From each horizon, the most zeolite-rich sample, as determined by x-ray diffraction, was analyzed for exchangeable calcium, sodium, potassium and magnesium and its cation exchange capacity (CEC) was determined (Table 7.2). x-ray diffraction and heating tests, as described by Boles (1972), indicate that clinoptilolite is the only zeolite present in more than minor amounts, and the exchangeable cation analyses (Table 7.2) show that monovalent exchangeable cations predominate and restrict the composition of the zeolite to clinoptilolite.

In the Tulameen basin, waterlain felsic tephra of the Cedar Formation and parts of the Allenby Formation are suitable hostrocks for the development of zeolites. In the Cedar Formation, waterlain tuff contains significant laumontite at FK0663100 E, FK5483075 N and 1065 metres (3500 feet) elevation. In the Allenby Formation, thin rhyolite ash layers in the Vermilion Bluffs shale contain minor clinoptilolite (Pevear *et al.*, 1980), and Summers Creek sandstone contains zeolitized tuff (showing Z1). The southwesterly dipping, waterlain tuff lies within a sandstone-granule conglomerate section and passes under drift along strike. In addition, a concentration of angular, felsic tephra float, containing heulandite- clinoptilolite, lies beside a barbed wire fence at FK0662100 E, FK5486100 N.

BRIEF DESCRIPTIONS OF OCCURRENCES

TULAMEEN BASIN

Z1 Fraser Gulch

MINFILE:	092HNE188	STATUS:	Showing
NTS:	92H/10E	TYPE:	Sedimentary
LAT./LONG.:	49°30´54″	120°46´04″	
UTM:	FK0663320 E	FK5486720 N	
ELEVATION:	1265 m (4150 feet)		

A waterlain layer of heulandite-clinoptilolite-rich vitric-crystal (biotite, quartz, feldspar) tuff that is at least 3 metres thick, with only its lower contact observed, can be

TABLE 7.2
PRINCETON AND TULAMEEN BASINS:
EXCHANGEABLE Ca, Na, K AND Mg ANALYSES

Unit		Exchangeable Cation Analysis (mequiv/100g)					CEC (mequiv/100g)
Sample**	**Loc*****	**Mg**	**Ca**	**K**	**Na**	**Total**	
TULAMEEN BASIN:							
Summers Creek sandstone							
C86-391N	Z1	4.5	35.0	29.3	0.7	69.5	84.8
Vermilion Bluffs shale							
T77-12****	B1	12.2	56.1	2.8	0.1	71.2	n.d.
OP79-1****	B2	21.2	32.6	2.0	0.0	55.8	n.d.
PRINCETON BASIN:							
Ashnola shale							
C86-348A	B8	6.7	11.3	1.3	22.3	41.6	68.5
C86-348B	B8	6.2	8.9	1.5	23.5	40.1	40.5
C86-349A	B10	6.5	16.0	1.0	24.3	47.8	35.4
C86-349B	B10	8.0	10.5	1.1	28.8	48.4	48.2
Bromley Vale tephra							
#1 Adit	Z5	1.0	23.3	45.4	27.9	97.7	120.4
#1 Adit	Z5	--	--	--	--	--	*168
VM88-11 8-9m	Z5	--	--	--	--	--	*125
VM88-11 7-8m	Z5	--	--	--	--	--	*139
VM88-11 6-7m	Z5	--	--	--	--	--	*139
VM88-11 5-6m	Z5	--	--	--	--	--	*132
VM88-11 4-5m	Z5	--	--	--	--	--	*135
VM88-11 3-4m	Z5	--	--	--	--	--	*103
VM88-11 2-3m	Z5	--	--	--	--	--	*142
VM88-11 1-2m	Z5	--	--	--	--	--	*153
VM88-11 0-1m	Z5	--	--	--	--	--	*78.1
BV18	Z6	1.4	20.0	46.9	25.6	93.9	105.2
Tailings ash							
Highway	Z4	0.6	10.8	33.9	37.5	82.8	100.3
VM88-10 17.5-20m	Z4	--	--	--	--	--	*89.3
VM88-10 15-17.5m	Z4	--	--	--	--	--	*105
VM88-10 12.5-15m	Z4	--	--	--	--	--	*91.1
VM88-10 10-12.5	Z4	--	--	--	--	--	*83.5
VM88-10 9-10	Z4	--	--	--	--	--	*75.0
VM88-10 8-9	Z4	--	--	--	--	--	*64.3
VM88-10 7-8	Z4	--	--	--	--	--	*83.1
VM88-10 6-7m	Z4	--	--	--	--	--	*78.1
VM88-10 5-6m	Z4	--	--	--	--	--	*137
VM88-10 4-5m	Z4	--	--	--	--	--	*110
VM88-10 3-4	Z4	--	--	--	--	--	*109
VM88-10 2-3	Z4	--	--	--	--	--	*118
VM88-10 1-2	Z4	--	--	--	--	--	*114
VM88-10 0-1	Z4	--	--	--	--	--	*104
RR Grade	Z7	1.5	27.2	31.3	32.9	92.9	102.8
RR Grade	Z7	--	--	--	--	--	*159
TA9	Z7	3.0	32.5	29.8	22.5	87.8	101.0
VM88-9 13-14m	Z7	--	--	--	--	--	*157
VM88-9 12-13m	Z7	--	--	--	--	--	*170
VM88-9 11-12m	Z7	--	--	--	--	--	*123
VM88-9 10-11m	Z7	--	--	--	--	--	*149
VM88-9 9-10m	Z7	--	--	--	--	--	*129
VM88-9 8-9m	Z7	--	--	--	--	--	*159
VM88-9 7-8m	Z7	--	--	--	--	--	*145
VM88-9 6-7m	Z7	--	--	--	--	--	*155
VM88-9 5-6m	Z7	--	--	--	--	--	*146
VM88-9 4-5m	Z7	--	--	--	--	--	*133
VM88-9 3-4m	Z7	--	--	--	--	--	*147
VM88-9 2-3m	Z7	--	--	--	--	--	*156
VM88-9 1-2m	Z7	--	--	--	--	--	*157
VM88-9 0-1m	Z7	--	--	--	--	--	*152
Summers Creek sandstone							
C86-345C	B4	4.1	36.7	12.4	6.2	59.4	40.6
Asp Creek ash							
Bridge	Z2	2.5	12.6	8.4	37.9	61.4	75.7
Bridge	Z2	--	--	--	--	--	*115
AC12	Z3	2.2	17.2	8.6	52.7	80.7	95.2
Vermilion Bluffs shale							
C86-370	B5	15.6	51.3	0.1	1.4	68.4	63.7
Sunday Creek tephra							
SS270	Z8	6.7	31.9	18.6	4.7	61.9	62.7
Highway	Z9	5.5	34.3	16.1	11.8	67.7	75.6
Highway	Z9	--	--	--	--	--	*93.2

* *CEC values determined by the NH_4Cl-KCl method, Department of Land Resource Science, Ontario Agricultural College, University of Guelph. Values for VM88- series from Marcille (1989).*

** *With the exception of the VM88- series, analyzed samples weigh 10-15 grams and are crushed to -120 mesh.*

*** *B=bentonite; K=kaolinite; Z=heulandite-clinoptilolite*

**** *Data from Pevear et al. (1980, Table 3, p.249)* followed for about 100 metres southeastwards from an exposure on a four-wheel-drive track. Northwestward, the roadbed outcrop disappears under extensive drift. The tuff has an attitude of 286/45SW and lies on the northeast limb of the major syncline preserved in the Tulameen basin. An exchangeable cation analysis indicates that the zeolite has an intermediate composition in the heulandite-clinoptilolite solid solution series (Table 7.2).

References: Read (1987a, 1987b).

PRINCETON AND SUNDAY BASINS

In the Princeton basin, rhyolite ash and crystal-vitric tuff form five zeolitized tephra lenses which range in thickness from 7 metres, with upper and lower contacts exposed, to more than 22 metres with neither contact exposed, and in length from 400 metres at Bromley Vale to 3500 metres for the Tailings ash. In ascending stratigraphic order, the zeolitized lenses are Sunday Creek tephra (showings Z8 and Z9), Snowpatch ash, Asp Creek ash (showings Z2 and Z3), Tailings ash (showings Z4 and Z7) and Bromley Vale tephra (showings Z5 and Z8). Zeolites are widespread in the rhyolite ash component of the Summers Creek sandstone along Summers Creek, but not present in sufficient quantities to be of economic interest. Princeton ash is not zeolitized.

Asp Creek ash is the stratigraphically lowest zeolitized horizon that has been sampled in detail in the Princeton basin. It lies about 30 metres below the unzeolitized Princeton ash. The tephra contain scattered plant fragments and consist of bedded, white ash with minor intercalated layers of vitric-crystal (biotite, plagioclase, sanidine, quartz) tuff. Because neither the top nor bottom contact is exposed at the showing on the highway to Tulameen (Z2), the tephra was sampled in detail in cliffs on the west bank of Asp Creek.

Z2 Tulameen Bridge

MINFILE:	092HSE164	STATUS:	Showing
NTS:	92H/7	TYPE:	Sedimentary
LAT./LONG.:	49°28′01″	120°30′37″	
YTM:	FK0680410 E.;	FK5481740 N	
ELEVATION:	630 m (2075 feet)		

The showing is a cut on the Princeton-Tulameen road at the northwest end of the bridge across the Tulameen River within the village of Princeton (Photo 7.1). White-weathering waterlain rhyolite ash of Asp Creek ash is 5 metres thick with neither top nor bottom contacts exposed. The minor crystal-vitric component and high ash content of the material are consistent with the x-ray diffractograms of samples which indicate significant amounts of montmorillonite at the expense of zeolites. The bedding attitude of 068/23SE reflects the position of the showing on the south limb of the Rainbow Lake anticline. Heating tests, as described by Boles (1972), and exchangeable cation analyses (Table 7.2) show that monovalent exchangeable cations predominate and the zeolite is clinoptilolite.

References: Read (1987a, 1987b).

Z3 Asp Creek

MINFILE:	092HSE164	STATUS:	Showing
STATUS:	Showing		
NTS:	92H/7E	TYPE:	Sedimentary
LAT./LONG.:	49°27′57″	120°31′21″	
UTM:	FK0679530 E	FK5481600 N	
ELEVATION:	685 m (2250 feet)		

The showing is in cliffs on the west bank of Asp Creek about 500 metres from its confluence with the Tulameen River (Figure 7.2b). Here a 7.3-metre thickness of Asp Creek ash overlies a fine-grained biotite-bearing sandstone and underlies a carbonaceous shale. The strike length of the tephra is about 1000 metres with both ends covered by drift, but with an eastern extension likely. The bedding attitude of 052/18SE reflects the position of the showing on the south limb of the Rainbow Lake anticline. Heating tests, as described by Boles (1972) and exchangeable cation analyses (Table 7.2) of the most zeolite-rich sample from a series of samples taken every 0.9 metre show that monovalent exchangeable cations predominate and the zeolite is clinoptilolite.

References: Read (1987a, 1987b).

Tailings ash is the most extensive zeolitized unit in the Princeton basin. It is exposed in a roadcut on the northwest side of Highway 3 south of Princeton at showing Z4. This and other exposures to the west and east, lie on the north limb of the westerly trending and gently plunging Tailings syncline. Tailings ash also outcrops on the south limb of the syncline from the west bank of the Similkameen River to the former Copper Mountain railway grade. Along the grade, a section of zeolitized tephra 8.2 metres thick outcrops at showing Z7 (Figure 7.2c). Marcille's (1989) detailed sampling and CEC determinations show that Tailings ash, particularly the Railway showing (Z7), has higher CEC values than those of Bromley Vale tephra (Table 7.2).

Z4 Highway #3

MINFILE:	092HSE165	STATUS:	Showing
NTS:	92H/7E	TYPE:	Sedimentary
LAT./LONG.:	49°25′48″	120°33′9″	
UTM:	FK0677480 E	FK5477570 N	
ELEVATION:	845 m (2775 feet)		

The showing is in a roadcut on the northwest side of Highway No. 3, 600 metres east of a side-road up Bromley Creek and 100 metres northeast of an operating gravel pit (Photo 7.2). It exposes a 13-metre thickness of rhyolite lapilli ash-tuff with neither top nor bottom contacts exposed. A few exposures up to 900 metres west of the showing, combined with several up to 2700 metres to the east, give a strike length of 3600 metres for the Tailings ash. The easterly strikes of bedding attitudes and dips ranging from 20 to 35° southerly over the strike length outline the north limb of the Tailings syncline. Heating tests, as described by Boles (1972), and exchangeable cation analyses (Table 7.2) of the most zeolite-rich sample from a series of samples taken every 0.9 metre show that monovalent exchangeable cations predmominate and the zeolite is clinoptilolite.

References: Hora and Kwong (1984); Marcille (1989); Read (1987a, 1987b).

Photo 7.1 The Tulameen Bridge showing (Z2) of white, bedded Asp Creek ash exposed in a roadcut 25 metres east of the north end of the bridge across the Tulameen River at the north end of Princeton, (Photo: Z.D. Hora).

Z7 Tailings RR

MINFILE:	092HSE167	STATUS:	Showing
NTS:	92H/7E	TYPE:	Sedimentary
LAT./LONG.:	49°25´20″	120°31´14″	
YTM:	FK0679830 mE	FK5476740 mN	
ELEVATION:	825 m (2700 feet)		

The showing is in a cut on the old Copper Mountain railway grade which exposes a 4-metre thickness of vitric-crystal (biotite, feldspar, quartz) tuff overlain by 4.2 metres of mainly vitric rhyolite tuff with neither the top nor bottom contacts of the zeolitized unit exposed (Figure 7.2c). Scattered exposures to the west of the grade combine to give a strike length of 1600 metres, but to the east, the Boundary fault probably truncates Tailings ash within a few hundred metres of the showing. The northerly dips of bedding, ranging from 23 to 57°, indicate that this showing lies on the south limb of the Tailings syncline. Heating tests, as described by Boles (1972), and exchangeable cation analyses show that monovalent exchangeable cations predominate and the zeolite is clinoptilolite rich.

References: Marcille (1989); Read (1987a, 1987b).

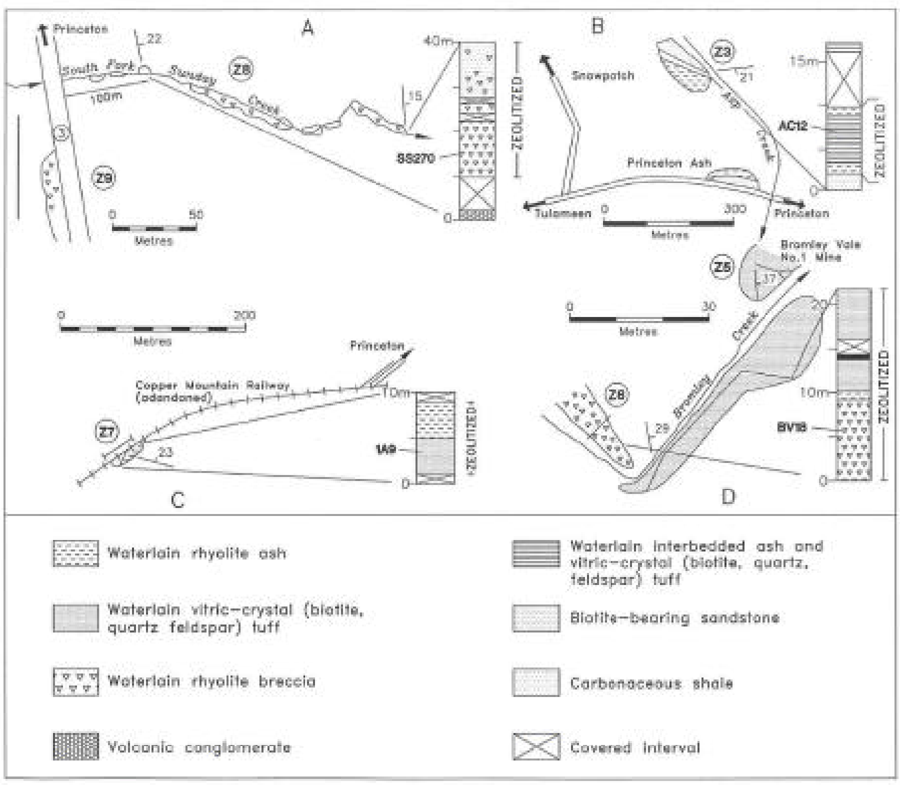

Figure 7.2. Geological sketch maps of major zeolite occurrences in the Princeton basin showing the locations of some of the analyzed samples in Table 7.2.
(a) Sunday Creek tephra at showings **Z8** and **Z9** in the south fork of Sunday Creek,
(b) Asp Creek ash at showing Z3 in Asp Creek,
(c) Tailings ash at Tailings RR showing **Z7** on the abandoned Copper Mountain railway,
(d) Bromley Vale tephra at Bromley Vale showings **Z5** and **Z6** near Bromley Vale No. 1 mine.

Photo 7.2. The Highway #3 showing (**Z4**) of white, layered ash and more massive, zeolite-rich lapilli tuff in the centre and right side of the rockcut. (Photo: Z.D. Hora).

Photo 7.3. The Sunday Creek showing (Z9) of zeolitized rhyolite lapilli tuff in a roadcut on Highway 3 immediately south of the fork of Sunday Creek. (Photo Z.D. Hora)

Bromley Vale tephra has a 22-metre thickness in its 100-metre-long exposure in Bromley Creek which extends from the portal of Bromley Vale No. 1 mine (showing Z5) upstream to showing Z6 (Figure 7.2d) with neither top nor bottom contacts exposed. These showings probably lie on the western limb of the southerly trending and gently plunging Tailings syncline. If the Asp Creek fault has a right-lateral strike-slip displacement of about 1200 metres, then the Bromley Vale tephra should correlate with the Tailings ash.

Z5, Z6 Bromley Vale

MINFILE:	092HSE166	STATUS:	Showing
NTS:	92H/7E	TYPE:	Sedimentary
LAT./LONG:	49°25′31″	120°35′37″	
UTM:	FK0674515 E	FK5476970 N	
ELEVATION:	930 m (3050 feet)		

The location given is centrally situated between the Bromley Vale No. 1 mine adit (showing Z5) at FK0674530 E, FK5477030 N and rhyolite tephra (showing Z6) at FK0674500 E, FK5476910 N (Figure 7.2d). Downstream, the easterly flowing Bromley Creek crosses 9 metres of fine, white to cream-coloured rhyolite lapilli tuff (Z6) overlain by 13 metres of white to light grey vitric-crystal (biotite, feldspar, quartz) bedded tuff and an intercalated thin, dark grey albitized tuff. The outcrop ends near the mine adit (Z5) with neither the top nor bottom contacts exposed. To the south of the showings, very thick overburden mantles any possible extension, and to the north the tephra does not reappear because of widespread overburden and finally truncation by Asp Creek fault. Heating tests, as described by Boles (1972), and exchangeable cation analyses (Table 7.2) show that monovalent exchangeable cations predominate and the zeolite is clinoptilolite.

References: Marcille (1989); Read (1987a, 1987b); Sadlier-Brown (1989).

Sunday Creek tephra is the only zeolitized unit in the Sunday basin, where it lies within 200 metres of the base of the Allenby Formation. The tephra is mainly a rhyolite lapilli tuff with a vitric-crystal (biotite, feldspar, quartz) matrix and a few percent subangular andesite clasts up to 5 centimetres in diameter. Although unbedded to crudely bedded, it contains fragments of carbonized wood up to 50 centimetres long. Zeolitized tephra outcrops on Highway 3 at showing Z9, and in the south fork of Sunday Creek downstream from the highway at showing Z8 (Figure 7.2a). Scattered outcrops indicate that it has a strike length of about 1300 metres on the northwest limb of the Kennedy Lake syncline, and a thickness of nearly 30 metres.

Z8, Z9 Sunday Creek

MINFILE:	092HSE168	STATUS:	Showing
NTS:	92H/2E, 92H/7E	TYPE:	Sedimentary
LAT./LONG:	49°15′08″	120°34′57″	
UTM:	FK0675930 E	FK5457780 N	
ELEVATION:	1195 m (3925 feet)		

The location given is centrally situated between roadcuts on Highway 3 (Z9) at FK0675910 E, FK5457690 N, and a zeolitized tephra intersection in the south fork of Sunday Creek (Z8) downstream from the highway at FK0675950 E, FK5457870 N (Figure 7.2a). A zeolitized lapilli tuff outcrops for a distance of 500 metres south of the south fork of Sunday Creek in a roadcut 5 metres high on the west side of the highway (Photo 7.3). The only other exposures are in the south fork of Sunday Creek downstream from Highway 3 where the creek twice intersects the tephra which outlines the open, gently southerly plunging Kennedy Lake syncline. In a section sampled in detail, starting about 100 metres downstream from the highway, the creek exposes a volcanic-pebble to cobble conglomerate underlying at least 30 metres of tephra which grades into an overlying brownish weathering sandstone (Figure 7.2a). The gentle easterly dipping bedding near showing Z9, and gentle southerly dips farther downstream, place the showings on the west limb close to the hinge of the syncline. Heating tests, as described by Boles (1972), and exchangeable cation analyses (Table 7.2) show that divalent exchangeable cations predmominate and the zeolite is a heulandite-rich intermediate member of the heulandite-clinoptilolite solid solution series.

References: Read (1987a, 1987b).

Snowpatch ash is exposed at 860 metres (2825 feet) elevation, 2300 metres up the road to the Snowpatch ski area from the Princeton-Tulameen Highway. A rockcut on the south side of road exposes about 5 metres of yellow ochre weathering, coarse tuffaceous sandstone composed mainly of quartz, feldspar and biotite grains. Although neither the top nor bottom contact is exposed, the zeolitized unit is probably not much thicker than 5 metres. About 800 metres to the south-southwest, at 945 metres (3100 feet) elevation and east of a powerline, a dip slope exposes a 30-metre width of white-weathering vitric-crystal tuff that is locally zeolitized. The strike length of the tephra horizon is 2400 metres with both ends passing under drift. The ash is crystal rich, only partly zeolitized, and not considered to be of economic interest.

Summers Creek sandstone contains a vitric-crystal (biotite, feldspar, quartz) component which increases northward along Summers Creek until the sandstone passes gradationally through a waterlain tuff into a tuff. Heulandite-clinoptilolite replaces the vitric component in the tuffaceous sandstone and waterlain tuff, but the tuff is not zeolitized. Because of the crystal-rich nature of Summers Creek sandstone, it is not considered to be of economic interest.

BENTONITE AND ITS OCCURRENCES

Bentonite is widespread throughout the Princeton basin (OF 1987-19) and usually occurs in the shale and coal-rich sections of the stratigraphy in layers up to 2 metres thick (McMechan 1983, p.19). In ascending stratigraphic order, bentonite showings are known in the Vermilion Bluffs shale, Summers Creek sandstone and Ashnola shale. Because bentonite outcrops slump shortly after exposure, only a few localites were sampled. At each showing, the occurrence of bentonite was confirmed by x-ray diffractograms of untreated, glycolated and heated material. Exchangeable cation analyses and cation exchange capacities (CEC) were determined for samples from showings yielding fresh and uncontaminated material (Table 7.2).

In the Tulameen basin, bentonite layers up to a metre thick are part of the medial shale and coal section. The mineralogy and petrology of the bentonites suggest that they formed by the alteration of glassy rhyolite tephra containing quartz, sanidine and biotite phenocrysts. Detrital components of a non-tephra origin are apparently absent. Exchangeable cation analyses of two bentonite samples indicate that calcium and magnesium are the major exchangeable cations (Pevear *et al.*, 1980).

BRIEF DESCRIPTIONS OF OCCURRENCES

TULAMEEN BASIN

B1 Hamilton Hill

MINFILE:	092HNE187	STATUS: Showing
NTS:	92H/10W	TYPE: Sedimentary
LAT./LONG:	49°30′29″	120°46′04″
UTM:	FK0661610 E;	FK5485900 N
ELEVATION:	1355 m (4450 feet)	

The showing is a bentonite-rich shale, 1 to 2 metres thick, in the upper part of the shale-coal sequence of the Tulameen basin. The sequence is correlated with the Vermilion Bluffs shale which is a widespread, bentonite-bearing unit in the Princeton basin. Although chemical analyses indicate that the bentonites are CaO and MgO poor (Table 7.3), exchangeable cation analyses (Table 7.2) of a sample from drillhole T77-12 show that divalent exchangeable cations dominate.

References: Pevear *et al*. (1980); Read (1987a, 1987b).

B2 Blakeburn

MINFILE:	092HSE157	STATUS: Showing
NTS:	92H/7E	TYPE: Sedimentary
LAT./LONG:	49°29′18″	120°44′41″
UTM:	FK0663340 E	FK5483760 N
ELEVATION:	1250 m (4100 feet)	

The showing is a bentonite-rich shale parting, 1 to 2 metres thick, in the coal-rich section of the shale-coal sequence exposed in the old open pit at Blakeburn coal mine on the southwest limb of the syncline preserved by the Tulameen basin. The sequence correlates with the Vermilion Bluffs shale of the Princeton basin. Although chemical analyses indicate that the bentonites are CaO and MgO poor (Table 7.4), exchangeable cation analyses of sample OP79-1 (Table 7.2) from the open pit show that divalent exchangeable cations dominate.

References:Pevear *et al*. (1980); Read (1987a, 1987b).

PRINCETON BASIN

In the Princeton basin, bentonite is widespread in the Vermilion Bluffs shale, but because this shale-rich unit outcrops poorly, only four showings (B3, B5, B6 and B7) are known of which showing B6 is the only past-producer of bentonite in the province. Summers Creek sandstone has a single showing near the old Gem mine (B4). The uppermost shale in the Princeton basin, Ashnola shale, has three showings of bentonite (B8 to B10). Chemical analyses of bentonites indicate that they are KO and NaO poor (Table 7.5), but exchangeable cation analyses from showings B9 and B10 yield bentonites with dominantly monovalent exchangeable cations (Table 7.2).

B3 Princeton Collier

MINFILE:	092HSE158	
NTS:	92H/7E	STATUS: Showing
TYPE:	Sedimentary	
LAT./LONG.:	49°25′31″	120°35′37″
UTM:	FK0681500 E,	FK5480930 N
ELEVATION:	610 m (2000 feet)	

Two bentonite beds within the Vermilion Bluffs shale intersect Princeton Colliery No. 2 slope. The upper bed forms an 8-centimetre parting in a coal seam, and the lower is a layer 50 centimetres thick between the lower coal seam and the shale floor. Two analyses of the material are given in Table 7.5 (showing B3), and a water absorption test (Cummings and McCammon, 1952) showed that 1 gram of bentonite absorbs only 1.6 grams of water.

References: Cummings and McCammon (1952); Freeland (1924); Read (1987a, 1987b); Rice (1947); Spence (1924).

B4 Gem

MINFILE:	092HSE159	STATUS: Showing
NTS:	92H/7E	TYPE: Sedimentary
LAT./LONG.:	49°27′11″	120°31′00″
UTM:	FK0680000 E;	FK5480180 m N
ELEVATION:	640 m (2100 feet)	

The occurrence is in a shale lens that is freshly exposed on the east bank of the Similkameen River below the Gem mine. The cut exposes a bentonite seam 1.5 metres thick underlying carbonaceous shale and coal and overlying a pebble conglomerate which all lie within the Summers Creek sandstone. Exchangeable cation analyses (Table 7.2) show that divalent exchangeable cations dominate.

References: Read (1987a, 1987b).

B5 L987

MINFILE:	092HSE	STATUS: Showing
NTS:	92H/7E	TYPE: Sedimentary
LAT./LONG.:	49°26′44″; 120°34′01″	
UTM:	FK0676370 E;	FK5479280 N
ELEVATION:	825 m (2700 feet)	

The showing is a freshly exposed roadcut in the uppermost part of the Vermilion Bluffs shale. The bed is less than 2 metres thick in a sequence of shale and carbonaceous shale. Exchangeable cation analyses (Table 7.2) show that divalent exchangeable cations dominate.

References: Read (1987a, 1987b).

B6 Princeton Properties

MINFILE:	092HES51	STATUS: Past producer
NTS:	92H/7E	TYPE: Sedimentary
LAT./LONG.:	49°26′52″	120°30′52″
UTM:	FK0680170 E;	FK5479580 N
ELEVATION:	670 m (2200 feet)	

Spence's (1924) description of the location of this showing does not fit the present configuration of the Copper Mountain railway grade, but Hughes' (1953) descrip-

TABLE 7.3
ANALYSES OF BENTONITES FROM HAMILTON HILL

SAMPLE	#TR 4-41-3	TR-4-70-1	T-77-12-99.4	TR-6-72-1	TR-1-V-C	TR-1-V1-E	TR-1-IX-F	TR-1-79-7
SiO_2	70.69	71.33	68.77	51.96	55.65	54.48	55.27	65.00
TiO_2	0.05	0.05	0.05	0.58	0.73	0.53	0.36	0.05
Al_2O3	14.33	14.23	14.22	28.50	25.35	26.02	28.51	21.66
Fe_2O3*	1.48	1.53	1.34	1.51	1.13	1.52	1.41	1.04
CaO	0.58	0.5	1.57	0.19	0.41	0.60	0.19	0.17
MnO	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
FeO	na	na	na	na	na	na	na	na
MgO	0.49	0.47	0.55	0.51	0.80	0.75	0.49	0.19
Na_2O	0.25	0.27	0.40	0.18	0.09	0.27	0.07	0.31
K_2O	4.24	4.01	3.33	2.18	2.66	1.55	1.60	3.58
H_2O-105°**	4.00	4.00	5.30	4.30	6.00	6.60	3.50	1.40
H_2O+105°**	3.82	3.51	4.53	10.30	7.55	8.10	8.68	6.59
TOTALS	99.94	99.96	100.07	100.22	100.38	100.43	100.09	100.00

* Total Fe given as Fe_2O3
**H_2O-105° = free water; H_2O+105° = combined water
Source of analyses: Pevear *et al.*1980

TABLE 7.4
ANALYSES OF BENTONITES
FROM BLAKEBURN
(SHOWING B2)

SAMPLE #	TR 4-41-3	TR-4-70-1
SiO_2	71.84	52.62
TiO_2	0.21	0.12
Al_2O_3	21.66	15.98
Fe_2O_3*	0.56	0.19
CaO	0.32	0.51
MnO	0.04	0.06
FeO	na	0.52
MgO	0.5	0.77
Na_2O	0.1	0.1
K_2O	2.51	4.44
H_2O-105°'	4.3	6.25
H_2O+105°'	3.71	5.52
TOTALS	100.07	100.22

*Total Fe given as Fe2O3 except for analysis TR-4-70-1
** H2O-105o = free water; H2O+105o = combined water
Source of analyses: Pevear *et al*.1980).)

TABLE 7.5
ANALYSES OF BENTONITES FROM
PRINCETON BASIN

Component	Showing B3¹	Showing B3	Showing B9
SiO_2	68.6	71.2	70.2
Al_2O_3	12.1	11.8	13.78
Fe_2O_3	2	3	3.59
TiO_2	0.14	--	0.2
FeO	0.32	--	--
MnO	--	--	0.02
P_2O_5	0.17	--	0.04
CaO	1.84	2.9	2.03
MgO	1.84	0.5	1.84
Na_2O	0.5	--	lt 0.30
K_2O	0.23	--	0.2
CO_2	0.17	--	8 00
H_2O-105°*	7.71	--	8
H_2O+105°*	3.24	11.3	10
TOTALS	98.86	100.7	102.24

*H_2O-105o = free water; H_2O+105° = combined water
Sources of analyses: Showing B3¹ from Cummings and McCammon (1952);
Showing B3 from Freeland (1924);
Showing B9 from McMechan (1983).

tion places the occurrence on the railway in Lot 2049 and the location given above is consistent with the photograph in Freeland (1932, p.A128). In spite of the uncertainty of location, the bentonite lies in the upper shale tongue of the Vermilion Bluffs shale. Spence described an upper 0.9 metre of brown bentonite overlying a yellow bentonite bed 3.35 metres thick with a 0.1-metre thickness of lignite in the lower third. In 1926, $150 worth of bentonite was shipped to England; in 1931, several railcar loads valued at $3529 were shipped to B.C. Refractories Ltd., Vancouver; in later years $176 of bentonite was shipped in 1932, $1363 in 1933, $1578 in 1934 and the last recorded shipment was in 1944. As a result of 466 metres of diamond drilling in 1952, several bentonite beds were discovered with the main zone averaging 3 to 3.4 metres in thickness (Hughes, 1953). Samples were sent for testing at the Massachusetts Institute of Technology, but the results are not public. Now the occurrence is too slumped to sample for exchangeable cation analysis.

References: Anonymous (1927, 1934, 1935); Freeland (1924, 1925, 1932); Cummings and McCammon (1952); Freeland (1932); Hughes (1953; 1954); McMechan (1983); Read

(1987a, 1987b); Rice (1947); Shaw (1952a); Spence (1924).

B7 Princeton Properties

MINFILE:	092HSE1	STATUS:	Showing
NTS:	92H/7E	TYPE:	Sedimentary
LAT./LONG:	49°26′40″	120°30′11″	
UTM:	FK0681020 E	FK5479220 N	
ELEVATION:	670 m (2200 feet)		

The description given by Spence (1924), which puts the showing on the Copper Mountain railway grade, does not fit the configuration of the railway. Cummings and McCammon (1952) placed the showing in Lot 388 and this is the location given here. In spite of the uncertainty of location, the bentonite lies in the upper shale tongue of Vermilion Bluffs shale.

References: Freeland (1932); Hughes (1953); Cummings and McCammon (1952); McMechan (1983); Read (1987a, 1987b); Rice (1947); Shaw (1952a); Spence (1924).

B8 Copper Mountain Railway

MINFILE:	092HSE1	STATUS:	Showing
NTS:	92H/7E	TYPE:	Sedimentary
LAT./LONG:	49°24′45″	120°31′53″	
UTM:	FK0679080 E	FK5475650 N	
ELEVATION:	855 m (2800 feet)		

The showing is in a freshly exposed pit on the abandoned Copper Mountain railway grade about 5.5 kilometres south of Princeton. The railway cut exposes an 8-metre section consisting of 7 metres of bentonitic shale and siltstone with 1 metre of carbonaceous shale a metre above the base; a metre of fine-grained sandstone caps the bentonite. The showing is near the base of the Ashnola shale and nearby slumping and disrupted drainage suggest that the bentonitic sediments are extensive. x-ray diffractograms of two analyzed samples indicate significant quartz and feldspar impurities. Exchangeable cation analyses (Table 7.2) show monovalent exchangeable cations dominate.

References: Cummings and McCammon (1952); Read (1987a, 1987b); Spence (1924).

B9 L3595

MINFILE:	092HSE162	STATUS:	Showing
NTS:	92H/7E	TYPE:	Sedimentary
LAT./LONG:	49°24′00″	120°32′20″	
UTM:	FK0678570 E	FK5474260 N	
ELEVATION:	775 m (2550 feet)		

About 400 metres east of the Similkameen River and 7.2 kilometres south-southwest of Princeton, McMechan (1983, p. 19-21) reported a sandy bentonite, 9 metres thick, which was encountered at shallow depths in boreholes penetrating the middle of the Ashnola shale. A chemical analysis (showing B9, Table 7.5) yields only minor NaO and KO which implies that divalent exchangeable cations are dominant.

References: McMechan (1983); Read (1987a, 1987b).

B10 Ashnola

MINFILE:	092HSE163	STATUS:	Showing
NTS:	92H/7E	TYPE:	Sedimentary
LAT./LONG:	49°22′58″	120°32′23″	
UTM:	FK0678570 E	FK5472330 N	
ELEVATION:	710 m (2325 feet)		

Two kilometres downstream from the mouth of Whipsaw Creek, the slumped east bank of the Similkameen River at Ashnola Bend exposes a sequence of siltstone, sodium-rich bentonitic siltstone and bentonite up to 20 metres thick which is part of the highest stratigraphy exposed in the Princeton basin. x-ray diffractograms of two analyzed samples indicate significant quartz and feldspar impurities. Exchangeable cation analyses (Table 7.2) show monovalent exchangeable cations dominate.

References: Read (1987a, 1987b).

KAOLINITE AND ITS OCCURRENCE

Kaolinite is a widespread major to minor constituent of shale and bentonite in the Tulameen basin. Of 80 samples of bentonite that were examined by x-ray diffraction, 80% contained kaolinite (Pevear *et al.*, 1980, Table 1). In the Princeton basin, kaolinite is only sparsely distributed even in the bentonites. Typically, the glassy rhyolite tephra alters to clinoptilolite, but at the Fairley showing (K1) it has altered to kaolinite.

BRIEF DESCRIPTIONS OF OCCURRENCES

K1 Failey

MINFILE:	092HSE171	STATUS:	Showing
NTS:	92H/7E	TYPE:	Sedimentary
LAT./LONG:	49°22′38″	120°33′20″	
UTM:	FK0677240 E;	FK5471680 N	
ELEVATION:	725 m (2375 feet)		

The showing is downstream from the confluence of Whipsaw Creek and the Similkameen River, on the west bank about 150 metres south-southwest of the portal to Fairley coal prospect. X-ray diffractograms of samples from a massive white-weathering rhyolite ash and lapilli tuff, that is 10 metres in thickness, indicate that the rock consists mainly of kaolinite with minor quartz and dolomite. However, a few heating tests on a single sample showed a low pyrometric cone equivalent (PCE) of about 11 and they indicate that this material is not suited for making refractory bricks.

Reference: Read (1987b).

MERRITT BASIN (92I/1, 2)

Apparently bentonite is the only industrial mineral present in the Coldwater Formation (Table 7.6), but because exposure in the area is so poor, the role that stratigraphy plays in controlling its distribution cannot be deciphered. Although bentonite has been known at Quilchena since 1911 (Ries and Keele, 1913), its inferior grade has precluded its exploitation.

BENTONITE AND ITS OCCURRENCES

Bentonite-rich zones up to 8 metres in thickness occur near coal seams in the Quilchena and Guichon valleys. Exchangeable cation analyses of samples (Table 7.7) from the Quilchena showings (B3 and B4) indicate that the major exchangeable cations are divalent, which corroborates the calcium-rich analyses of bentonite obtained by Thompson and Sadler (1923, p. 74) (Table 7.8). A water absorp-

TABLE 7.6
INDUSTRIAL MINERALS, MERRITT BASIN

Loc #	Property	Commodity	Rock Unit	Status	Location Easting	Location Northing	Cert	MINFILE Number
GUICHON CREEK:								
B1	Coutlee	Bentonite	EAcp	Showing	FL0653150	FL5562300	1	092ISE203
B2	Coutlee	Bentonite	EAcp	Showing	FL0653900	FL5562300	1	092ISE203
QUILCHENA CREEK:								
B3	Quilchena Creek	Bentonite	EAcp	Showing	FL0679250	FL5556725	1	092ISE138
B4	Quilchena Creek	Bentonite	EAcp	Showing	FL0679100	FL5556540	1	092ISE138

tion test showed that the Quilchena bentonite is inferior to that from Wyoming.

North of Coutlee in the Guichon Valley, slumped trenches and roadcuts expose three bentonite-bearing shale-rich zones that comprise the Coutlee showing (B1 and B2). The stratigraphically lowest contains a layer of bentonitic shale and siltstone, that is 3 to 5 metres thick, (showing B1), and the intermediate, a bentonite-bearing shale that is 7 to 9 metres thick (showing B2). The upper layer was not sampled. Cation exchange analyses indicate that both contain mainly divalent exchangeable cations (Table 7.7).

BRIEF DESCRIPTIONS OF OCCURRENCES

B1 Coutlee

MINFILE:	092ISE203	STATUS:	Showing
NTS:	92I/2W	TYPE:	Sedimentary
LAT./LONG.:	50°11′47″	120°51′16′′	
UTM:	FL0653150 E	FL5562300 N	
ELEVATION:	730 m (2400 feet)		

The showing is located west of the Gouchon Creek road in a series of trenches which expose about 30 metres of interbedded siltstone, shale and sandstone with a medial layer 4 metres thick of bentonitic shale and siltstone and at the base, 8 metres of white sandstone. The sequence is in the middle of the gentle northeasterly dipping Coldwater Formation. An x-ray diffractogram of sample C86-410A shows a significant feldspar and cristobalite contamination of the montmorillonite. An exchangeable cation analysis indicates an intermediate sodium-calcium montmorillonite (Table 7.7).

References: Read (1987a, 1988d).

B2 Coutlee

MINFILE:	092ISE203	STATUS:	Showing
NTS:	92I/2W	TYPE:	Sedimentary
LAT./LONG.:	50°11′47′	120°50′38″	
UTM:	FL0653900 E;	FL5562300 N	
ELEVATION:	860 m (2825 feet)		

The showing is located in an old bulldozer-cut east of the Gouchon Creek road. The cut exposes a sequence of shale, siltstone and sandstone with a white claystone bed that is 8 to 10 metres thick. An x-ray diffractogram of sample C86-410E shows that the claystone consists of quartz, feldspar, cristobalite and kaolinite in addition to montmorillonite. An exchangeable cation analysis indicates a sodium-bearing calcium montmorillonite with a low cation exchange capacity (Table 7.7).

References: Read (1987a, 1988d).

B3 Quilchena Creek

MINFILE:	092ISE138	STATUS:	Showing
NTS:	92I/1W	TYPE:	Sedimentary
LAT./LONG.:	50°08′29′″	120°29′30″	
UTM:	FL0679250 E	FL5556725 N	
ELEVATION:	740 m (2425 feet)		

The location given is a bulldozer-cut which exposes a bentonite-rich zone several metres thick. An x-ray diffractogram of sample C86-409G taken from the trench shows minor feldspar and quartz accompanying the dominant montmorillonite. An exchangeable cation analysis of the sample is typical of a sodium-bearing calcium montmorillonite (Table 7.7). The bentonite-rich shale dips about 45° southeasterly and at the showing lies a few hundred metres above the base of the Coldwater Formation.

References: Read (1987a, 1988d).

B4 Quilchena Creek

MINFILE:	092ISE138	STATUS:	Showing
NTS:	92I/1W	TYPE:	Sedimentary
LAT./LONG.:	50°08′23″	120°29′38″	
UTM:	FL0679100 E	FL5556540 N	
ELEVATION:	720 m (2355 feet)		

The location given is midway between a caved adit at FL0679050 E, FL5556540 N and 700 metres (2300 feet) elevation, and a slumped outcrop of bentonite at FL0679150 E, FL5556540 N at 732 metres (2400 feet) elevation. The caved adit exposes a layer of bentonite at least 2.8 metres thick overlying a carbonaceous shale. Although uncertainty exists as to the location of the Quilchena samples (Table 7.7), as indicated in the footnote to the table, they probably came from the caved adit. A powder x-ray diffraction film taken from these samples showed that cristobalite is a contaminant present in an amount greater than 5% (Earley *et al.*, 1953). An analysis of the bentonite (Table 7.8) indicates an unusually high silica content of which a significant proportion is soluble or uncombined. This corroborates the significant cristobalite contamination of the sample indicated by the x-ray diffraction investigation. The cation exchange capacity of these samples is larger than

TABLE 7.7
MERRITT BASIN:
EXCHANGEABLE Ca, Na, K AND Mg ANALYSES

Unit/ Sample	Loc.# **	Exchangeable Cation Analysis					CEC
		Mg	Ca	K	Na	Total	
GUICHON CREEK:							
Coldwater Formation							
C86-410A	B1	9.4	19.4	2.1	15.0	45.9	47.6
C86-410E	B2	9.2	12.5	1.8	9.7	33.2	32.1
QUILCHENA CREEK:							
Coldwater Formation							
C86-409G	B3	8.1	28.8	0.56	8.3	45.8	38.1
C86-409E	B4	4.2	26.1	1.9	17.8	50.0	45.2
Quilchena	B4	10.0	32.5	1.5	23.9	67.9	57.5
500-1600m	B4	--	--	--	--	--	47.0
300-500m	B4	--	--	--	--	--	60.0
200-300m	B4	--	--	--	--	--	67.3
70-200m	B4	--	--	--	--	--	65.9
50-70m	B4	--	--	--	--	--	69.7

* B = bentonite
** Analyzed samples, with the exception of the Quilchena, weigh 10-15 g, and were crushed to -120 mesh. According to Osthaus (1955), the Quilchena sample was supplied by H.S. Spence, from a locality pictured by him (1924, Plate X), but which Ries and Keele (1913, p.73) collected from and probably incorrectly described as being on the west side of Quilchena valley.

TABLE 7.8
ANALYSES OF BENTONITE FROM QUILCHENA

Component	Quilchena	Quil 1	Quil 2	Quil 3
SiO_2	71.60*	69.7	67.04	69.6
Al_2O_3	15.75	14	13.46	11.84
Fe_2O_3	3.78	2.88	2.79	1.79
TiO_2	0.24	0.23	0.25	0.2
FeO	na	0.23	0.23	0.22
MnO	trace	na	na	na
P_2O_5	0.04	0.014	0.09	0.09
CaO	0.07	1.56	1.78	2.28
MgO	0.97	1.81	1.93	1.75
Na_2O	1.88	1.09	0.53	0.48
K_2O	0.09	0.29	0.22	0.14
H_2O+105°'	5.34	3.92	6.64	6.09
TOTALS	99.76	100.15	100.01	100.01
Cation exchange capacity (CEC))	65 9			

*Determination of soluble SiO_2 gave 29.90 per cent, and uncombined silica gave 37.65 per cent.
'H_2O+105° = combined water.
Sources of analyses: Quilchena from Earley *et al*. (1953); Quil 1 to Quil 3 from Thompson and Sadler (1923)
A 24-hour absorption test of 1 g of Quilchena bentonite indicated that it absorbed 1.53 g of water (Thompson and Sadler, 1923).

that measured from samples collected in the present investigation. Because this material is no longer accessible, sample C86-409E was taken from the same zone 150 metres to the east at 732 metres (2400 feet) elevation. An x-ray diffractogram of C86-409E indicates minor quartz, feldspar and kaolinite accompany the dominant montmorillonite. An exchangeable cation analysis of this sample is typical of sodium-bearing calcium montmorillonite (Table 7.7).

References: Cockfield (1948); Cummings (1938); Cummings and McCammon (1952); Thomson (1921); Earley *et al. (*1953); Keele (1920); Osthaus (1955); Read, (1987A, 1988d); Ries and Keele (1913); Spence (1924); Thompson and Sadler (1923).

ZEOLITES

Because waterlain acid tephra is apparently absent from the Merritt basin, zeolitized ash has not been discovered. However, outcrop is very sparse, and zeolitized tephra, which is difficult to recognize, may have been missed during the logging of holes in the exploration for coal seams.

SOUTH HALF OF ARROWSTONE HILLS (92I/14, 15)

Zeolites and bentonite occur in the Eocene rocks, and diatomaceous earth has developed in the Miocene sediments exposed in the southern part of the Arrowstone Hills (Table 7.9). In the Kamloops Group, only two of the sedimentary lenses at the base of the group and two in the lower part of the group contain zeolites. An x-ray diffraction investigation of samples from the remainder of the lenses including unit Ebx shows that these rocks are barren. Bentonite is restricted to the base of the group in Deadman valley. The McAbee aggregate quarry, near the northern margin of the Guichon Creek batholith, is an intermittent producer of railway ballast.

ZEOLITES AND THEIR OCCURRENCES

Bedded zeolite deposits are restricted to tuffaceous sedimentary rocks of the Kamloops Group. North and east of the village of Cache Creek, two basal tuffaceous lenses of unit Etf, and potentially a third lens, are zeolitized with heulandite-clinoptilolite replacing original vitric material. North of Cache Creek and near the west end of the Cache Creek Hills, one of the zeolitized basal tuffaceous lenses is host to the Cache Creek zeolite occurrence (Z1). At East Battle (Z3), a minimum thickness of 6 metres of bedded vitric-crystal (biotite, hornblende, quartz, feldspar) tuff forms the second zeolitized basal lens. A third basal lens of similar bedded crystal-lithic tuff at FM0624400 E, FM5629300 N is very poorly exposed and an x-ray diffractogram from a single sample indicated no zeolites.

Within a few hundred metres of the base of the group, Cuffaceous sediments of Unit Eptf of the east and west sedimentary lenses north of McAbee are commonly zeolitized. Shale, claystone and siltstone, containing zeolitized vitric-crystal tuffs, comprise the upper 10 to 70 metres of the lenses. Bedded tuffaceous sandstone and ash lenses range in thickness from less than a metre to 10 metres and in rock type from heulandite to clinoptilolite-bearing vitric-crystal (biotite, hornblende, quartz, feldspar) tuffs to finely-laminated vitric tuffs. In the latter, mineral assemblages range from dominantly cristobalite through mixtures containing some of heulandite-clinoptilolite, kaolinite, montmorillonite, feldspar and quartz, to essentially pure heulandite. Each lens has been sampled every metre, where possible, along a cross-section. Of the two sedimentary lenses described north of McAbee (Read 1987a, p. 253), a section through the 89-metre-thick western lens contains the McAbee zeolite showing (Z4), and the eastern lens hosts the West Battle zeolite showing (Z2) in the upper third of the lens.

All zeolite localities lie within 11 kilometres of the Canadian National Railway at McAbee or Ashcroft, and are within 3 kilometres of the Trans-Canada Highway.

BRIEF DESCRIPTIONS OF OCCURRENCES

Z1 Cache Creek

MINFILE:	092INW096	STATUS:	Showing
NTS:	92I/14W	TYPE:	Sedimentary
LAT./LONG.:	50°49′46′′	121°16′19′′	
UTM:	FM0621700 E	FM5632025 N	
ELEVATION:	730 m (2400 feet)		

The showing is a gently southeasterly-dipping quartz-feldspar-biotite-hornblende crystal-vitric tuff in which the vitric rhyolite component has been zeolitized (Photo 7.4). A minimum thickness of 6 metres of zeolitized tuff, with neither top nor bottom contact exposed, overlies grey shale of the Ashcroft Formation and underlies aphanitic dacite and andesite flows of unit Evd of the Kamloops Group. x-ray diffractograms of nine samples indicate that

TABLE 7.9
INDUSTRIAL MINERALS, CACHE CREEK AND TRANQUILLE RIVER

Loc #	Property	Commodity*	Rock Unit	Status	Location Easting	Location Northing	Cert	MINFILE Number
A1	McAbee	Aggregate	TAJdi	Producer	FM0632960	FM5628000	1	092INW092
Z1	Cache Creek	Zeolite	Etf	Showing	FM0621700	FM5632025	1	092INW096
Z2	West	Zeolite	Eptf	Showing	FM0631105	FM5629430	1	092INW094
Z3	East	Zeolite	Etf	Showing	FM0633770	FM5629330	1	092INW093
Z4	McAbee	Zeolite	Eptf	Showing	FM0626860	FM5628930	1	092INW095
B1	Deadman River	Bentonite	Evdx	Showing	FM0641030	FM5645800	1	092INE162
B2	Split Rock	Bentonite	Evdx	Showing	FM0642950	FM5642880	1	092INE170
D1	Gorge Creek	Diatomite	Mvr	Showing	FM0641950	FM5648250	1	092INE171
D2	Red Lake (DEM)	Diatomite	Mvr	Producer	FM0653700	FM5645150	1	092INE081
D3	North Uren	Diatomite	Mvr	Showing	FM0647180	FM5639930	1	092INE172

* Diatomite = Diatomeaceous Earth

Photo 7.4. In a small tributary on the north side of Cache Creek at showing (Z1), a white, crystall (biotite, hornblende, feldspar, quartz)-vitric ash tuff lens (Etf) at the base of the Kamloops Group dips gently southeastward under cliffs of aphanitic andesite and daciteflows and interflow breccia (Evd). The waterlain tuff is moderately zeolitized by a member of the heulandite-clinoptilolite series.

all are heulandite-clinoptilolite-bearing. Exchangeable cation analyses of two of these samples (C86-430E1 and C86-430E4) indicate a sodium and potassium-rich intermediate clinoptilolite (Table 7.10).

References: Read (1987, 1988d)

Z2 West Battle

MINFILE:	092INW094	STATUS:	Showing
NTS:	92I/14E	TYPE:	Sedimentary
LAT./LONG.:	50°48´15´´	121°08´22´´	
UTM:	FM0631105 E;	FM5629430 N	
ELEVATION:	695 m (2275 feet)		

The location given is half way between occurrences of zeolites at UTM coordinates of FM0631330 E, FM5629280 N and 655 metres (2150 feet) elevation, and at FM0630880 E, FM5629580 N and 732 metres (2400 feet) elevation. Gently dipping beds of tuff and tuffaceous sandstone up to 10 metres thick lie in the upper third of the east sedimentary lens which contains conglomerate in its lower half. The zeolite-rich sample BC 20´, from a tuffaceous sandstone that is 10 metres thick, has an exchangeable cation analysis typical of intermediate clinoptilolite (Table 7.10). A second analysis (C86-418G5) from zeolitized rhyolite ash immediately beneath the overlying aphanitic andesite and dacite breccia of unit Evdx at FM0630900 E and FM5629700 N is an intermediate clinoptilolite and has the highest cation exchange capacity of presently analyzed zeolites outside the Princeton basin (Table 7.10 and Figure 7.1).

Reference: Read (1988d).

Z3 East Battle

MINFILE: 092INW093

MINFILE:	092INW093	STATUS:	Showing
NTS:	92I/14E	TYPE:	Sedimentary
LAT./LONG.:	58°48´10´´	121°06´06´´	
UTM:	FM0633770 E;	FM5629330 N	
ELEVATION:	565 m (1850 feet)		

A minimum thickness of 6 metres of biotite-hornblende-feldspar-quartz crystal-vitric tuff overlies a thin sedimentary breccia, composed of Guichon Creek diorite clasts, that nonconformably rests on the northern margin of the batholith. The sediments dip gently and underlie aphanitic andesite and dacite flows of unit Evd. x-ray diffractograms of three samples indicate that all are heulandite-clinoptilolite bearing. An exchangeable cation analysis of sample C86-422F3 indicates an intermediate clinoptilolite (Table 7.10).

References: Read (1987a, 1988d).

Z4 McAbee

MINFILE:	092INW095	STATUS:	Showing
NTS:	92I/14E	TYPE:	Sedimentary
LAT./LONG.:	50°48´02″	121°12´00″	
UTM:	FM0626860 E	FM5628930 N	
ELEVATION:	740 m (2425 feet)		

The location given is half way between two zeolite occurrences at UTM coordinates FM0626750 E, FM5628980 N and 740 metres (2425 feet) elevation, and at FM0626870 E, FM5628880 N and the same elevation (Photo 4.1). In the upper third of the western sedimentary lens, zeolitized rhyolite vitric ashes are intercalated with shale and tuffaceous sandstone. Waterlain, zeolitized rhyolite tephra locally underlies the upper 4 metres of the lens, and forms a bed 10metres thick in the middle of the lens (Photo 7.5). Thermal stability investigations (Boles, 1972) of the zeolitized samples suggest that heulandite and heulandite-rich intermediate compositions predominate (samples MR77°33´ and MR77°36´), and that clinoptilolite occurs only in sample MR77°15´ taken near the margin of the bed, but exchangeable cation analyses indicate that all are intermediate clinoptilolite with moderate to low cation exchange capacities (Table 7.10).

Reference: Read (1988d).

BENTONITE AND ITS OCCURRENCES

Bentonite was first collected in the Deadman valley near the mouth of Gorge Creek by W.F. Ferrier in 1918 (Keele 1920, p.161). Cockfield (1948, p.150) repeated the description but the material has not been tested. Both occurrences reported are from partly waterlain andesite and dacite tephra lenses in unit Evdx close to the base of the Kamloops Group.

BRIEF DESCRIPTIONS OF OCCURRENCES

B1 Deadman River

MINFILE:	092INE162	STATUS:	Showing
NTS:	92I/15W	TYPE:	Volcanogenic
LAT./LONG.:	50°56´58´´	120°59´32´´	
UTM:	FM0641030 E;	FM5645800 N	
ELEVATION:	730 m (2400 feet)		

The bentonite probably results from alteration of andesite and dacite lapilli tuff and ash of unit Evdx near the base of the Kamloops Group. Bentonite-rich exposures form at the base of slope but may not be in place.

References: Cockfield (1948); Keele (1920); Read (1988e).

B2 Split Rock

MINFILE:	092INE170	STATUS:	Showing
NTS:	92I/15W	TYPE:	Volcanogenic
LAT./LONG.:	50°55´22´´	120°57´58´´	
UTM:	FM0642950 E;	FM5642880 N	
ELEVATION:	745 m (2450 feet)		

The bentonite probably results from alteration of andesite and dacite lapilli tuff and ash of unit Evdx near the base of the Kamloops Group. The bentonite-rich lenses measure tens of metres in thickness and hundreds of metres in length (Photo 4.2). An x-ray diffractogram shows montmorillonite and minor feldspar present. Exchangeable cation analyses for sample C87-607 show that the bentonite is an intermediate sodium-calcium montmorillonite (Table 7.10).

Reference: Read (1988e).

DIATOMACEOUS EARTH AND ITS OCCURRENCES

All diatomaceous earth deposits occur in the Miocene Chilcotin Group either in lacustrine accumulations within the Deadman River Formation (showings D1, D2 and D3), or in thin intercalations, up to 10 metres in thickness, of unit Mcr of the Chasm Formation. Eardley-Wilmot (1928) tested and reported on diatomaceous earth from the only producer in the area near Red Lake (D2).

BRIEF DESCRIPTIONS OF OCCURRENCES

D1 Gorge Creek

MINFILE:	092INE171	STATUS:	Showing
NTS:	92I/15W	TYPE:	Sedimentary
LAT./LONG.:	50°58´17´´	120°58´42´´	
UTM:	FM0641950 E;	FM5648250 N	
ELEVATION:	1005 m (3300 feet)		

The location given is centrally located between two roadcuts 100 metres to either side which have clasts of diatomaceous earth (Photo 4.7). The diatomaceous clasts come from the Deadman River Formation between the base of the overlying basalt flows at 1120 metres (3675 feet) elevation and this point at 1005 metres (3300 feet). At this location the Deadman River and Chasm formations form the filling of the northward-draining Miocene Deadman channel which is 2 kilometres wide and 440 metres deep.

Reference: Read (1988e).

TABLE 7.10
SOUTH HALF OF ARROWSTONE HILLS:
EXCHANGEABLE Ca, Na, K AND Mg ANALYSES AND
CATION EXCHANGE CAPACITY (CEC)'

		Exchangeable Cation Analysis (mequiv/100g)					
Sample	Loc.#**	Mg	Ca	K	Na	Total	(Mequiv/100g)
C87-607	B2	16.25	20.50	1.50	36.75	75.0	79.5
C86-430E1	Z1	2.25	23.25	14.50	22.00	62.0	67.0
C86-430E4	Z1	0.65	15.50	7.00	24.50	47.65	50.0
C86-418G5	Z2	9.4	47.2	19.7	38.6	114.9	111.8
BC 20'	Z2	3.75	17.75	8.75	32.00	62.25	41.5
C86-422F3	Z3	2.75	20.50	12.75	38.25	74.25	78.6
C86-424B	Z4	4.4	9.6	5.6	8.1	27.7	22.3
C86-424B	Z4	4.8	12.5	7.5	12.3	37.1	28.1
MR 10'	Z4	2.29	10.00	4.58	3.75	20.62	22.3
MR 66' White	Z4	6.75	21.75	18.75	18.50	65.75	58.9
MR 66'	Z4	1.28	3.25	1.70	2.00	8.23	13.9
MR 77°15'	Z4	7.00	14.25	7.25	18.00	46.5	46.1
MR 77°33'	Z4	5.25	29.75	13.75	36.25	85.00	63.8
MR 77°36'	Z4	1.75	31.25	12.50	19.58	65.08	56.7

* Analyzed samples weigh 10-15 grams and are crushed to -120 mesh.
** Z = heulandite-clinoptilolite; B = bentonite

Photo 7.5 The McAbee showing (Z4) of well-bedded, cream-weathering, zeolite and cristobalite-bearing rhyolite ash. (Photo Z.D. Hora)

D2 DEM (Red Lake)

MINFILE:	092INE081	STATUS:	Producer
NTS:	92I/15W	TYPE:	Sedimentary
LAT./LONG.:	50°56´28´´;	120°48´45´´	
UTM:	FM0653700 E;	FM5645150 N	
ELEVATION:	1230 m (4025 feet)		

In 1984, D.E.M. Resource Processors Ltd. built a plant and started a quarry on this diatomaceous earth deposit which was first discovered in the 1920s on B. Chester's farm. The quarry is in a flat-lying lacustrine accumulation of diatoms, mainly *Melosira granulata,* accompanied by devitrified rhyolite ash composed of mixed-layer montmorillonite-bearing clay, quartz, cristobalite, feldspar and glass shards. The low silica and high alumina content of a single sample of diatomaceous earth indicate a significant contamination by ash, montmorillonite and other clay minerals (Table 7.11).

Industrial Clay Products Ltd. of Kamloops presently (1991) operates the deposit and produces domestic and industrial absorbent (fuller's earth).

Drilling shows that the deposit covers an area of more than 65 hectares up to depths of 37 metres. Samples tested by Hora (1986) have the following physical properties:

Density:	0.61 g/cc
Absorption (ASTM):	111.4%
Physical strength:	4.8 to 7.9 MPa

Based on palynology, the deposit is Middle to Late Miocene in age (Mathews and Rouse, 1963) and not Eocene as implied or reported by Monger and McMillan (1984, 1989) and Hora (1986). The deposit has been correlated with the Deadman River Formation because 10 kilometres to the northwest, on the east side of Deadman Valley, rhyolite tephra of the Deadman River Formation outcrops at 1205 metres (3950 feet) elevation. However, the deposit may be one of the diatomaceous layers (unit Mcr) within the Chasm Formation and a correlation with the Chasm Formation cannot be excluded.

References: Cockfield (1948); Eardley-Wilmot (1928); Hora (1986); Monger and McMillan (1984, 1989)

D3 North Uren

MINFILE:	092INE172	STATUS:	Showing
NTS:	92I/15W	TYPE:	Sedimentary
LAT./LONG.:	50°53´44´´;	120°54´26´´	
UTM:	FM0647180 E;	FM5639930 N	
ELEVATION:	1200 m (3925 feet)		

Two samples taken from an old bulldozer-trench above an abandoned logging road on the north side of an unnamed peak due north of Sedge Lake and Mount Uren, show diatoms in oil immersion mounts. The diatomaceous layer cannot be more than 5 metres thick and forms the top of a thin lens of rhyolite tephra of the Deadman River Formation lying between volcanics of the Nicola Group and basalt flows of the overlying Chasm Formation.

RAILWAY BALLAST AND ITS OCCURRENCE

The McAbee quarry lies adjacent to a siding on the main line of the Canadian National Railway at McAbee.

A1 McAbee Aggregate Quarry

MINFILE:	092INW095	STATUS:	Producer
NTS:	92I/14E	TYPE:	Igneous
LAT./LONG.:	50°48´02´´;	121°12´00´´	
UTM:	FM0626860 E;	FM5628930 N	
ELEVATION:	740 m (2425 feet)		

TABLE 7.11
ANALYSES OF DIATOMACEOUS EARTH,
ARROWSTONE HILL, BRITISH COLUMBIA

Showing	Red Lake D2	Loon Creek D4	North Snohoosh D19
SiO_2	61.08	80.3	24.2
Al_2O_3	18.76	9.01	0.35
Fe_2O_3	2.96	3.55	0.24
CaO	1.41	nil	38.31
MgO	0.95	1.21	1.61
Na_2O	n.d.	n.d.	n.d.
K_2O	n.d.	n.d.	n.d.
H_2O+105°*	12	6	6.5
Organic Matter	56	n.d.	28.64
TOTALS	97.7	100.07	99.85

* H_2O+105° = combined water
Source of analyses: Eardley-Wilmot (1928, p.94)

The intermittently operated quarry has provided 11 to 13.5 million tonnes of crushed Guichon Creek diorite for use as railway ballast throughout western Canada. It has estimated reserves which approximately equal the production to date.
Reference: Read (1988a).

NORTH HALF OF ARROWSTONE HILLS (92P/2, 3)

Industrial minerals in the Chilcotin Group are restricted to volcanic ash and diatomaceous earth which are found in the Deadman River Formation and interbeds of unit Mcr of the Chasm Formation (Table 7.12). The rhyolite ash is so widespread in the Deadman River Formation that only ash showings already prospected are described. All showings of diatomaceous earth are plotted (Maps 4 and 5) and described. A majority of the showings are at various levels within the Deadman River Formation, but some are in beds, probably less than 10 metres thick, in unit Mcr of the Chasm Formation. Because much less than 1% of the area underlain by the Deadman River Formation contains outcrops, it cannot be adequately prospected for industrial minerals without trenching or drilling. All occurrences of diatomaceous earth have been verified under the petrographic microscope by means of oil-immersion grain mounts.

DIATOMACEOUS EARTH AND ITS OCCURRENCES

Within the Deadman River Formation, most of the occurrences of diatomaceous earth lie within the channel fillings of the Miocene drainage system. The westernmost of these is the northward-draining Miocene Bonaparte channel which contains the Chasm Creek (D1), Pipeline (D2) and Loon Creek (D4) showings, which are near the base of the channel filling, and Wohlleben Creek (D3) which is near the top. Of all the occurrences of diatomaceous earth in the Arrowstone Hills, including the intermittently operated D.E.M. deposit to the east, the Chasm Creek (D1) and Pipeline (D2) showings are closest to rail and road transportation. Both showings lie within 11 kilometres of the British Columbia Railway at Clinton and within 4 kilometres of Highway 97.

In the Deadman River valley, the Deadman River Formation is the host to numerous occurrences of diatomaceous earth. In the northwestward-draining Miocene Snohoosh channel, occurrences at South Snohoosh (D15), Skookum Lake (D16), Knight Lake Road 1 (D18), Knight Lake Road 2 (D17), North Snohoosh (D19), Sherwood Creek (D20) and Deadman River (D21) lie towards the southwestern side and middle to lower levels of the channel fill. Where the outcrop is sufficient, as at showings D16, D20 and D21, the diatomaceous layers are known to be 2 to 3 metres thick. The Deadman Lake showing (D14) is near the base of the channel fill of the southward-draining Miocene Falls channel. Three occurrences of diatomaceous earth in the Deadman River Formation lie immediately under the basalt flows of the Chasm Formation. Two of these, Mowich Lake 1 (D8) and Mowich Lake 2 (D9), are on the southwestern edge of the Miocene Snohoosh channel, and the third, Coal Creek (D6), is located in the southward-draining Miocene Hamilton channel.

West of the Deadman River valley, diatomaceous earth forms layers in unit Mcr intercalated in the Chasm Formation. Roadcuts on logging roads near Brigade Creek expose diatomaceous earth at Brigade Creek (D5), and north and south of Moose Creek at Moose Creek South 2 (D7), Moose Creek South 1 (D10), West Escarpment (D13), Moose Creek North 1 (D11) and Moose Creek North 2 (D12). The layers may be up to several metres thick.

BRIEF DESCRIPTIONS OF OCCURRENCES

D1 Chasm Creek

MINFILE:	092P 100	STATUS:	Showing
NTS:	92P/3W	TYPE:	Sedimentary
LAT./ LONG.:	51°08′51′′	121°27′45′′	
UTM:	FM0607550 E;	FM5667100 N	
ELEVATION:	740 m (2425 feet)		

On the north side of Bonaparte River 0.5 kilometre downstream from Chasm Creek is a slumped bulldozer-cut in diatomaceous siltstone. Several samples show numerous diatoms in oil-immersion mounts. The poor exposures are immediately beneath an unusual quartzite-pebble to cobble conglomerate that may mark the top of the Deadman River Formation which here fills the northward-draining Miocene Bonaparte channel.
Reference: Read (1989b).

D2 Pipeline

MINFILE:	092P 052	STATUS:	Showing
NTS:	92P/3W	TYPE:	Sedimentary
LAT./LONG.:	51°07′34′′	121°26′48′′	
UTM:	FM0608700 E;	FM5664750 N	
ELEVATION:	790 m (2600 feet)		

The location given is a cutbank 2 metres high on a pipeline right-of-way, but float of diatomaceous earth also

TABLE 7.12
INDUSTRIAL MINERALS, BONAPARTE TO DEADMAN RIVERS

Loc #	Property	Commodity*	Rock Unit	Status	Location Easting	Location Northing	Cert	MINFILE Number
A1	Skookum Lake	Volc. Ash	Mvr	Showing	FM0649000	FM5664300	1	092P095
A2	Sherwood Creek	Volc. Ash	Mvr	Showing	FM0649300	FM5661000	1	092P093
A3	Snohoosh Lake	Volc. Ash	Mvr	Showing	FM0649000	FM5659750	1	092P094
D1	Chasm Creek	Diatomite	Mvr	Showing	FM0607550	FM5667100	1	092P100
D2	Pipeline	Diatomite	Mvr	Showing	FM0608700	FM5664750	1	092P052
D3	Wohlleben Creek	Diatomite	Mvr	Showing	FM0612350	FM5660250	1	092P161
D4	Loon Creek	Diatomite	Mvr	Showing	FM0611050	FM5655900	1	092P099
D5	Brigade Creek	Diatomite	Mcr	Showing	FM0643150	FM5663150	1	092P073
D6	Coal Creek	Diatomite	Mvr	Showing	FM0644850	FM5673070	1	092P162
D7	Moose Ck South 2	Diatomite	Mcr	Showing	FM0645880	FM5657800	1	092P075
D8	Mowich Lake 1	Diatomite	Mvr	Showing	FM0645950	FM5657320	1	092P076
D9	Mowich Lake 2	Diatomite	Mvr	Showing	FM0645950	FM5657640	1	092P090
D10	Moose Ck South 1	Diatomite	Mcr	Showing	FM0646040	FM5658120	1	092P151
D11	Moose Ck North 1	Diatomite	Mcr	Showing	FM0646400	FM5662525	1	092P165
D12	Moose Ck North 2	Diatomite	Mcr	Showing	FM0646570	FM5661570	1	092P166
D13	West Escarpment	Diatomite	Mcr	Showing	FM0647890	FM5661550	1	092P167
D14	Deadman Lake	Diatomite	Mvr	Showing	FM0648450	FM5666400	1	092P098
D15	South Snohoosh	Diatomite	Mvr	Showing	FM0648700	FM5659100	1	092P168
D16	Skookum Lake	Diatomite	Mvr	Showing	FM0648750	FM5664300	1	092P164
D17	Knight Lake Rd 2	Diatomite	Mvr	Showing	FM0649430	FM5659200	1	092P169
D18	Knight Lake Rd 1	Diatomite	Mvr	Showing	FM0649780	FM5659540	1	092P170
D19	North Snohoosh	Diatomite	Mvr	Showing	FM0649400	FM5662700	1	092P097
D20	Sherwood Creek	Diatomite	Mvr	Showing	FM0649200	FM5661200	1	092P163
D21	Deadman River	Diatomite	Mvr	Showing	FM0648700	FM5658500	1	092P096

* Volc. Ash = Volcanic Ash; Diatomite = Diatomaceous Earth

occurs at FM0608350 E, FM5664400 N at 755 metres (2475 feet) elevation. The showing is in the Deadman River Formation at about the middle level of the northward-draining Miocene Bonaparte channel which here is 2.5 kilometres wide and 450 metres deep.

D3 Wohlleben Creek

MINFILE:	092P 161	STATUS:	Showing
NTS:	92P/3W	TYPE:	Sedimentary
LAT./LONG.:	51°05′06′′	121°23′46′′	
UTM:	FM0612350 E;	FM5660250 N	
ELEVATION:	1035 m (3400 feet)		

The showing is in roadcuts between 1030 and 1045 metres (3375 and 3425 feet) elevation on an old logging road passing 1.6 kilometres east of Wohlleben Lakes. Three samples show numerous diatoms in oil-immersion mounts. The diatomaceous earth is interbedded with rhyolite ash bearing sediments of the Deadman River Formation which are no more than 15 metres beneath the base of basalt flows of the Chasm Formation. In this area, the Deadman River Formation fills the northward-draining Miocene Bonaparte channel. The showing is at the top of this channel fill which is about 5 kilometres wide and 400 metres deep.

References: Read (1989a, 1989b).

D4 Loon Creek (Loon Lake)

MINFILE:	092P 099	STATUS:	Showing
NTS:	92P/3W	TYPE:	Sedimentary
LAT./LONG.:	51°02′46′′	121°24′57′′	
UTM:	FM0611050 E;	FM5655900 N	
ELEVATION:	700 m (2300 feet)		

The showing is a cutbank on Tomlin Road within 100 metres of its junction with Loon Lake Road. A bank 2 metres high exposes a bed of white diatomaceous earth 3 metres thick, for a length of 60 metres. The showing is in the Deadman River Formation near the base of the northward-draining Miocene Bonaparte channel which here is about 5 kilometres wide and 400 metres deep. The alumina and iron contents of a sample of diatomaceous earth indicate some contamination by rhyolite ash and clay minerals (D4, Table 7.11).

References: Campbell and Tipper (1971); Eardley-Wilmot (1928); Read (1989a, 1989b).

D5 Brigade Creek

MINFILE:	092P 073	STATUS:	Showing
NTS:	92P/2W	TYPE:	Sedimentary
LAT./LONG.:	51°06′18′′;	120°57′19′′	
UTM:	FM0643150 E;	FM5663150 N	
ELEVATION:	1160 m (3800 feet)		

The showing is an overgrown cutbank, on an old logging road, which contains chips of rhyolite ash and diatomaceous earth. The distribution of outcrops of basalt flows permits a layer 10 metres thick of rhyolite ash and diatomaceous earth of unit Mcr between basalt flows of the Chasm Formation.

D6 Coal Creek

MINFILE:	092P 162	STATUS:	Showing
NTS:	92P/2W	TYPE:	Sedimentary
LAT./LONG.:	51°11´38´´;	120°55´38´´	
UTM:	FM0644850 E;	FM5673070 N	
ELEVATION:	1060 m (3475 feet)		

The showing is an old roadcut on a logging road which cuts down the east wall of Deadman valley northwards to the mouth of Coal Creek. The diatomaceous earth is present in three samples collected within 5 metres of the contact of the Deadman River Formation and overlying basalt flows of the Chasm Formation. The showing is in the southward-draining Miocene Hamilton channel just south of its confluence with Miocene Coal Creek channel.

References: Read (1989b).

D7 Moose Creek South 2

MINFILE:	092P 075	STATUS:	Showing
NTS:	92P/2W	TYPE:	Sedimentary
LAT./LONG.:	51°03´23´´	120°55´07´´	
UTM:	FM0645880 E;	FM5657800 N	
ELEVATION:	1135 m (3725 feet)		

The showing is based on chips and slumped outcrop of bedded rhyolite tuff and diatomaceous earth in a cutbank 13 metres high which implies the presence of a diatomaceous layer that is at least 15 metres thick. Because basalt flows are both above and below this layer, the diatomaceous earth belongs to unit Mcr of the Chasm Formation.

D8 Mowich Lake 1

MINFILE:	092P 076	STATUS:	Showing
NTS:	92P/2W	TYPE:	Sedimentary
LAT./LONG.:	51°03´07´´;	120°55´04´´	
UTM:	FM0645950 E; FM5657320 N		
ELEVATION:	1060 m (3475 feet)		

The showing is a roadcut in diatomaceous earth within 10 metres of the top of the Deadman River Formation. The thickness of the layer is unknown but it is probably the same sequence of beds that outcrops 300 metres away at Mowich Lake 2 (showing D9).

D9 Mowich Lake 2

MINFILE:	092P 090	STATUS:	Showing
NTS:	92P/2W	TYPE:	Sedimentary
LAT./LONG.:	51°03´18´´;	120°55´03´´	
UTM:	FM0645950 E;	FM5657640 N	
ELEVATION:	1060 m (3475 feet)		

The showing is a roadcut in diatomaceous earth that was identified in oil-immersion grain mounts. It lies within 10 metres of the top of the Deadman River Formation, but its thickness is unknown and its lateral extent probably continues for at least 300 metres to the Mowich Lake 1 (showing D8).

D10 Moose Creek South 1

MINFILE:	092P 151	STATUS:	Showing
NTS:	92P/2W	TYPE:	Sedimentary
LAT./LONG.:	51°03´33´´;	120°54´58´´	
UTM:	FM0646040 E;	FM5658120 N	
ELEVATION:	1135m (3725 feet)		

The showing was recognized by examination of oil-immersion grain mounts of samples taken from blocks of diatomaceous earth exposed in an old logging landing area. The dimensions of the diatomaceous layer are unknown, but because it lies between basalt flows, it must belong to unit Mcr of the Chasm Formation.

D11 Moose Creek North 1

MINFILE:	092P 165	STATUS:	Showing
NTS:	92P/2W	TYPE:	Sedimentary
LAT./LONG.:	51°05´55´´;	120°54´33´´	
UTM:	FM0646400 E;	FM5662525 N	
ELEVATION:	1110 m (3650 feet)		

At the showing the reliable float in the roadbed is of diatomaceous earth in an area so devoid of outcrops that its extent is unknown. However, the material must lie between basalt flows and belong to unit Mcr of the Chasm Formation. Plentiful diatoms were identified in oil-immersion mounts of samples of the material.

D12 Moose Creek North 2

MINFILE:	092P 166	STATUS:	Showing
NTS:	92P/2W	TYPE:	Sedimentary
LAT./LONG.:	51°05´24´´;	120°54´26´´	
UTM:	FM0646570 E;	FM5661570 N	
ELEVATION:	1130 m (3700 feet)		

The showing consists of slumped outcrop and roadbed float of diatomaceous earth which has been verified with oil-immersion grain mounts. The area is so devoid of outcrops that the dimensions of the diatomaceous earth occurrence cannot be assessed, however, the layer must lie between basalt flows and thus it belongs to unit Mcr of the Chasm Formation.

D13 West Escarpment

MINFILE:	092P 167	STATUS:	Showing
NTS:	92P/2W	TYPE:	Sedimentary
LAT./LONG.:	51°05´23´´;	120°53´18´´	
UTM:	FM0647890 E;	FM5661550 N	
ELEVATION:	1065 m (3500 feet)		

The showing is at the base of a cliff of basalt flows, in a flat-lying bed 3 metres thick consisting of rhyolite ash and a layer of diatomaceous earth 0.7 metre thick which is underlain by basalt flows. The diatomaceous earth belongs to unit Mcr of the Chasm Formation.

D14 Deadman Lake

MINFILE:	092P 098	STATUS:	Showing
NTS:	92P/2W	TYPE:	Sedimentary
LAT./LONG.:	51°07´59´´;	120°52´42´´	
UTM:	FM0648450 E;	FM5666400 N	
ELEVATION:	875 m (2875 feet)		

A fresh (1989) roadcut on the east side of the Deadman valley, 0.3 kilometre north of the north end of Deadman Lake, exposes a flat-lying zone of diatomaceous earth more than 10 metres thick. Several samples taken from the roadcut show numerous diatoms in oil-immersion mounts. The diatomaceous earth is hosted by a bedded section of siltstone and underlying rhyolite ash near the bottom of the southward-draining Miocene Falls channel.

References: McCammon (1960); Read (1989a, 1989b).

D15 South Snohoosh

MINFILE:	092P 168	STATUS:	Showing
NTS:	92P/2W	TYPE:	Sedimentary
LAT./LONG:	51°04′03′′;	120°52′40′′	
UTM:	FM0648700 E;	FM5659100 N	
ELEVATION:	930 m (3050 feet)		

The showing is in a slumped outcrop on the old Knight Lake logging road. Samples yield numerous diatoms in oil immersion grain mounts. The showing is in the Deadman River Formation near the western edge of the northwestward-draining Miocene Snohoosh channel.

D16 Skookum Lake

MINFILE:	092P 095	STATUS:	Showing
NTS:	92P/2W	TYPE:	Sedimentary
LAT./LONG:	51°06′51′′;	120°52′30′′	
UTM:	FM0648750 E;	FM5664300 N	
ELEVATION:	875 m (2875 feet)		

Two flat-lying layers of diatomaceous earth, each 2 metres thick, are exposed near the base of a 128-metre section of massive to crudely bedded rhyolite tephra that fills the northwesterly-draining Miocene Snohoosh channel.

References: Campbell and Tipper (1971); Eardley-Wilmot (1927); Read (1989a, 1989b).

D17 Knight Lake Road 2

MINFILE:	092P 169	STATUS:	Showing
NTS:	92P/2W	TYPE:	Sedimentary
LAT./LONG:	51°04′06′′;	120°52′02′′	
UTM:	FM0649430 E;	FM5659200 N	
ELEVATION:	1020 m (3350 feet)		

The showing is in roadcuts of bedded rhyolite tuff and diatomaceous earth which have been verified in oil-immersion grain mounts. It is in the middle of the northwestward-draining Miocene Snohoosh channel at the middle level of the Deadman River Formation.

D18 Knight Lake Road 1

MINFILE:	092P 170	STATUS:	Showing
NTS:	92P/2W	TYPE:	Sedimentary
LAT./LONG:	51°04′16′′;	120°51′44′′	
UTM:	FM0649780 E;	FM5659540 N	
ELEVATION:	1045 m (3425 feet)		

Numerous diatoms are seen in oil-immersion grain mounts of samples from an excellent roadcut of bedded rhyolite tuff and diatomaceous earth in the middle of the channel fill of the northwestward-draining Miocene Snohoosh channel filled by the Deadman River Formation.

D19 North Snohoosh

MINFILE:	092P 097	STATUS:	Showing
NTS:	92P/2W	TYPE:	Sedimentary
LAT./LONG:	51°05′59′′;	120°51′59′′	
UTM:	FM0649400 E;	FM5662700 N	
ELEVATION:	915 m (3000 feet)		

This showing has not been relocated and the following description is that given in the original reference as: “diatomaceous earth mixed with silt in a low roadcut”. This locality may also correspond to a locality that Eardley-Wilmot (1928, p. 81) described as “a small deposit of shell marl full of diatoms, on the east side of [Deadman] river between Snohoosh and Skookum lakes.” The high lime and low silica of a single sample of diatomaceous earth from this locality indicate that the material is a diatomaceous marl (Table 7.11).

Reference: Eardley-Wilmot (1928).

D20 Sherwood Creek

MINFILE:	092P 163	STATUS:	Showing
NTS:	92P/2W	TYPE:	Sedimentary
LAT./LONG.:	51°05′10′′;	120°52′11′′	
UTM:	FM0649200 E;	FM5661200 N	
ELEVATION:	855 m (2800 feet)		

Two flat-lying beds, 1.5 and 3 metres thick, lie near the base of a 105-metre-thick section of the Deadman River Formation on the east side of Snohoosh Lake, north of Sherwood Creek. These beds are deep in the Deadman River Formation which here fills the northwesterly-draining Miocene Snohoosh channel.

References: Campbell and Tipper (1971); Read (1989a, 1989b).

D21 Deadman River

MINFILE:	092P 096	STATUS:	Showing
NTS:	92P/2W	TYPE:	Sedimentary
LAT./LONG.:	51°03′44′′;	120°52′41′′	
UTM:	FM0648700 E;	FM5658500 N	
ELEVATION:	975 m (3200 feet)		

The showing is a cut 0.8 kilometres south of Snohoosh Lake which exposes a bed of diatomaceous earth 2 metres thick for a length of 15 metres. The material is part of the Deadman River Formation which fills the northwestward-draining Miocene Snohoosh channel. The showing was not relocated in this study.

References: Read (1989a, 1989b).

VOLCANIC ASH AND ITS OCCURRENCES

Massive rhyolite ash of the Deadman River Formation is the dominant rock filling the Miocene channels. To date, prospecting efforts and testing have concentrated on the north side of Sherwood Creek at the Sherwood Creek showing (A1). McCammon (1960) tested this ash for pozzolanic properties. Although it meets ASTM specifications, it has not been used as a pozzolan. Similar-appearing but untested ash is widespread and localities in the Miocene Bonaparte channel, such as the south side of Loon Creek, are much closer to major transportation routes.

BRIEF DESCRIPTIONS OF OCCURRENCES

A1 Skookum Lake

MINFILE:	092P 095	STATUS:	Showing
NTS:	92P/2W	TYPE:	Volcanogenic
LAT./LONG.:	51°06′51′′;	120°52′30′′	

UTM: FM0648750 E; FM5664300 N
ELEVATION: 875 m (2875 feet)

On the east side of Deadman valley and the north side of Skookum Lake, a cliff exposes a 135-metre thickness of mostly rhyolite tephra which is buff coloured with a few thin white layers. The cliff is near the base of the northwestward-draining Miocene Snohoosh channel.

References: Campbell and Tipper (1971); McCammon (1960); Western Miner and Oil Review (1959); Read (1989b).

A2 Sherwood Creek (Last Chance)

MINFILE:	092P 093	STATUS:	Prospect
NTS:	92P/2W	TYPE:	Volcanogenic
LAT./LONG:	51°05′04′′;	120°52′06′′	
UTM:	FM0649300 E;	FM5661000 N	
ELEVATION:	915 m (3000 feet)		

The prospect is on the north side of Sherwood Creek above the Deadman Valley road where an old bulldozer-cut exposes mostly a rhyolite vitric ash and tuff with minor tuffaceous sediments and a few thin layers of diatomaceous earth (Photos 4.5 and 7.6). The lowest ash beds are buff to grey-green, followed by a bed of chalky white ash 3 metres thick, then upwards through 30 metres of buff to yellow ash beds which are overlain by 2 metres of white ash and higher buff beds. The white beds are a uniform, fine ash with a size analysis and chemical composition typical of rhyolite ash as reported in Table 7.13. Analyses given by Eardley-Wilmot (1927) show that the white ash (Samples 1 to 4) and yellow tuff (Samples 5 to 7) are both rhyolite (Table 7.14).

McCammon (1960) tested the ash according to A.S.T.M. Designation C402-58T (1957, revised 1958) for its pozzolanic properties with the results given in Table 7.15. Other tests have indicated that the white ash is suitable for cream glazes on ceramic ware and as an ingredient for certain ceramic bodies.

References: Campbell and Tipper (1971); Cummings (1948); Eardley-Wilmot (1927); Keele (1920); McCammon (1960); Read (1989a, 1989b); Western Miner and Oil Review (1959)

TABLE 7.13
SIZE ANALYSIS AND CHEMICAL COMPOSITION OF SHERWOOD CREEK ASH (SHOWING A2)

+35	0.0%	SiO_2
-35+48	0.1%	Al_2O_3
-48+65	0.3%	Fe_2O_3
-65+100	0.6%	CaO
-100+150	0.8%	MgO
-150+200	14.5%	Alkalies
-200	83.6%	H_2O+105°C*
Total	99.9	Total

The material has a very low melting point at cone 9.
* H_2O+105° = combined water.
Source of data: Keele (1920).

A3 Snohoosh Lake

MINFILE:	092P 094	STATUS:	Showing
NTS:	92P/2W	TYPE:	Volcanogenic
LAT./LONG.:	51°06′51′′;	120°52′17′′	
UTM:	FM0649000 E;	FM5659750 N	
ELEVATION:	915 m (3000 feet)		

Scattered outcrops and a cliff 15 to 25 metres high expose up to 50 metres of crudely bedded, mainly buff-coloured rhyolite ash which overlies a thin white ash layer at the base of the cliffs. The showing is in the Deadman River Formation near the western edge of the northwesterly draining Miocene Snohoosh channel.

References: McCammon (1960); Read (1989b).

UPPER HAT CREEK VALLEY (92I/12 to 14)

In Upper Hat Creek valley, kaolinite and bentonite are the industrial minerals of importance (Table 7.16); zeolites are absent from all 63 surface samples collected in this

TABLE 7.14
ANALYSES OF SHERWOOD CREEK ASH
(SHOWING A2)

	White ash				Yellow tuff		
Component	**1**	**2**	**3**	**4**	**5**	**6**	**7**
SiO_2	73.10	71.70	70.10	70.80	67.60	68.70	67.80
Al_2O_3	12.46	13.88	14.31	11.95	15.84	13.14	13.34
Fe_2O_3	1.74	1.82	2.69	2.05	3.16	3.16	3.86
CaO	nil	nil	1.60	1.15	2.00	2.40	2.20
MgO	0.46	0.38	0.47	nil	0.39	nil	0.38
Na_2O	2.98	1.80	1.64	n.d.	0.36	n.d.	3.41
K_2O	3.46	3.09	2.66	n.d.	2.95	n.d.	1.36
H_2O+105°	1.90	3.10	4.30	5.22	5.00	6.00	3.00
Organic Matter	3.86	4.01	2.27	7.78	2.42	5.40	4.92
TOTALS	99.96	99.78	100.04	100.79	99.72	98.95	100.27

H_2O+105° = combined water
Source of analyses: Eardley-Wilmot (1927).

TABLE 7.15
COMPARISON OF SHERWOOD CREEK ASH
(SHOWING A**2**)
TO A.S.T.M. REQUIREMENTS

Component	Chemical Analysis A.S.T.M. Requirement	Sample
$SiO_2 + Al_2O_3 + Fe_2O_3$	Min. 70%	84.8
MgO	Max. 5%	0.49
SO_3	Max. 3%	0.10
Ignition loss	Max. 10%	7.25
Moisture content	Max. 3%	3.23

Source of data: McCammon (1960).

TABLE 7.16
INDUSTRIAL MINERALS, UPPER HAT CREEK VALLEY

Loc #	Property	Commodity	Rock Unit	Status	Location Easting	Location Northing	Cert	MINFILE Number
B1	Pacific	Bentonite	Escg	Showing	EM0597630	EM5625140	1	092INW084

study and examined by x-ray diffraction. Most of the following data, derived from a B.C. Hydro report (1978), are based on the x-ray diffraction studies of 112 samples of drill core from the No. 1 deposit.

Although the B.C. Hydro report concluded that the clay from Hat Creek would not be mined in the foreseeable future without the development of the coal resources, Pacific Bentonite Ltd. is investigating bentonite resources in an area of thin overburden on the west side of the No. 1 deposit (B1) (Map 6).

BENTONITE AND ITS OCCURRENCES

Claystone in the claystone member and in the upper half of the Hat Creek Member contains appreciable bentonite. Samples from the B, C and D zones of the Hat Creek Member have low bentonite contents, but exceptions are present on the west side of the deposit. Of the 112 samples studied from the No. 1 deposit, only two of the claystone samples with bentonite representing more than 98% of the clay minerals present, are from beds more than 5 metres thick. Determinations of exchangeable cations and cation exchange capacity (CEC) from a single surface sample indicate that the exchangeable cations are dominantly divalent (Table 7.17). Similar analyses have been performed on samples of the drill core, but the danger of contamination of the samples with bentonite drilling mud renders the analyses suspect. Preliminary swelling tests were carried out on several bentonite-rich samples from the claystone member. With the exception of sample 76-170 704-705', the results were disappointing (Table 7.18). Although the sandstone member is low in bentonite according to B.C. Hydro (1978), Pacific Bentonite Ltd. has located appreciable bentonite in some of the drill cores penetrating this unit. Because the sandstone member is thick and widespread along the west side of Hat Creek valley, this discovery greatly increases the area of bentonite potential.

BRIEF DESCRIPTIONS OF OCCURRENCES

B1 Pacific Bentonite

MINFILE:	092INW084	STATUS:	Prospect
NTS:	92I/13E	TYPE:	Sedimentary
LAT./LONG.:	50°46´17.4´;	121°36´57.2´´	
UTM:	EM0597600 E;	EM5625100 N	
ELEVATION:	1135 m (3725 feet)		

Bentonite occurs in siltstone and minor shale intercalations at the south end of a partly slumped bulldozer-trench 9 metres deep in the Hat Creek Member. An x-ray diffractogram of this material shows that it consists mostly of montmorillonite and minor feldspar. An exchangeable cation analysis and cation exchange capacity of this uncontaminated surface sample show that it contains mainly divalent exchangeable cations (Table 7.17). Pacific Bentonite Ltd. has discovered significant bentonite-bearing intersections in diamond-drillhole 76-802 which penetrates the sandstone member.
Reference: Read (1990a).

KAOLINITE

The concentration of kaolinite is inversely related to the concentration of bentonite. The kaolinite content is low

TABLE 7.17
HAT CREEK: EXCHANGEABLE Ca, Na, K,
AND Mg ANALYSES
AND CATION EXCHANGE CAPACITY (CEC)

Unit/ Sample	Loc #**	Exchangeable Cation Analysis (mequiv./100) Mg	Ca	K	Na	Total	CEC (mequiv./100
Hat Creek Member							
C86-439A	B1	10.6	18.3	1.6	14.7	45.4	46.8

* samples weigh 10-15and are crushed to -120 mesh.
** B = bentonite

TABLE 7.18
PRELIMINARY SWELLING TESTS ON BENTONITES FROM HAT CREEK*

Drill Hole	Footage	Preliminary Swelling Test	
		1 Hour	24 Hour
claystone member			
76-126	205-208	0	3
	208-210	2	4
	210-212	1	2
76-130	235-238	0	1
	323	0	1
	338	3	6
	342	3	5
	1621-1622	3	4
76-136	119	0	0
	219-221	0	0
76-170	704-705	8	9
	703-704	0	2

*Tests performed by Alberta Research Council by adding approximately 2 grams of air-dried material in small increments to 100 millilitres of demineralized water. Amount of 'gel' formed measured after 1 hour and 24 hours.

in the claystone member and increases through zones A, B and D of the Hat Creek Member. Samples from Zone C have a highly variable kaolinite content which locally ranges up to 75 to 80% of the clay minerals present. The kaolinite content of the sandstone member is low and irregular. From the 112 samples studied, 24 of the claystone samples, with kaolinite representing more than 98% of the clay minerals present, are from beds ranging from 1.5 to 6 metres in thickness, and seven are from beds more than 6 metres thick.

Clay and/or fly ash may be a source of alumina. The alumina content is highest in the kaolinite-bearing intervals of the claystone and siltstone sections, and lowest on the west side of the No. 1 deposit and in the sandstones. Analyses of the amount of alumina present in the ash of Zones C and D of the Hat Creek Member yield an average of 25 to 30% for core lengths of 20 to 80 metres, and for Zones A and D, 25 to 35% for core lengths averaging 100 to 150 metres. A single determination of the alumina extractable by acid leaching gives approximately 80% of the 20.59% alumina present in the core from diamond-drill hole 74-37A between 353.6 and 393.2 metres. In spite of these encouraging results, the Hat Creek kaolinite remains untested.

FRASER RIVER - LILLOOET TO THE CHILCOTIN RIVER (92I/11, 12; 92O/1, 8, 9; 92P/4)

For 125 kilometres northward along the Fraser River from Lillooet to the mouth of the Chilcotin River, industrial minerals occur in Eocene and Miocene Pliocene rocks but are absent in Cretaceous rocks (Table 7.19). The Eocene volcanic rocks contain perlite and volcanic glass, and sediments of the same age are locally bentonitic or zeolitized. Among these occurrences, the Frenier deposit has been an intermittent producer of perlite. The Miocene Pliocene sediments of the Chilcotin Group are the host for lenses of diatomaceous earth and rhyolite ash, but all are undeveloped.

PERLITE AND ITS OCCURRENCES

Perlitic rhyolite flows and subvolcanic intrusions form part of the Eocene succession on the west side of the Fraser River between Ward and Grinder creeks. The Frenier deposit (P2) has been an intermittent producer of perlite. The only other perlite occurrences, one near Higginbottom Creek (P1) and the other on the ridge northwest of Moore Lake (P3) do not have the expansion qualities of the Frenier perlite and are undeveloped.

BRIEF DESCRIPTIONS OF OCCURRENCES

P1 Lot 4786

MINFILE:	092O **	STATUS:	Prospect
NTS:	92O/8W	TYPE:	Volcanic
LAT./LONG.:	51°21´00´´;	122°19´46´´	
UTM:	EM0546700 E;	EM5688750 N	
ELEVATION:	1385 m (4550 feet)		

References: Green (1989); McCammon (1950).

P2 Frenier Deposit

MINFILE:	092O 072	STATUS:	Past Producer
NTS:	92O/8W	TYPE:	Volcanic
LAT./LONG.:	51°20´28´´;	122°20´59´´	
UTM:	EM0545300 E;	EM5687750 N	
ELEVATION:	1235 m (4050 feet)		

In 1949, perlite was first discovered on the Gem 1 and Gem 2 claims which McCammon (1950) described as being on Lot 5151 on Higginbottom Creek. Although McCammon noted that the expanded perlite floated in water and that a large volume was present, the showing changed hands several times and remained undeveloped until 1978 when preliminary mapping, sampling, testing and economic evaluation began (Meyers, 1978). In 1982, after Aurun Mines Ltd. acquired the property, these activities continued (Horne, 1982) and escalated in 1983 (Schindler, 1983) after encouraging results from expansion tests on a 1-ton bulk sample. In 1983, a program involving 29 hand-dug test pits, 1554 lineal metres of trenching, 340.5 metres of HQ diamond drilling, and 332 expandability tests, outlined a perlite reserve that Aurun Mines Ltd. estimated as 3.8 million tonnes, based on a specific gravity of crude perlite of 2.3 and assuming a depth of 30 metres. In the fall of 1983 the company mined a 1000-tonne bulk sample and trucked it to a perlite expansion plant that it had constructed in Aldergrove. The company started intermittent production from an open pit in 1984 at a rate of about 3000 tonnes per year (Anonymous, 1987), and terminated production in 1989. The crude perlite was trucked to Aldergrove where it was expanded, packaged and shipped.

Chemical analyses (Table 7.20) show that the perlite is a siliceous rhyolite, as are the nearby rocks (ST analyses) which are not expandible (Figure 7.3). Product specification data (Table 7.21) yield an expandability factor, calculated from the ratio of true density:bulk density, ranging

TABLE 7.19
INDUSTRIAL MINERALS ALONG THE FRASER RIVER FROM
LILLOOET TO THE CHILCOTIN RIVER

Loc #	Property	Commodity*	Rock Unit	Status	Location Easting	Location Northing	Cert	MINFILE Number
WORD CREEK TO LONE CABIN CREEK								
B1	Table Mountain	Bentonite	**	Showing	EN0542000	EN5708600	1	092O111
B2	Churn Creek	Bentonite	**	Showing	EN0546600	EN5708000	1	092O112
B3	Empire Valley Rd.	Bentonite	**	Showing	EN0548800	EN5705800	1	092O113
B4	Empire	Bentonite	**	Showing	EN0549950	EN5702150	1	092O114
B5	Grinder Creek	Bentonite	**	Showing	EM0553150	EM5693000	1	092O115
B6	Lone Cabin Creek	Bentonite	**	Showing	EM0548750	EM5686500	1	092O116
D1	Airfield	Diatomite	Ms	Showing	EN0549400	EN5719140	1	092O130
D2	Prentice West	Diatomite	Ms	Showing	EN0544800	EN5718630	1	092O129
D3	Prentice East	Diatomite	Ms	Showing	EN0546390	EN5718400	1	092O127
D4	Prentice South	Diatomite	Ms	Showing	EN0546130	EN5717550	1	092O128
D5	Gang Ranch	Diatomite	Ms	Showing	EN0542890	EN5709770	1	092O126
P1	**	Perlite	Eva	Prospect	EM0546700	EM5688750	1	092O072
P2	Frenier	Perlite	Eva	Producer	EM0545300	EM5687750	1	092O072
Z1	Churn Valley	Zeolite	**	Showing	EN0546450	EN5707800	1	092O117
Z2	Lot 4622	Zeolite	**	Showing	EN0548100	EN5705500	1	092O118
Z3	Lot 843	Zeolite	**	Showing	EN0549150	EN5703900	1	092O119
Z4	Lot 156	Zeolite	**	Showing	EM0552700	EM5693750	1	092O120
CROWS BAR TO BIG BAR CREEK:								
B7	Crows Bar	Bentonite	Evax	Showing	EM0556300	EM5683650	1	092O098
B8	French Bar	Bentonite	Evdx	Showing	EM0560700	EM5674000	1	092O099
Z5	L3155	Zeolite	Evax	Showing	EM0554000	EM5685450	1	092O100
WARD CREEK TO WATSON BAR CREEK:								
B9	N.Ward Creek	Bentonite	Etfs	Showing	EM0562500	EM5664900	1	092O101
B10	S.Ward Creek	Bentonite	Etfs	Showing	EM0564400	EM5662100	1	092O102
G1	Moore Lake	Vol. Glass	Eva	Showing	EM0555900	EM5667925	1	092O103
G2	Mooney's Ranch	Vol. Glass	Eva	Showing	EM0562800	EM5665750	1	092O104
G3	Ward Creek	Vol. Glass	Eva	Showing	EM0563700	EM5664700	1	092O105
P3	French Bar Creek	Perlite	Eva	Showing	EM0554550	EM5669450	1	092O106
Z6	North Mooney's	Zeolite	Evax	Showing	EM0563800	EM5667250	1	092O107
Z7	South Mooney's	Zeolite	Evax	Showing	EM0564000	EM5664550	1	092O108
Z8	Ward Canyon	Zeolite	Eva	Showing	EM0563900	EM5664000	1	092O109
Z9	Watson Bar	Zeolite	Eva	Showing	EM0566350	EM5660900	1	092O110
McKAY CREEK TO GLEN FRASER:								
B11	W.Blue Ridge	Bentonite	Evdx	Showing	EM0578100	EM5638350	1	092INW092
B12	E.Blue Ridge	Bentonite	Evdx	Showing	EM0579400	EM5638100	1	092INW093
B13	Glen Fraser	Bentonite	Evdx	Showing	EM0580100	EM5631100	1	092INW094

* Diatomite = Diatomaceous Earth; Vol. Glass = Volcanic Glass

from 14.4 to 57.5.

References: Anonymous (1979, 1985, 1986, 1987); Green (1989, 1990); Green and Trupia (1989); Horne (1983); McCammon (1950); Mathews (1949); Meyers (1978); Schindler (1983); Trupia (1989); Wilson (1981).

P3 French Bar Creek

MINFILE:	092O 106	STATUS:	Showing
NTS:	92O/1E	TYPE:	Volcanic
LAT./LONG.:	51°10′33′′;	122°13′11′′	
UTM:	EM0554550 E;	EM5669450 N	
ELEVATION:	1590 m (5225 feet)		

The showing is on a ridge crest overlooking South French Bar and Moore creeks at the northwestern end of a northwesterly trending syncline. It is a perlitic, slightly porphyritic (biotite, hornblende, plagioclase) rhyolite flow of unit Eva, and has a minimum thickness of 10 metres with top and bottom contacts unexposed. Upon heating in a blowtorch bench-test, the sample expanded to 50% of the volume attained by perlite from the Frenier deposit (Table 7.22).

References: Read (1988b, 1988c).

TABLE 7.20
FRENIER DEPOSIT, CHEMICAL ANALYSES OF PERLITE

Component	Frenier	#6603	ST-1A	ST-6P	ST-10
SiO_2	74.41	71.50	72.87	73.79	74.09
TiO_2	n.d.	n.d.	0.07	0.07	0.07
Al_2O_3	11.97	12.23	11.90	11.96	11.98
Fe_2O3**	0.97	1.37	0.78	0.81	0.81
CaO	1.19	0.64	1.18	0.89	0.55
MnO	n.d.	n.d.	0.03	0.04	0.04
MgO	0.23	0.06	0.18	0.32	0.16
Na_2O	2.27	2.37	2.21	2.41	3.12
K_2O	4.58	3.89	4.60	4.71	4.85
P_2O_5	n.d.	n.d.	0.01	0.01	0.01
H_2O+105°***	5.38	4.10	5.53*	4.74*	4.11*
H_2O-105°***	0.80	0.19	5.53*	4.74*	4.11*
TOTALS	101.80	96.35	99.36	99.75	99.79

* Values for Loss on Ignition
** Total iron expressed as Fe2 O3
*** H_2O-105° = free water; H_2O+105° = combined water

Sources of analyses: Frenier, Willson (1981); #6603, Horne (1982); ST-1A to ST-10, Trupia (1989).

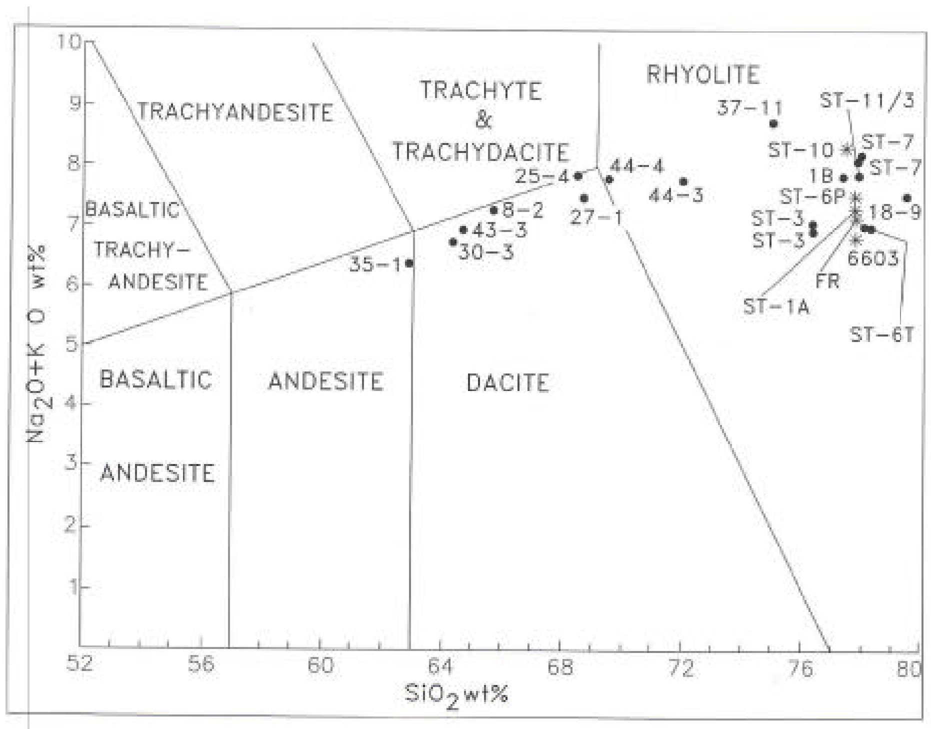

Figure 7.3. Total alkali silica (TAS) diagram (LeMaitre, 1989) showing the composition distribution of analyzed Eocene volcanic rocks from the Gang Ranch area. The asterisked samples are perlite from the Frenier deposit (P2). The C-series are nonperlitic volcanic glasses.

VOLCANIC GLASS AND ITS OCCURRENCES

The remainder of the materials collected as possible perlite showed no expansion upon heating with a blowtorch (Table 7.22), and are reported as volcanic glass localities. The glass is from slightly porphyritic (hornblende, pyroxene, biotite, quartz, plagiolase) rhyolite vitrophyre flows which probably occur at two different stratigraphic levels within the thick succession of Eocene flows of unit Evd. On the southwest face of the ridge northeast of Moore Lake (G1), a vitrophyre flow is part of a thick succession of aphanitic dacite flows. Volcanic glass outcrops in two places (G2 and G3) at the top of the aphanitic dacite flows of unit Evd. In outcrop and in thin section, the volcanic glass shows a perlitic texture.

BRIEF DESCRIPTIONS OF OCCURRENCES

G1 Moore Lake

MINFILE:	092O 103	STATUS:	Showing
NTS:	92O/1E	TYPE:	Volcanic

TABLE 7.21
FRENIER DEPOSIT, TYPICAL PHYSICAL PROPERTIES

Form	fine granules
Colour	white (brightness = 75)
Diameter	4 mesh (4.8 mm) and finer, as desired
Refractive index	1.5
True density	2.3 g/cc (140pcf)
Bulk density	0.04-0.16 g/cc (2.5-10 pcf)
Softening point	870-1090°C (1600-2000°F))
Fusion point	1260-1340ºC (2300-2450ºF)
Specific heat	840 J/kg °K (0.2./g °C)
Thermal conductivity	0.04 W/m °K (0.3 BTU in/h/ft2/°F)
Solubles, water	less than 0.1%

LAT./LONG:	51°09´42´´;	122°12´02´´
UTM:	EM0555900 E;	EM5667925 N
ELEVATION:	1555 m (5100 feet)	

The location given is centrally located relative to three outcrops of volcanic glass which span an elevation range of 1510 to 1615 metres (4950 to 5300 feet) on the ridge northeast of Moore Lake. In this area the attitudes of the flow-layered rocks suggest that the grey vitrophyric flows and French Bar perlite (P3) may be part of the same horizon which outlines a northwesterly trending and horizontally plunging, upright syncline with a preserved hinge line 2500 metres long.
References: Read (1988b, 1988c).

G2 Mooney's Ranch

MINFILE:	092O 104	STATUS:	Showing
NTS:	92O/1E	TYPE:	Volcanic
LAT./LONG:	51°08´30´´;	122°06´08´´	
UTM:	EM0562800 E;	EM5665750 N	
ELEVATION:	1080 m (3550 feet)		

On an unused section of the farm road descending to Mooney's Ranch, a low roadcut and the roadbed expose medium to dark grey volcanic glass. Although this exposure is a kilometre distant from the next outcrop, it is probably part of the same horizon as the Ward Creek volcanic glass (G3) 1.4 kilometres to the southeast.
References: Read (1988b, 1988c).

G3 Ward Creek

MINFILE:	092O 105	STATUS:	Showing
NTS:	92O/1E	TYPE:	Volcanic
LAT./LONG.:	51°07´56´´;	122°05´23´´	
UTM:	EM0563700 E;	EM5664700 N	
ELEVATION:	1050 m (3450 feet)		

The ridge top on the north side of Ward Creek exposes a strike length of 45 metres of a subvertical volcanic glass of unknown thickness. Although the showing is limited by overburden on the northwest, the attitude of flow layering suggests that it is part of the same horizon as that exposed at Mooney's Ranch (G2).
References: Read (1988b, 1988c).

DIATOMACEOUS EARTH AND ITS OCCURRENCES

Diatomaceous earth is restricted to the Miocene sediments of the Fraser Bend Formation which underlie the basalt flows of the Chilcotin Group. In the Fraser River valley, the southernmost occurrence of diatomaceous earth is as clasts in a lahar exposed between Churn and Gaspard creeks (D5) (Green, 1989; Green and Trupia, 1989). North of Gaspard Creek, between Prentice Gulch and Word Creek, diatomaceous earth outcrops in three places (D2, D3 and D4) and probably underlies some of the rolling topography between 625 metres (2050 feet) and 840 metres (2750 feet) elevation. On the east side of the Fraser River, diatomaceous rhyolite ash is exposed at 855 metres (2800 feet) elevation (D1).

BRIEF DESCRIPTIONS OF OCCURRENCES

D1 Airfield

MINFILE:	092O 130	STATUS:	Showing
NTS:	92O/9W	TYPE:	Sedimentary
LAT./LONG.:	51°37´23´´;	122°17´11´´	
UTM	EN0549400 E;	EN5719140 N	
ELEVATION:	855 m (2800 feet)		

The showing is a layer of diatomaceous, bedded rhyolite ash, 6 metres thick, immediately under basalt flows of

TABLE 7.22
WARD CREEK TO WATSON BAR CREEK:
PERLITE AND VOLCANIC GLASS: BLOW TORCH EXPANSION DATA

Loc #	Property	Commodity	Location Easting	Location Northing	Expansion* (%)	Comments
P2	Frenier	Perlite	EM0545300	EM5687750	100	all expanded
P3	French Bar Creek	Perlite	EM0554550	EM5669450	50	some unexpanded inclusions
G1	Moore Lake	Volcanic glass	EM0555800	EM5668300	0	no expansion
G1	Moore Lake	Volcanic glass	EM0560030	EM5667580	0	no expansion
G1	Moore Lake	Volcanic glass	EM0555850	EM5668330	0	no expansion
G2	Mooney's Ranch	Volcanic glass	EM0562800	EM5665750	0	no expansion
G3	Ward Creek	Volcanic glass	EM0563700	EM5664700	0	no expansion

* Percentage of expansion relative to perlite from Frenier deposit (P2) taken as 100% expansion.

the Chilcotin Group. Microscopic examination shows abundant rhyolite glass shards (refractive index: 1.500(0.002) and common diatoms.

References: Hickson *et al*. (1991a, 1991b).

D2 Prentice West

MINFILE:	092O 129	STATUS:	Showing
NTS:	920/9W	TYPE:	Sedimentary
LAT./LONG:	51°37′08′′;	122°21′10′′	
UTM:	EN0544800 E;	EN5718630 N	
ELEVATION:	840 m (2750 feet)		

The showing is a bank of white-weathering, disaggregated diatomaceous siltstone that is so slumped that the dimensions of the occurrence cannot be estimated. Microscopic examination shows that the material contains abundant diatoms.

References: Hickson *et al*. (1991a, 1991b).

D3 Prentice East

MINFILE:	092O 127	STATUS:	Showing
NTS:	92O/9W	TYPE:	Sedimentary
LAT./LONG:	51°37′00′′;	122°19′48′′	
UTM:	EN0546390 E;	EN5718400 N	
ELEVATION:	655 m (2150 feet)		

The showing is at the top of a steep bank, over 100 metres high, composed of slumped outcrop of white-weathering rhyolite ash, bentonitic ash and diatomaceous earth underlying the upper 20 metres. Another occurrence at EN0546520 E, EN5718700 N may be part of a slide. Microscopic examination shows that the material contains abundant diatoms.

References: Hickson *et al*.(1991a, 1991b).

D4 Prentice South

MINFILE:	092O 128	STATUS:	Showing
NTS:	92O/9W	TYPE:	Sedimentary
LAT./LONG:	51°36′32′′;	122°20′02′′	
UTM:	EN0546130 E;	EN5717550 N	
ELEVATION:	700 m (2350 feet)		

The showing consists of slumped outcrops of white-weathering rhyolite ash and diatomaceous earth exposed at the top of a bank 100 metres high that ends in Prentice Gulch. Microscopic examination shows that it contains abundant diatoms.

References: Hickson *et al*. (1991a, 1991b).

D5 Gang Ranch

MINFILE:	092O 126	STATUS:	Showing
NTS:	92O/9W	TYPE:	Sedimentary
LAT./LONG:	51°32′22′′;	122°22′54′′	
UTM:	EN0542890 E;	EN5709770 N	
ELEVATION:	790 m (2600 feet)		

A roadcut exposes a Miocene lahar composed of Eocene volcanic clasts and fragments of Miocene rhyolite ash and diatomaceous earth.

References: Green (1989); Green and Trupia (1989).

BENTONITE AND ITS OCCURRENCES

Bentonite-rich rocks are restricted to the Eocene succession where they occur in sediments of the upper part, and in the partly waterlain tephra within the underlying thick volcanic package. Bentonite is apparently absent from Cretaceous and older rocks and is sparsely developed in the Miocene and younger sediments. In the Eocene sediments, bentonite develops in waterlain tuff and tuffaceous shale and siltstone in Churn Creek (B2), along the Empire Valley road a few kilometres to the southeast, and about 23 kilometres to the south-southeast in the sediments straddling the lower part of Crows Bar Creek (B7). In the Eocene volcanic rocks, waterlain lenses of ash and lapilli tuff of aphanitic dacite and andesite are host to scattered bentonite occurrences in units Evdx and Etfs for 45 kilometres from north of Big Bar Creek (B8) to Glen Fraser (B13) along the Fraser River. Chemical analyses of montmorillonite (Table 7.23), the principal mineral of bentonite, and exchangeable cation analyses of bentonite (Table 7.24) show that divalent cations dominate.

BRIEF DESCRIPTIONS OF OCCURRENCES

B1 Table Mountain

MINFILE:	092O 111	STATUS:	Showing
NTS:	920/9W	TYPE:	Volcanogenic
LAT./LONG.:	51°31′44″	122°23′40″	
UTM:	EN0542000 E;	EN5708600 N	
ELEVATION:	1010 m (3300 feet)		

TABLE 7.23
ANALYSES OF MONTMORILLONITE FROM THE GANG RANCH AREA

Sample #	**14-6/2**	**20-10**	**22-5/1**	**43-4/1**	**43-11/2**
SiO_2	60.87	64.49	49.94	53.89	59.80
TiO_2	0.99	0.44	0.63	0.86	0.63
Al_2O_3	13.29	14.80	16.90	19.35	22.36
Fe_2O_3*	7.49	5.20	6.22	8.32	4.90
CaO	2.47	2.62	8.89	2.55	1.16
MnO	0.11	0.05	0.06	0.14	0.01
FeO	na	na	na	na	na
MgO	6.30	3.28	4.18	3.99	1.68
Na_2O	0.68	0.88	0.31	lt 0.15	0.89
K_2O	1.87	1.30	1.08	3.42	0.31
P_2O_5	0.29	0.06	0.26	0.22	0.66
H_2O+105°*	na	na	na	na	na
TOTALS	94.34	93.13	88.47	92.73	92.40
Ions per unit cell on the basis of 44 -charges					
Si	8.13	8.42	7.27	7.44	7.85
Al	2.09	2.28	2.90	3.15	3.46
Fe*	0.75	0.51	0.68	0.87	0.48
Mg	1.25	0.64	0.91	0.82	0.33
Ca	0.35	0.37	1.39	0.38	0.16
Na	0.17	0.22	0.09	0.04	0.23
K	0.32	0.22	0.20	0.60	0.05
Ca+Mg	1.60	1.01	2.30	1.20	0.49
Na+K	0.49	0.44	0.29	0.64	0.28
$\frac{Na+K}{Na+K+Ca+Mg}$	0.23	0.30	0.11	0.35	0.36

* Total Fe given as Fe_2O_3, and water content not determined due to insufficient amount of sample

Source of analyses: Green (1990).

TABLE 7.24
FRASER RIVER - LILLOOET TO THE CHILCOTIN RIVER:
EXCHANGEABLE Ca, Na, K, AND Mg ANALYSES
AND CATION EXCHANGE CAPACITY (CEC)*

Location/ Sample	Loc# UTM	Exchangeable Cation Analysis (mequiv./100 g)					
		Mg	Ca	K	Na	Total	CEC
WORD CREEK TO LONE CABIN CREEK:							
C1	B3	1.40	7.02	1.04	4.68	14.14	15.5
C2	Z3	3.14	31.8	9.23	41.4	85.6	87.0
C3	0550450 5700250	0.96	22.6	4.35	23.2	51.1	52.8
C4	0549200 5698100	3.25	31.6	1.24	0.47	36.6	34.7
C5	Z4	1.60	54.5	15.1	34.0	105.2	106.0
C6	0552810 5692590	0.53	17.3	2.02	18.9	38.8	42.8
C7	0550690 5693700	3.07	27.3	7.84	4.09	42.3	43.9
C8	0545875 5689300	5.81	14.1	7.19	0.44	27.5	27.7
CROW'S BAR CREEK TO BIG BAR CREEK:							
C87-556J1	B7	15.50	28.75	3.75	6.50	54.50	45.5
C87-557N1	Z5	2.75	42.50	8.50	29.25	83.00	82.1
WARD CREEK TO WATSON BAR CREEK:							
C87-534(1)	Z6	1.13	28.25	6.50	33.00	68.88	69.9
C87-532C4	Z7	0.53	18.75	18.75	23.75	61.78	58.5
C87-529D	Z8	2.75	29.25	5.25	38.50	75.75	72.3
McKAY CREEK TO GLEN FRASER:							
C87-494(2)	B13	9.00	52.25	1.35	31.75	94.35	67.0

* B = bentonite Z = zeolite
Analyzed samples, with the exception of C1 to C8, weigh 10-15 grams, and were crushed to -120 mesh.

The location given is centrally situated within an east-west elongate area measuring 100 by 750 metres along the south-facing slope of a flat-topped mountain locally known as “Table Mountain”. White, bentonitic ash layers occur within a succession of pink to maroon dacite breccias.
Reference: Green (1989).

B2 Churn Creek

MINFILE:	092O 112	STATUS:	Showing
NTS:	92O/9W	TYPE:	Volcanogenic
LAT./LONG:	51°31′23′′;	122°19′42′′	
UTM:	EN0546600 E;	EN5708000 N	
ELEVATION:	425 m (1400 feet)		

The location is centrally located within a south-southeast elongate area measuring 250 by 1000 metres along the southern slopes of Churn Creek canyon. At least two bentonitic ash layers, typically 10 to 20 metres thick, occur within an accumulation of dacite breccia along Churn Creek. Deformation along the Fraser fault has structurally repeated these layers on high-angle, easterly-dipping, reverse faults. This bentonite occurrence is the largest of the structurally repeated bentonite layers exposed along Churn Creek. It is likely that such bentonite layers extend both north and south beneath the Quaternary cover.
Reference: Green (1989).

B3 Empire Valley Road

MINFILE:	092O 113	STATUS:	Showing
NTS:	92O/9W	TYPE:	Volcanogenic
LAT./LONG.:	51°30′11′′;	122°17′49′′	
UTM:	EN0548800 E; EN5705800 N		
ELEVATION:	520 m (1700 feet)		

A roadcut at the northern end of Empire Valley road exposes a subvertical lens of greenish bentonitic ash that is 5 to 10 metres wide. About 300 metres east of this exposure, motion along the Fraser fault caused a complex zone of high-angle faulting. In the roadcut, faults juxtapose the bentonite against Eocene conglomerate (unit Ecg) to the

west and dark brown weathering basalt of unit Evb to the east. An exchangeable cation analysis indicates a sodium-bearing calcium montmorillonite (Table 7.24).
Reference: Green (1989).

B4 Empire

MINFILE:	092O 114	STATUS:	Showing
NTS:	92O/8W	TYPE:	Volcanogenic
LAT./LONG:	51°28′13′′;	122°16′51′′	
UTM:	EN0549950 E;	EN5702150 N	
ELEVATION:	695 m (2275 feet)		

At this locality, bentonite is exposed in a small seasonal drainage gully less than 300 metres west of Empire Valley road. The bentonite lies close to a brownish red weathering basalt flow that extends northward for 2 kilometres where it is overlain by rhyolite crystal tuff with similar interbedded bentonite layers.
Reference: Green (1989).

B5 Grinder Creek

MINFILE:	092O 115	STATUS:	Showing
NTS:	92O/8W	TYPE:	Volcanogenic
LAT./LONG:	51°23′18′′;	122°14′10′′	
UTM:	EM0553150 E;	EM5693000 N	
ELEVATION:	550 m (1800 feet)		

The location given is centrally located in a northwesterly elongate area measuring 150 by 1000 metres. Within the area, the Fraser fault places white bentonite-rich ash layers against black chert and argillite of the Cache Creek Complex on the east. The bentonite layers are intercalated with maroon to brown basalt flows (unit Evb) and volcanic breccia (unit Evt) and stratigraphically underlie a well-bedded sequence of Eocene sediments (unit Ecg).
Reference: Green (1989).

B6 Lone Cabin Creek

MINFILE:	092O 116	STATUS:	Showing
NTS:	92O/8W	TYPE:	Volcanogenic
LAT./LONG:	51°19′47′′;	122°18′01′′	
UTM:	EM0548750 E;	EM5686500 N	
ELEVATION:	840 m (2750 feet)		

On the northern slope above Lone Cabin Creek are outcrops of a bentonite layer, 10 to 20 metres wide, that it exposed for a strike length of about 750 metres. The bentonite is inferred to underlie well-bedded Eocene siltstone, but slumping has made stratigraphic relationships uncertain.
Reference: Green (1989).

B7 Crows Bar

MINFILE:	092O 098	STATUS:	Showing
NTS:	92O/8E	TYPE:	Sedimentary
LAT./LONG:	51°18′12′;	122°11′33′′	
UTM:	EM0556300 E;	EM5683650 N	
ELEVATION:	640 m (2100 feet)		

The location given is centrally situated within a northwesterly elongate area measuring 500 by 1500 metres that straddles the lower part of Crows Bar Creek. Within it, rounded hills expose slumped bentonite in bentonitic shale and siltstone of unit Ep, and maroon and brown aphanitic dacite/andesite lapilli tuff and rhyolite tephra of unit Evax. Analysis of a sample shows that it contains mainly divalent exchangeable cations (Table 7.24).
References: Read (1988b, 1988c).

To the southeast, an 8-kilometre outcrop gap, probably underlain by bentonitic rocks, separates showing B7 from B8 (Photo 6.4).

B8 French Bar

MINFILE:	092O 099	STATUS:	Showing
NTS:	92O/1E	TYPE:	Volcanogenic
LAT./LONG.:	51°12′58′′;	122°07′51′′	
UTM:	EM0560700 E;	EM5674000 N	
ELEVATION:	745 m (2450 feet)		

The location is centrally situated in a northwesterly elongate area of rounded hills and landslides measuring 300 by 2500 metres that expose bentonitic lapilli ash tuff composed of aphanitic dacite and andesite of unit Evdx (Photo 6.4). Some cream-weathering rhyolite tephra and some brown and maroon-weathering andesite lapilli layers and lenses occur within the bentonite. The area is the source of debris flows and a block slide which flowed through a breach in the volcanic conglomerate cliffs (unit Ecg) and dropped nearly 500 metres to the Fraser River. The two bentonite-rich areas of B7 and B8 lie either immediately above or below the volcanic conglomerate.
References: Read (1988b, 1988c).

To the southeast, between Big Bar Ferry and Watson Bar Creek, the bentonite of showings B9 and B10 lies lower in the stratigraphy beneath andesite breccia and rhyolite flows and tephra. In a northwesterly elongate area measuring about 1 by 5 kilometres, straddling Ward Creek, bentonite lenses up to a few metres thick are scattered through fine, varicoloured dacite and andesite breccia, rhyolite tephra and bedded volcaniclastic sediments.

B9 North Ward Creek

MINFILE:	092O 101	STATUS:	Showing
NTS:	92O/1E	TYPE:	Sedimentary
LAT./LONG.:	51°08′03′′;	122°06′24′′	
UTM:	EM0562500 E;	EM5664900 N	
ELEVATION:	1005 m (3300 feet)		

The location given is centrally situated within a 1000-metre-long area on the north side of Ward Creek. A gently north-dipping sequence contains 5% white quartz sandstone, 15% bentonite-rich sediments, 20% quartz-feldspar sandstone with bentonite and 60% maroon and buff dacite and andesite lapilli tuff of unit Etfs (Photo 6.3).
References: Read (1988b, 1988c).

B10 South Ward Creek

MINFILE:	092O 102	STATUS:	Showing
NTS:	92O/1E	TYPE:	Sedimentary
LAT./LONG.:	51°06′31′′;	122°04′48′′	
UTM:	EM0564400 E;	EM5662100 N	
ELEVATION:	1035 m (3400 feet)		

The location given is centrally situated in an area about 800 metres long. The bentonite-rich rocks lie in the core of a northerly trending anticline composed of maroon and brown-weathering lapilli tuff of dacite and andesite composition, rhyolite tuff and bentonite-rich lenses of unit Etfs up to 1.5 metres thick.

References: Read (1988b, 1988c).

To the south of B10, the Hungry Valley fault truncates the waterlain bentonitic sediments that host showings B9 and B10, and on the east, the Fraser fault terminates the Eocene rocks. For the next 20 kilometres to the south-southeast, to as far as the area north of Slok Creek, Eocene rocks are absent. A few kilometres south of Slok Creek, between McKay Creek and Glen Fraser, bentonitic rocks outcrop east of the Fraser fault at showings B11 and B12, and another 7 kilometres southward and they reappear west of the fault at showing B13. These showings are within the basal few hundred metres of the Eocene section.

B11 West Blue Ridge

MINFILE:	092INW092	STATUS:	Showing
NTS:	92I/13W	TYPE:	Volcanogenic
LAT./LONG:	50°53′37′′;	121°53′22′′	
UTM:	EM0578100 E;	EM5638350 N	
ELEVATION:	565 m (1850 feet)		

The showing is located on Blue Ridge Ranch, within 100 metres of the Fraser fault. Bentonite-rich layers, up to several metres in thickness, lie in a sequence of brown, maroon and grey aphanitic dacite and andesite lapilli tuff of unit Evdx. The bedding attitude of 340/28SW yields a strike parallel to the fault, but the moderate southwesterly dip indicates that the bentonitic rocks terminate against the fault.

References: Read (1988b, 1988c).

B12 East Blue Ridge

MINFILE:	092INW093	STATUS:	Showing
NTS:	92I/13W	TYPE:	Volcanogenic
LAT./LONG:	50°53′28′′;	121°52′16′′	
UTM:	EM0579400 E;	EM5638100 N	
ELEVATION:	455 m (1500 feet)		

The showing is located below the irrigated fields of Blue Ridge Ranch. It measures about 100 metres square of slumped outcrop of unit Evdx, but additional material may subcrop beneath the benches in this area of sparse outcrops. The showing is within 100 metres of the base of the Eocene section and appears free of lapilli tuff.

References: Read (1988b, 1988c).

B13 Glen Fraser

MINFILE:	092INW094	STATUS:	Showing
NTS:	92I/13W	TYPE:	Volcanogenic
LAT./LONG:	50°49′41′′;	121°51′46′′	
UTM:	EM0580100 E;	EM5631100 N	
ELEVATION:	490 m (1600 feet)		

The showing is located in the gullies below Highway 12 where intercalated brown, grey and maroon-weathering, aphanitic lapilli tuff of unit Evdx outcrops about 100 metres above the base of the Eocene section. Analysis of a sample indicates mainly divalent exchangeable cations (Table 7.24).

References: Read (1988b, 1988c).

ZEOLITES AND THEIR OCCURRENCES

Zeolitized rocks are restricted to the volcanic portion of the Eocene succession. They develop within waterlain lenses of rhyolite tephra which are up to 100 metres thick and a few kilometres long and are located up to 1000 metres beneath the upper sedimentary package. x-ray diffraction, heat treatment, exchangeable cation analyses (Table 7.24) and four chemical analyses of zeolites from rhyolite tuff (Table 7.25) show that the zeolites present are compositionally intermediate to potassium-rich members of the heulandite-clinoptilolite series. Showings of zeolitized waterlain rhyolite ash and accompanying rhyolite and andesite tephra occur between Gang Ranch and the Hungry Valley fault at Watson Bar Creek; they are absent to the north and south. Within and up to 100 metres beneath the volcanic conglomerate of unit Ecg, local tuffaceous arenite layers are weakly zeolitized with heulandite-clinoptilolite.

TABLE 7.25
ANALYSES OF ZEOLITES FROM
GANG RANCH AREA

Sample # / Map #	16-9Z / Z3	18-7Z	19-10Z	36-12Z
SiO_2	73.72	73.25	74.12	72.41
TiO_2	0.10	0.10	0.10	0.09
Al_2O_3	11.63	12.21	11.81	11.50
Fe_2O_3*	0.79	0.73	0.86	0.68
CaO	1.72	1.68	1.26	1.81
MnO	0.01	0.01	0.01	0.01
FeO	na	na	na	na
MgO	lt 0.35	0.40	lt 0.35	0.37
Na_2O	2.01	0.86	1.13	1.20
K_2O	2.88	5.31	5.40	3.62
P_2O_5	0.01	0.02	0.01	0.01
H_2O+105°**	6.31	4.67	4.25	8.27
TOTALS	99.50	99.24	99.15	99.97
Ions per unit cell on the basis of 72 oxygens				
Si	30.68	30.05	30.33	30.38
Al	5.71	5.91	5.70	5.69
Fe*	0.25	0.23	0.26	0.21
Mg	lt 0.20	0.24	lt 0.20	0.23
Ca	0.77	0.74	0.55	0.81
Na	0.54	0.68	0.89	0.97
K	1.53	2.78	2.82	1.94
Ca+Mg	lt 0.97	0.98 lt	0.75	1.04
Na+K	2.07	2.46	3.71	2.91
$\frac{Na+K}{Na+K+Ca+Mg}$	0 66	0.72	0.83	0.74

* Total Fe given as Fe_2O_3
** H_2O+105° = combined water
Source of analyses: Green (1990).

BRIEF DESCRIPTIONS OF OCCURRENCES

Z1 Churn Valley

MINFILE:	092O 117	STATUS:	Showing
NTS:	92O/9W	TYPE:	Volcanogenic
LAT./LONG.:	51°31´17´´;	122°19´50´´	
UTM:	EN0546450 E;	EN5707800 N	
ELEVATION:	535 m (1750 feet)		

This location is the westernmost occurrence of zeolitized rhyolite tephra along the south side of Churn Creek. Here, bedded light green to white crystal lapilli-ash tuff ranges from 10 to 20 metres in thickness and overlies dacite breccia. X-ray diffractograms of samples from this locality indicate the presence of heulandite-clinoptilolite.
Reference: Green (1989).

Z2 Lot 4622

MINFILE:	092O 118	STATUS:	Showing
NTS:	92O/9W	TYPE:	Volcanogenic
LAT./LONG.:	51°30´02´´;	122°18´25´´	
UTM:	EN0548100 E;	EN5705500 N	
ELEVATION:	710 m (2325 feet)		

The location given is centrally situated in a 50 by 500 metre, northwesterly trending exposure of rhyolite tephra. In the outcrop, bentonite-rich ash layers grade upward into well-bedded crystal and lapilli tuff. X-ray diffractograms of samples indicate the presence of heulandite-clinoptilolite.
Reference: Green (1989).

Z3 Lot 843

MINFILE:	092O 119	STATUS:	Showing
NTS:	92O/8W	TYPE:	Volcanogenic
LAT./LONG.:	51°29´10´´;	122°17´34´´	
UTM:	EN0549150 E;	EN5703900 N	
ELEVATION:	610 m (2000 feet)		

Outcrops of green and white rhyolite tephra overlie ochre-red to brown volcanic breccia of unit Evb. The tephra is about 20 metres thick and consists of well-bedded lapilli tuff with minor interbeds of bentonite-rich ash. X-ray diffractograms indicate the presence of heulandite-clinoptilolite and an exchangeable cation analysis (Table 7.24) shows dominantly monovalent exchangeable cations which implies a clinoptilolite-rich composition.
Reference: Green (1989).

Z4 Lot 156

MINFILE:	092O 120	STATUS:	Showing
NTS:	92O/8W	TYPE:	Volcanogenic
LAT./LONG.:	51°23´44´´;	122°14´34´´	
UTM:	EM0552700 E;	EM5693750 N	
ELEVATION:	730 m (2400 feet)		

The location is centrally situated along a northwesterly elongate tephra layer that measures approximately 20 by 300 metres. The tephra, composed mainly of green lapilli tuff, is interlayered with andesite volcanic breccia of unit Evt. X-ray diffractograms of the tuff show heulandite-clinoptilolite and an exchangeable cation analysis (Table 7.24) indicates an intermediate composition in the heulandite-clinoptilolite group with the highest cation exchange capacity, at 106.0 milli equivalents per 100 grams, of all samples analyzed in the Gang Ranch and Empire Valley Ranch area.
Reference: Green (1989).

Z5 L3155

MINFILE:	092O 100	STATUS:	Showing
NTS:	92O/8E	TYPE:	Sedimentary
LAT./LONG.:	51°19´11´´;	122°13´30´´	
UTM:	EM0554000 E;	EM5685450 N	
ELEVATION:	580 m (1900 feet)		

This location is an old roadcut at the northeast end of a lens, 700 metres long, of waterlain rhyolite tephra of unit Evax which widens and drops 260 metres in elevation to the east bank of the Fraser River. The lens has an attitude of 030/72SE, is over 10 metres wide at the roadcut where it has been sampled, and widens to hundreds of metres to the southwest where it is unsampled. Heating tests, as described by Boles (1972), and an exchangeable cation analysis (Table 7.24) from the northeastern end of the lens indicate that the zeolite has an intermediate composition in the heulandite-clinoptilolite group.
References: Read (1988b, 1988c).

Z6 North Mooney's

MINFILE:	092O 107	STATUS:	Showing
NTS:	92O/1E	TYPE:	Sedimentary
LAT./LONG.:	51°09´18´´;	122°05´16´´	
UTM:	EM0563800 E;	EM5667250 N	
ELEVATION:	900 m (2950 feet)		

The showing is an isolated outcrop of layered rhyolite ash tuff of unit Evax with an attitude of 085/53SE. In outcrop the layer is over 5 metres thick with neither the top nor bottom contact exposed. Heating tests, as described by Boles (1972), and an exchangeable cation analysis (Table 7.24) indicate that the zeolite is a clinoptilolite-rich intermediate member of the heulandite-clinoptilolite solid solution series.
References: Read (1988b, 1988c).

Z7 South Mooney's

MINFILE:	092O 108	STATUS:	Showing
NTS:	92O/1E	TYPE:	Sedimentary
LAT./LONG.:	51°07´51´´;	122°05´07´´	
UTM:	EM0564000 E;	EM5664550 N	
ELEVATION:	1020 m (3350 feet)		

Layered white-weathering rhyolite ash of unit Evax forms a zeolitized lens over a kilometre long and up to a hundred metres thick. Heating tests, as described by Boles (1972), and an exchangeable cation analysis (Table 7.24) indicate that the zeolite is near the clinoptilolite end of the heulandite-clinoptilolite solid solution series.
References: Read (1988b, 1988c).

Z8 Ward Canyon

MINFILE:	092O 109	STATUS:	Showing
NTS:	92O/1E	TYPE:	Sedimentary
LAT./LONG.:	51°07´33´´;	122°05´13´´	
UTM:	EM0563900 E;	EM5664000 N	
ELEVATION:	890 m (2925 feet)		

The showing is a northerly trending and steeply dipping layer of rhyolite lapilli tuff of unit Eva, about 20 metres thick, which is accessible at the base of cliffs on the north side of Ward Creek. Heating tests, as described by

Boles (1972), and an exchangeable cation analysis (Table 7.24) indicate that the zeolite is near the clinoptilolite end of the heulandite-clinoptilolite solid solution series.
Reference: Read (1988b, 1988c).

Z9 Watson Bar

MINFILE:	092O 110	STATUS:	Showing
NTS:	92O/1E	TYPE:	Sedimentary
LAT./LONG.:	51°05´52´´;	122°03´09´´	
UTM:	EM0566350 E;	EM5660900 N	
ELEVATION:	640 m (2150 feet)		

In the first stream gully which enters the west side of the Fraser River north of Watson Bar Creek, is an unbedded rhyolite lapilli ash tuff of unit Eva of unknown dimensions. A heating test, as described by Boles (1972), indicates that the zeolite is a clinoptilolite-rich member of the heulandite-clinoptilolite solid solution series.
Reference: Read (1988b, 1988c).

CHAPTER 8 PROSPECTING FOR INDUSTRIAL MINERALS IN CENOZOIC ROCKS

INTRODUCTION

This investigation has covered the occurrences of bentonite, kaolinite, zeolites, volcanic glass, perlite, and diatomaceous earth in south-central British Columbia. The occurrence of any of these industrial minerals requires a combination of suitable hostrocks and the appropriate physical and chemical conditions during and following the formation of the industrial mineral. The presence of rocks, that may act as suitable hosts for an industrial mineral deposit, may be gleaned from the geological literature. The presence of suitable environments for the development of industrial minerals may be interpreted from the age and geological setting of the enclosing stratigraphy and in part from any data which reflect the temperatures that have affected the hostrocks. Ultimately, the discovery of any occurrrence of an industrial mineral rests upon the prospector's ability to recognize it.

SUITABLE HOST ROCKS AND DETERMINATIVE TESTS FOR INDUSTRIAL MINERALS

Sedimentary or volcaniclastic sedimentary rocks are suitable hosts for the development of bentonite, kaolinite, and zeolites. Although these rocks usually have an abundant clay or silt-sized fraction, hostrocks suitable for zeolite occurrences may contain lapilli up to a few centimetres in size. To be suitable, the depositional environment should be subaqueous, as indicated by the presence of plant debris in the sediments, not subaerial. At least initially, a subaqueous environment insures the presence of a fluid that will modify the original sedimentary material, be it volcanic glass for bentonite or zeolite occurrences, or extensively weathered bedrock in kaolinite occurrences. Unfortunately the Cenozoic shale and siltstone hosts for bentonite and kaolinite deposits are poorly exposed and their presence may have to be interpreted from any unstable topography mentioned in the literature or seen in aerial photographs. In addition, bentonite-rich rocks yield a characteristic "popcorn" soil (McMechan 1983, Plate V, p.18) resulting from successive expansion and contraction cycles caused by wetting and drying of the soil. Bentonite deposits develop from waterlain volcanic ash or later-altered ash and lapilli tuff of intermediate composition. Kaolinite occurrences usually lie near unconformities and are the product of a period of intense weathering of the underlying granitic or quartzofeldspathic rocks. X-ray diffractograms of samples from occurrences not only determine the presence of kaolinite and other clay minerals, but also yield a qualitative estimate of the mineral content. However, pyrometric cone equivalent tests are required to determine the refractory nature of the samples.

Rhyolite and dacite ash and lapilli tuff act as hosts for zeolite occurrences. In British Columbia all the known bedded zeolite occurrences probably developed in open, nonmarine hydrologic systems (Hay and Sheppard, 1977) in contrast to the closed systems (Surdam, 1977) present in alkaline lakes. The discovery of dawsonite may indicate that closed systems existed locally. The percolation of groundwater in an open system can develop thick, areally extensive zeolite deposits of economic importance. Although extensive zeolitization decreases the density of the hostrock, and increases its porosity and whiteness, these changes are easily missed in the field. The presence of zeolites as coatings on joints and fillings of amygdules in nearby volcanic rocks suggests that extensive zeolitization may have occurred, but only the application of x-ray diffraction powder methods to samples will identify the zeolite species present and yield a qualitative estimate of its amount.

Thin-section examinations usually misidentify the finely crystalline, low birefringent zeolites as devitrified glass instead of heulandite-clinoptilolite, or as potash feldspar instead of laumontite.

Glassy dacite or rhyolite flows and hypabyssal intrusions are not only suitable candidates for the occurrence of volcanic glass, but also perlite. Rhyolite, and particularly dacite, are fairly common in Eocene volcanic rocks, but glasses are rare and not reported from the Miocene and younger Chilcotin Group. Although the characteristic crumbly outcrop and microbotryoidal weathering surface of perlite are helpful distinguishing characteristics, to determine qualitatively the perlitic nature of the glass requires a blowtorch expansion test. The expansion of perlite upon heating depends on retention of the water in the glass. Because devitrification of the glass spoils its perlitic nature, the volcanic glass should be unaltered. The presence of vesicles and lack of mineral coatings on joints or fillings of amygdules in nearby volcanic rocks are encouraging signs that the glass has not been altered. Near the Frenier deposit (P2, Map 7), Mathews and Rouse (1984, p.1135) noted

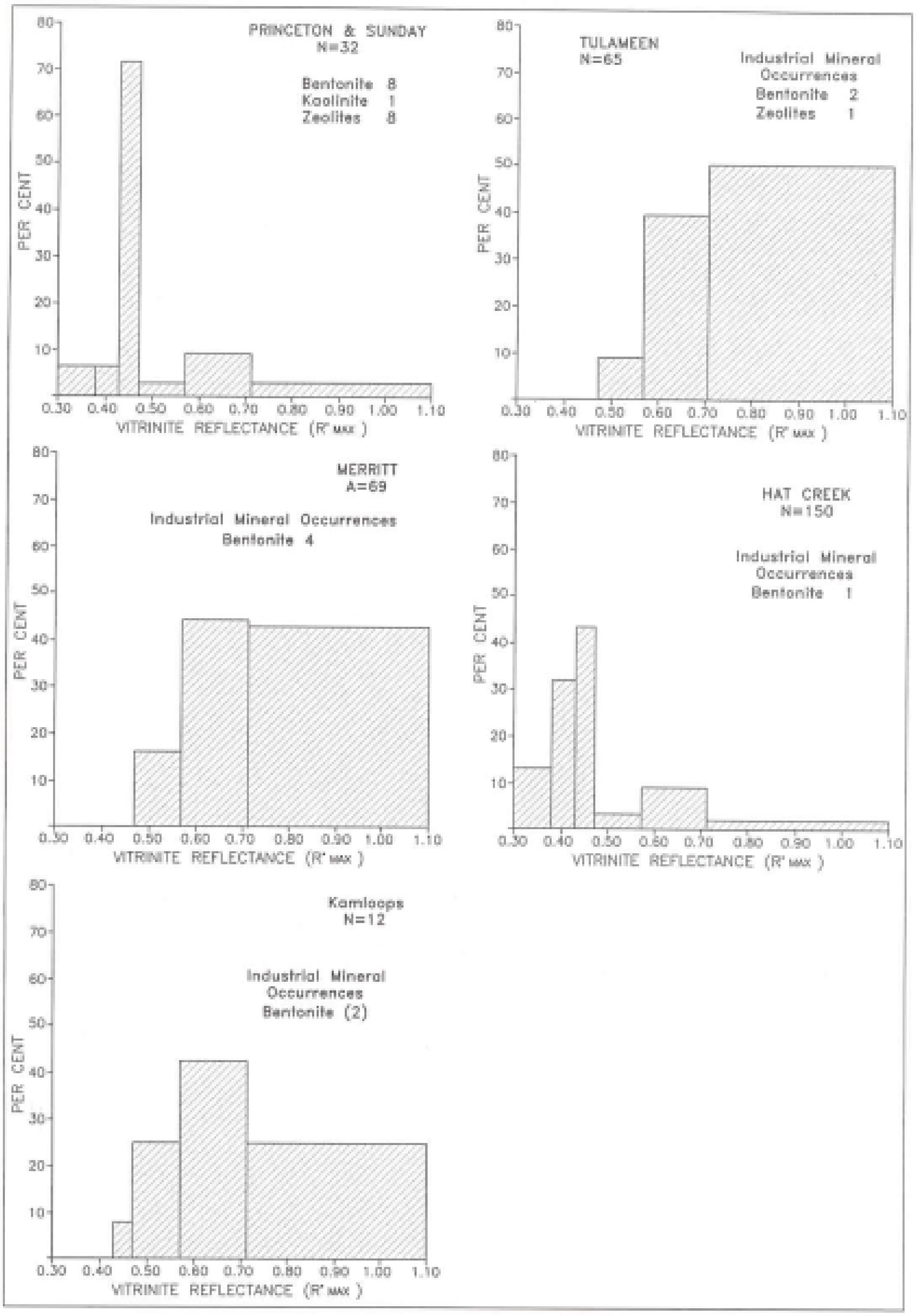

Figure 8.1. Vertical bar graphs showing thedistribution of vitrinite reflectance (Ro) and coal rank of Eocene coals for some of the industrial mineral bearing successions of Eocene age in southern British Columbia.

the lack of mineral coatings and vesicle fillings in the Eocene volcanic rocks.

Diatomite and diatomaceous earth occurrences are widespread in the Miocene and younger sedimentary Deadman River and Fraser Bend formations that fill Miocene channels up to 450 metres deep beneath the basalt flows of the Chilcotin Group. Some diatomite occurrences are compact, brittle and require crushing and screening for industrial use, such as the material from the Red Lake deposit. Others are soft, chalky and need sintering for use, such as the material from the Buck Ridge deposit south of Quesnel. Because natural exposures are slumped and weathered, the two types and amounts of impurities present cannot be distinguished without drilling. Southeastward from Clinton and northward from Gaspard Creek, fluviatile sediments, rhyolite tephra and accompanying diatomaceous sediments fill the northwestward to northward-draining Miocene channels. In the channel fill, unbedded rhyolite tephra up to 125 metres thick (Figure 4.1) indicates a massive filling and disruption of the pre-existing drainage system with the development of silica-rich lacustrine environments favourable to the growth of diatoms. Because the Miocene and younger sediments weather easily and are preferentially covered by slide debris from the overlying olivine basalt flows, outcrops of diatomaceous sediments are very rare. All the known occurrences are within the sediments of major channel fillings, such as Miocene Bonaparte, Miocene Deadman and Miocene Snohoosh channels (OF 1989-21), and Miocene Fraser channel north of Gaspard Creek (Map 7), or in sedimentary intercalations in the basalt flows immediately overlying these channels. As a result of this distribution prospecting should be restricted to the margins of extensive areas of basalt flows of the Chilcotin Group where present erosion is deep enough to expose the underlying Miocene channel sediments. In the field, the low density and stickiness to the damp tongue of diatomite-bearing samples are characteristic. The stickiness results from the absorption of moisture by the highly porous and permeable diatoms. If the sample has a high clay content, within a few dampenings, it will feel slick to the tongue. By scraping a minute quantity from a suspected diatomite-bearing sample onto a glass slide, capping it with a cover slip and using a refractive index liquid of 1.54 or less (mineral oil purchased from a drug store will suffice) to produce an oil-immersion grain mount, you can check a diatomite field identification. Because of the small diameter of the diatom genera present in most diatomaceous sediments in British Columbia, you will need to look at the oil immersion grain mount under transmitted light at a magnification of at least 60 power.

SIGNIFICANCE OF COAL RANK AND VITRINITE REFLECTANCE

All of the industrial minerals studied in this investigation are temperature sensitive. Their sensitivity ranges from the most sensitive, diatomite, through zeolites, bentonite and perlite, to the least sensitive mineral, kaolinite. Vitrinite reflectance and data on coal rank have been gathered from most of the mapped areas (Figure 8.1) and are tabulated together with industrial mineral occurrences from these and other areas which have an industrial mineral potential (Table 8.1). Because organic maturity data, specifically vitrinite reflectance, can be interpreted in terms of temperatures affecting the rocks since their deposition, the

TABLE 8.1
RELATIONSHIPS AMONG VITRINITE REFLECTANCE, COAL RANK AND
THE OCCURRENCE OF INDUSTRIAL MINERALS IN CENOZOIC AND MESOZOIC ROCKS

Area	Vitrinite Reflectance and/or Coal Rank*	Number of Analyses	Occurrences
Lang Bay (92F)	0.75-0.95	6	1 kaolinite
Clayburn (92G)	0.67	1	1 kaolinite
Princeton (92H)	sb:B and sb:C	32	8 bentonites; 8 zeolites; 1 kaolinite
Tulameen (92H)	hb:A and hb:B	65	2 bentonites; 1 zeolite
Merritt (92I)	hb:A and hb:B	69	4 bentonites
Kamloops (92I)	hb:B and hb:C	12	2 bentonites
Hat Creek (92I)	sb:B and sb:C	150	1 bentonite; 1 kaolinite
Gang Ranch (92O)	hb:B and hb:C	5	5 bentonites; 5 zeolites
Chu Chua (92P)	hb:A and hb:B	4	none reported
Quesnel (93B)	sb:B and sb:C	9	bentonite present
Cheslatta Falls (93F)	0.36	1	waterlain ash present
Nazko (93G)	0.22 and 0.26	2	waterlain ash present
Bowron (93H)	hb:B and hb:C	16	none reported
Telkwa (93L)	hb:A and mb	15	none reported
Sustut (94D)	hb:A and mb	6	zeolites widespread

* sb:C, sb:B — sub-bituminous:C, sub-bituminous:B;
hb:C, hb:B, hb:A — high-volatile bituminous:C, high-volatile bituminous:B, high-volatile bituminous:A;
mb — medium-volatile bituminous.

TABLE 8.2
STABILITY LIMITS OF INDUSTRIAL MINERALS IN TERMS OF
COAL RANK AND VITRINITE REFLECTANCE

Industrial Mineral	**Stability Limits in Terms of**	
	Vitrinite Reflectance	**Coal Rank**
Diatomite	lower: 0.0 upper: about 0.30	no rank ligniteA(boundary)
Zeolites	Lower about 0.35 upper: 1.00 to 1.10 range	within lignitefield near the upper limit of high volatile A bituminous field
Bentonite	lower: within lignite B upper: 1.10 to 1.50 range	less than 0.25 within the medium-volatile bituminous field
Kaolinite	lower: 0.0 upper: more than 4.6	no rank graphite

* Zeolite data are for heulandite-clinoptilolite. The upper stability limit should be reduced in the range of 0.1 to 0.30 for the other industrially important zeolites mordenite, erionite and chabazite.

data can be used to target prospecting, as summarized in Table 8.2.

The opaline silica forming diatoms recrystallizes with the infilling of the skeletal voids at very low temperatures and depths of only a few kilometres. This renders the diatoms unuseable as an industrial mineral. Because they recrystallize easily, the search for them should be restricted to young rocks that have never been deeply buried. In southern British Columbia, the Miocene and younger Chilcotin Group are unmetamorphosed (Read *et al*., 1991a), but older rocks, such as the Eocene sedimentary and volcanic rocks are mostly in the zeolite metamorphic facies and the few occurrences of Eocene diatoms are recrystallized, such as in the Princeton basin at Vermilion Bluffs (Hills 1962, p.49), which lies within a kilometre of a vitrinite reflectance measurement of Romax = 0.60 (OF 1987-19), or near Cache Creek at showing Z4 (OF 1988-30). In general, if the vitrinite reflectance of organic material from the enclosing sediments exceeds about 0.30, or the coal rank is greater than lignite B, diatoms will be recrystallized.

Zeolites are present in rocks of the zeolite metamorphic facies (Table 8.3), but the industrially useful zeolites are only stable in the low temperature and pressure area of the zeolite facies field (Figure 8.2). Because these zeolites, such as erionite, mordenite, chabazite and heulandite-clinoptilolite, are highly hydrated and/or have large channelways in their crystal structures, they decompose at low temperatures and pressures within the zeolite facies to other minerals which do not have industrial applications. Organic maturity data (Read *et al*., 1991a) are available for stratigraphic successions containing heulandite-clinoptilolite which is the most widespread industrial zeolite in the Canadian Cordillera. These data show that heulandite-clinoptilolite is widespread in appropriate hostrocks that are part of successions containing sub-bituminous and high-volatile bituminous coals. Widespread heulandite-clinoptilolite-bearing tuffs from the upper part of the Sustut Group, the Brothers Peak Formation (Read and Eisbacher, 1974), combined with a few vitrinite reflectance measurements (McKenzie, 1985) yield sparse data to suggest that heulandite-clinoptilolite disappears near the coal rank boundary between the high-volatile bituminous A and medium-volatile bituminous. At present, industrially useful zeolites are not known to occur in successions containing medium-volatile bituminous or higher rank coals. A vitrinite reflectance (Romax) in the range 1.00 to 1.10 probably indicates that conditions exceeded the stability field for heulandite-clinoptilolite during the thermal history of the succession. In the Canadian Cordillera, organic maturity data are lacking for the other industrial zeolites, but as a first approximation, similar or slightly lower values for organic maturity parameters should be expected to represent the upper limit of stability for erionite, mordenite and chabazite.

Bentonite is widespread in industrial zeolite bearing successions in the Canadian Cordillera from coal ranks as low as the lignite-bearing succession at Hat Creek (showing B2, OF 1990-23) to the high-volatile bituminous A bearing succession in the Merritt basin. The apparent absence of montmorillonite along the western edge of the Okanagan Metamorphic Complex (Figure 1.1) may result from a lack of suitable hostrocks or it may reflect the fact that Eocene rocks were subjected to temperatures which exceeded the stability limit of montmorillonite, the principal mineral in bentonite. Along the western edge of the metamorphic complex, a few vitrinite reflectance and coal analyses indicate a low-volatile bituminous rank (Read *et al*., 1991a). In the absence of further organic maturity data, the upper thermal stability limit for montmorillonite probably lies within the medium-volatile bituminous rank between vitrinite reflectance values (Romax) of 1.10 to 1.50.

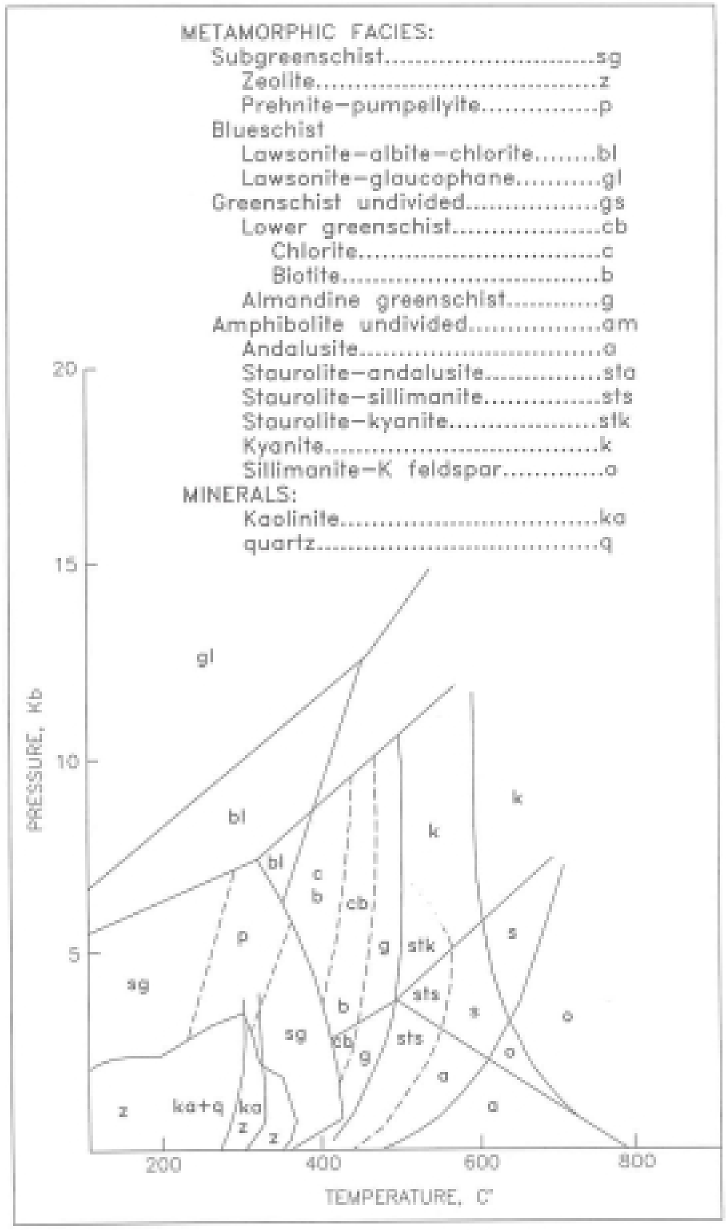

Figure 8.2. A pressure-temperature grid showing the distribution of metamorphic facies [slightly modified from Greenwood's diagram in Read *et al.* (1988) by the addition of the stability fields for kaolinite and kaolinite+quartz].

The extensive stability field of kaolinite (Figure 8.2) shows that the mineral is stable over a wide range of pressure-temperature conditions and may occur in rocks subjected to metamorphic conditions typical of the subgreenschist facies (zeolite and prehnite-pumpellyite) (Table 8.3). A wide range in vitrinite reflectance values from successions containing kaolinite occurrences or deposits reflects its large stability field. In the kaolinite-bearing sediments of Hat Creek, most of the vitrinite reflectance values lie in the range 0.38-0.47 (Figure 8.1). At the Fairley kaolinite showing (K1, Map 1) in the Princeton basin nearby Romax values lie in the range 0.43-0.47, a value of 0.67 comes from the kaolinite deposit at Clayburn (Soares, 1982), the nearest values to the Lang Bay deposit (Hora, 1989) lie in the range 0.75- 0.95 (Kenyon and Bickford, 1989), and the Groundhog coal basin, which has widespread kaolinite in the Cretaceous sediments, has vitrinite reflectance values in the range 2.6-4.6 (Moffat, 1985). As a result, the geological setting common to kaolinite deposits is much more useful than organic maturity in restricting the search area.

INDUSTRIAL MINERAL POTENTIAL IN CENOZOIC AND MESOZOIC ROCKS

Because the prospecting rationale outlined above is important in assessing the potential for industrial mineral occurrences in the Cenozoic and Mesozoic rocks of British

TABLE 8.3
CORRELATIONS AMONG COAL RANK, FIXED CARBON (F.C.), Btu/lb,
VITRINITE REFLECTANCE (Ro), TAI, CAI AND METAMORPHIC FACIES OR ZONES
(from Read *et al.*, 1988)

Rank	F.C.	R^{o}_{max}	TAI	CAI	Metamorphic Facies or Zones
				7.0	
					Biotite & Garnet Zones
				6.0	
					Chlorite Zone
				5.0	
				5.0	
Meta-anthracite					
	98	4.00	4.0	4.0	
Anthracite					**Prehnite Pumpellyite**
	92	3.00			
Semi-anthracite					
	86	2.05	3.75		
Low-volatile bituminous				3.5	
	78	1.50	3.5	3.0	
Medium-volatile bituminous					
	69	1.10	3.0	2.0	
High-volatile bituminous A					
	14,000*	0.71	2.75		
High-volatile bituminous B					
	13,000*	0.57		1.5	**Zeolite**
High-volatile bituminous C					
	11,500*	0.47	2.5		
Sub-bituminous A					
	10,500*				
Sub-bituminous B					
	9,500	0.43			
Sub-bituminous C					
	8,300	0.38	2.25	1.0	
Lignite A					
	6,300				**Unmetamorphosed**
Lignite B					

* Moist, mineral matter-free B.t.u./lb

Columbia, particularly southern British Columbia, it is presented in point form before proceeding to specific areas.

The geological factors important in the development of industrial minerals in Cenozoic and Mesozoic rocks are:

Kaolinite, bentonite, zeolites and diatomite develop in Cenozoic and Mesozoic sedimentary rocks; only volcanic glass and perlite are restricted to volcanic rocks of the same age.

Occurrences of diatomaceous earth are restricted to Miocene and younger sediments spatially associated with rhyolite tephra.

Waterlain dacite and rhyolite tuffs of Eocene or older age are suitable hosts for industrial zeolites, except on the Queen Charlotte Islands,

Waterlain intermediate ash and lapilli tuff of Miocene or older age are suitable hosts for bentonite.

Volcanic glass, and particularly perlite, require a water-free, low-temperature environment for their preservation.

Kaolinite is stable over a wide range of temperature and pressure conditions, but its occurrences lie close to deeply weathered unconformities developed on granitic or compositionally equivalent volcanic rocks.

Because each of these industrial minerals is stable within a different range of pressure and particularly temperature conditions, the stability field of each industrial mineral can be expressed in terms of coal rank and vitrinite reflectance (Table 8.2).

The overriding economic factors in transforming an industrial mineral occurrence into an industrial mineral deposit are development of a product that meets a market need, and proximity of the deposit to that market.

DIATOMACEOUS EARTH

In southern British Clumbia, all occurrences of diatomaceous earth are in the sediments filling the Miocene drainage system buried beneath basalt flows of the Chilcotin Group, or in thin sedimentary intercalations in the immediately overlying basalt flows. The potential for finding additional deposits lies in tracing the very poorly exposed sedimentary fill of the drainage system which extends northwestward from Deadman River to Bonaparte River north of Clinton, and probably projects farther to the Fraser River near Gang Ranch.

Near Clinton, two unexplored occurrences lie within 4 kilometres of the railway (showings D1 and D2, OF 1989-21). From Gang Ranch, the Miocene drainage system continues northward, probably close to the present course of the Fraser River, for another 230 kilometres to at least Prince George. Many of the known diatomaceous earth occurrences along this length are close to rail transportation. Because of the poor exposure of Miocene sediments and the extensive overburden along the river, many occurrences await discovery.

To the west, in the Chilcotin-Nechako area, an occurrence of diatomite on the south side of Tsacha Lake (Tipper, 1963) is associated with pumice and underlies basalt flows of the Chilcotin Group. The stratigraphic setting matches that of diatomite occurrences in the Bonaparte-Deadman river area (Maps 4 and 5) and implies that other occurrences, lying in buried Miocene channels, await discovery in this area of deep overburden.

A small Miocene drainage system underlies remnants of basalt flows east of Vernon and Kelowna (Mathews, 1988), Examination of drill core collected by Z.D. Hora from the Grouse Creek, Fuki, Hydraulic Lake, Lassie Lake, McCulloch and Cup Lake uranium properties southeast of Kelowna shows that diatomaceous earth is present only at Cup Lake where a compact and brittle variety is widespread, It is in excess of 8 metres thick and occupies a southeast-draining channel.

On the Queen Charlotte Islands, beds of marine diatomaceous clay in the Skonun Formation, up to 4 metres thick, form cutbanks along the lower Yakoun River between Black Bear and Canoe creeks (Sutherland Brown, 1968).

At most occurrences the combination of poor exposures and lack of drilling precludes any assessment of the dimensions, purity and compactness of the diatomaceous earth.

ZEOLITES

At present, all occurrences of industrial zeolites in British Columbia are heulandite-clinoptilolite developed in waterlain rhyolite and dacite tephra under open hydrologic conditions. These zeolitized tephra horizons form intercalations in sediment-rich Eocene and Upper Cretaceous terrestrial successions. With the exception of the Queen Charlotte Islands, Eocene and Upper Cretaceous sediments containing waterlain vitric or crystal-vitric tuffs of felsic to intermediate composition offer the best potential for industrial zeolite occurrences.

Organic maturity data curtail the vitrinite reflectance of potential zeolite hostrocks to the Romax range of 0.30 to 1.00-1.10 (Table 8.2). The combination of rocks of suitable age, bulk composition and organic maturity probably occurs in the Eocene exposed near Kamloops and northward up the North Thompson River. X-ray diffractograms of some tuffs from the Kamloops area indicate the presence of heulandite-clinoptilolite and analcime (Read, 1978).Farther to the southeast, Eocene rocks of suitable bulk composition occur in the Springbrook and Kettle River formations, but a few vitrinite reflectance values in the range 1.69 to 1.79 (Mathews and Bustin, 1986; Read *et al.*, 1991a) from the Springbrook suggest that the stability limit of industrial zeolites may have been exceeded because of the Eocene deformation and metamorphism affecting the high grade metamorphic rocks composing the south end of the Omineca Belt. Only the sedimentary and volcaniclastic rocks of the White Lake Formation with a few Romax values in the range 0.69 to 0.95 (Mathews and Bustin, 1986; Read et al., 1991a), may lie within the stability field of industrial zeolites.

Northwest of Kamloops, up the Fraser River, Lower Oligocene, Eocene and probably Upper Cretaceous sediments lie within the stability field of industrial zeolites. Although Tertiary sedimentary rocks are not common in the Chilcotin-Nechako area, earlier age assignments of rocks in this area to a Miocene and(?) later unit, and a Paleocene(?), Eocene and Oligocene unit (Tipper 1959, 1961, 1963, 1969) may be locally incorrect. Work by Rouse and Mathews (1988) showed that rocks outcropping along the Nechako River near Cheslatta Falls are not Miocene and (?) later as suggested by Tipper (1963), but instead Late Eocene in age, whereas at Nazko they corroborated Tipper's Paleocene(?) to Oligocene assignment (1961) with a Middle Eocene age.

The significance of the age of the stratified units is that Miocene and younger sedimentary rocks probably contain only diatomite occurrences, whereas Eocene and possibly Upper Cretaceous units will have an organic maturity suitable for bentonite and zeolite occurrences. In the absence of more reliable ages for the Tertiary units in the Chilcotin-Nechako area, all potential hostrocks, such as waterlain tephra, should be sampled and subjected to x-ray diffraction. Of the very few samples tested to date, x-ray diffractograms of samples of Eocene waterlain tephra from east of Horsefly on Black Creek road (Lay, 1930) and 3 kilometres north of Francois Lake on the road to Burns Lake (Armstrong, 1949) indicate that zeolites are present in some of the waterlain tuffs.

Farther to the north, in the upper part of the Sustut Group, waterlain rhyolite crystal-vitric tuff of the Brothers Peak Formation is extensively altered to heulandite-clinoptilolite (Read and Eisbacher, 1974).

The sediments of the Nanaimo Group are weakly altered by zeolites with laumontite acting as a cement and replacement of plagioclase (Stewart and Page, 1974). Heulandite is restricted to the uppermost Gabriola Formation. The sparse but widespread occurrence of laumontite probably reflects the lack of waterlain felsic to intermediate vitric ash in the sediments.

In the Queen Charlotte Islands, zeolitized tuffs have not been reported from the Tertiary in spite of the suitable bulk composition of the rocks and range of organic maturity. Although Read (1979) made a petrographic and x-ray diffraction examination of volcanic rocks collected by Sutherland Brown (1968) during his studies of the islands, zeolitized rocks were absent. Because the samples were as fresh as possible, the collection preferentially excluded the altered rocks so typical of zeolitized tephra and should not be considered a good test of the zeolite potential of the area. Zeolitized tephra containing erionite, chabazite or mordenite as the dominate zeolite species are presently unknown in British Columbia.

BENTONITE

Montmorillonite, the major mineral constituent of bentonite, is widespread in altered, waterlain ashes of intermediate composition that are Miocene and earlier Tertiary in age. Eocene sediments are a particularly favourable host for bentonite occurrences, but the organic maturity of the sediments may restrict the development of bentonite to hostrocks that have Romax values in the range of less than 0.25 to 1.10-1.50 (Table 8.2).

The combination of rocks of suitable age, bulk composition and organic maturity occurs in the Eocene exposed near Kamloops and possibly northward up the North Thompson River. X-ray diffractograms of tuffs from the Kamloops area indicate the presence of dominant montmorillonite in some tuffs of the Tranquille Formation (Read, 1977).

To the southeast, the development of bentonite may be curtailed in sediments of the Springbrook and Kettle River formations because, in some areas, they may have been heated beyond the stability field of montmorillonite, and in others waterlain intermediate ash may be absent. Northward along the Fraser River, Eocene and Lower Oligocene sediments outcrop, and at Quesnel the Lower Oligocene Australian Creek Formation contains swelling clays (Rouse and Mathews, 1979) in a succession with sub-bituminous B and C coals (Graham, 1978).

West of the Fraser River, a widespread cover of Tertiary volcanics and local thin sediments underlies the Chilcotin-Nechako region, and provides suitable hostrocks for bentonite occurrences, but the only occurrence known is on the banks of the Nechako River at Mile-post 19 on the Canadian National Railway west of Prince George (Cummings and McCammon, 1952). As explained, the uncertainty of the ages of Tertiary stratified rocks in the Chilcotin-Nechako area means that all waterlain ashes should be examined for bentonite.

On the Queen Charlotte Islands the Upper Oligocene to Upper Miocene Massett Formation contains some pyroclastic rocks and, along the west coast of Graham Island, intercalated sedimentary units (Hickson, 1989). Some of the tephra should form a suitable host for bentonite, and Sutherland Brown (1968, p. 176) reported bentonite from the formation in a road quarry on Blackwater Creek near Juskatla.

KAOLINITE

Kaolinite occurs in primary deposits formed by intense chemical weathering, and is generally more abundant in subtropical and tropical regions than in more temperate zones (Carroll, 1970).

In southern British Columbia, most of the occurrences or deposits of kaolinite lie close to either a Cretaceous or Eocene unconformity. In the Upper Cretaceous rocks of the Nanaimo Group, Bell (1957) noted that the flora include a number of genera that are now confined to warm temperate, subtropical or tropical floras and concluded that the climate during the deposition of the late Coniacian to late Campanian (Upper Cretaceous) plant-bearing formations of the group was probably warm temperate, and G.E. Rouse (personal communication, 1991) prefers a frost-free subtropical climate. For the Middle and Late Eocene, paleoclimatic interpretations based on palynomorph assemblages in the Canadian Cordillera indicate that subtropical conditions prevailed and were followed by a sharp temperature drop in the Early Oligocene (Rouse, 1977; Rouse and Mathews, 1988). As a result, Cretaceous and intra-Eocene and sub-Eocene unconformities of low relief in tectonically inactive areas might receive deep weathering. Where the underlying rocks are granitic or quartzofeldspathic, kaolinite may have accumulated. At Blue Mountain, Lower Cretaceous (Albian) sediments overlie diorite (Mustard and Rouse, 1991). Among the sediments, a blue shale, which did not fuse until cone 30 (Ries and Keele, 1915), probably contains significant kaolinite.

At Lang Bay, Upper Cretaceous (Santonian to Campanian) kaolinite-bearing sediments lie on a deeply weathered granodiorite (Hora, 1989; Mustard and Rouse, 1991). These kaolinite occurrences indicate that areas are worth prospecting for kaolinite where the sedimentary rocks of the Nanaimo and Gambier groups disconformably lie on plutonic rocks or stratified rocks of similar composition. The Middle and Upper Eocene sedimentary rocks of the Huntingdon Formation contain kaolinite-rich fireclay seams where they unconformably overlie a kaolinized metavolcanic and plutonic basement on Sumas Mountain (Church *et al.*, 1983). The remainder of this unconformity is unexposed in the lower Fraser Valley area.

In the interior of British Columbia, prospecting on the sub-Eocene unconformity is complicated by the lack of basal Eocene sediments west of the metamorphic core complexes. The typical Eocene succession in southwestern British Columbia is Eocene sediments overlying Eocene volcanic rocks (Read, 1990b).

Only in the sedimentary basins, where the underlying Eocene volcanics have been eroded, do the sediments lie directly on older rocks. The only plutonic basement so exposed is in Guichon Creek where the Coldwater Formation probably lies disconformably on the Guichon Creek batholith.

At Giscome Rapids, north of Prince George, china clay with pyrometric cone equivalents in the range 28 to 32?

(Cummings and McCammon, 1952) implies that kaolinite is an important constituent of the clay. Although the exact age of the Tertiary stratigraphy is uncertain and its geological setting unknown, the occurrence indicates that Tertiary unconformities in the Chilcotin-Nechako area should be prospected where they are overlain by sediments. Lay (1941, p.42) described such an unconformity 4 kilometres upstream from the mouth of Baker Creek west of Quesnel where extensively kaolinized Eocene(?) flows are overlain by Early Oligocene sediments.

Much of the Tertiary at the south end of the Omineca Complex is faulted onto the underlying rocks, but where unfaulted, the basal Eocene comprises coarse clastic sediments apparently without kaolinite. The combination of faulted basal Eocene contacts and coarse basal Eocene sediments, where the contact is unfaulted, apparently precludes the development of kaolinite.

VOLCANIC ASH

Rhyolite ash of Miocene age is a widespread component of the Deadman River Formation (Campbell and Tipper, 1971) and is in the southern exposures of the Fraser Bend Formation in the Fraser River south of its confluence with the Chilcotin River (Hickson *et al.*, 1991a). Its northern limit is in Sword Creek, west of the Fraser River at latitude 52 N.

In southern British Columbia, aside from the Bridge River ash, the areas of best potential for relatively unaltered rhyolite or dacite ash are underlain by the Deadman River and Fraser Bend formations south of Williams Lake between the Fraser River and Kamloops. As noted by McCammon (1960), the ash is suitable for use as a pozzolan. Eocene ash may be too altered to act as a suitable pozzolan.

PERLITE AND VOLCANIC GLASS

In southern British Columbia, perlite and volcanic glass mainly occur in Middle Eocene volcanic successions where rhyolite and dacite are volumetrically important. Volcanic rocks of the Princeton and Penticton groups and the Kamloops Group east of the Fraser River are usually too basic. However, the detailed stratigraphy of Eocene volcanic rocks is largely unknown and a restriction of the area of best potential for perlite and volcanic glass to along and west of the Fraser River may not be warranted.

MIOCENE DRAINAGE AND PLACER GOLD POTENTIAL

Miocene drainage channels are the sites of placer gold concentrations near Prince George on the Fraser River and southeast of Kelowna. North of Quesnel, the placer gold production of 62 500 grams from the Tertiary mine comes from the bottom 1.8 metres of the basal Fraser Bend conglomerate of Miocene age and cracks and crevices in the immediately underlying bedrock in a southeast-flowing channel of the ancestral Fraser River (Lay, 1940). Sediments of the Fraser Bend Formation are hosts of the nearby Canyon mine and placer workings of Frank Delong.

Northeast of Kelowna, placer gold occurs in a Miocene conglomerate filling a channel 160-metres deep near King Edward Creek (Church and Suesser, 1983), and in Miocene sandstone and conglomerate on the Winfield property (Hedley, 1937) where 2300 grams of gold were extracted from a series of small adits (Jones, 1959). Because Miocene drainage channels were unknown in the area covered by this investigation until their discovery in 1988 (Read, 1989a), a placer gold potential may exist in Miocene channels in this intervening area.

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APPENDIX A

DESCRIPTIONS OF FOSSIL LOCALITIES

These fossil data are for those localities established during the fieldwork and from unpublished data from other localities within the mapped areas (Table A.1). The details of published fossil localities appear in the references given in the paleontology and palynology tables of the map areas (Maps 1 to 7). The data are organized from oldest to youngest within each map area, starting with the southeasternmost area and ending with the northwesternmost.

A1. PRINCETON AND TULAMEEN BASINS (92H/7 to 10)

A1.1. Nicola Group

Map No.: F1 GSC Loc. No.: C-116701

UTM Coordinates:
FK0678800 E Latitude: 49°33'47"
FK5492400 N Longitude: 120°31'39"
NTS Sheet: 92H/10 Identified By: M.J. Orchard
Location: At 915 metres (3000') elevation on the north valley wall of Allison Creek, 2.65 kilometres at 346° from the junction of Highway 5 and Summers Creek Road.
Rock Unit: Nicola Group, unit uTRc
Lithology: Medium grey tuffaceous limestone and limy volcanic breccia.
Fauna: *Metapolygnathus nodosus* Hayashi (16)
Metapolygnathus cf.M. n.sp. F Orchard (4)
ichthyoliths
sponge spicules
C.A.I.: approximately 4
Age: Late Triassic, late Carnian

TABLE A.1
FOSSIL COLLECTIONS IN STRATIGRAPHIC ORDER

Map No.	UTM Coordinates Easting	Northing	NTS Sheet	Rock Unit	Age
CHILCOTIN GROUP					
Deadman River Formation					
F1	FM0644200	FM5674350	92P/2	Mvr	Middle Miocene
F2	FM0644850	FM5673000	92P/2	Mvr	Middle Miocene
PRINCETON GROUP and unnamed Eocene sediments					
F2	FL0653150	FL5562300	92I/2	EAcp	Eocene to Miocene
F3	FL0652900	FL5562000	92I/2	EAcp	Middle Eocene
F4	FL0679250	FL5556740	92I/1	EAcp	Middle Eocene to Early Oligocene
F**	EM0562230	EM5664840	92O/1	Etfs	younger than mid-Paleocene
Silverquick Formation					
F6	FM0647920	FM5655450	92P/2	luKs	Albian
SPENCES BRIDGE GROUP					
F**	EM0579500	EM5632070	92I/13	lKSBS	unrefined Mesozoic or Tertiary
JACKASS MOUNTAIN GROUP					
F**	EM0565330	EM5658270	92O/1	lKJM	Middle to Late Albian
NICOLA GROUP					
F6	FM0644170	FM5645520	92I/15	uTAV	Late Triassic, Early Norian
F8	FM0644270	FM5642630	92I/15	uTAC	Middle Triassic, Ladinian
F17	FM0640050	FM5628630	92I/14	uTAC	Late Triassic, Early Norian
F18	FM0640200	FM5628400	92I/14	uTAC	Late Triassic, Early Norian
F1	FK0678800	FK5492400	92H/10	uTAC	Late Triassic, Late Carnian
F59	FK0679000	FK5459600	92H/7	uTAV	Late Triassic, Norian

Map No.: F59 GSC Loc. No.: C-087490
UTM Coordinates:
FK0679000 E Latitude: 49°14'45"
FK5459600 N Longitude:120°32'50"
NTS Sheet: 92H/7 Identified By: M.J. Orchard
Location: At 1035 metres (3400') elevation in a roadcut a few hundred metres south of Sunday Creek.
Rock Unit: Nicola Group, unit uTRv
Lithology: Carbonate
Fauna: *Epigondolella* sp. (2)
ichthyoliths
C.A.I.: approximately 4
Age: Late Triassic, Norian
Remarks: Both specimens are broken posteriorly, but have high nodes.This collection was previously published (Monger, 1989c) as Triassic - late Carnian.

A2. MERRITT BASIN (92I/1, 2)

A2.1. Princeton Group, Coldwater Formation

Map No.: F2 GSC Loc. No.: C-039526
UTM Coordinates:
FL0653150 E Latitude: 50°11'50"
FL5562300 N Longitude: 120°51'10"
NTS Sheet: 92I/2 Identified By: J.M. White
Location: At 745 metres (2450') elevation in Guichon Valley 0.3 kilometre west of the highway to Logan Lake and5.15 kilometres at 020° from Lower Nicola.
Rock Unit: Princeton Group, Coldwater Formation, unit EPcp
Lithology: Carbonaceous siltstone.
Flora: unsieved fraction:
Monoporisporites sp. common
Reduviasporonites sp. rare
Osmunda sp. common
Tsuga sp. abundant
cf. *Picea* sp. common
Sequoiapollenites sp. rare
Taxodiaceae - Cupressaceae - Taxaceae common
Liquidambar sp. rare
Potamogeton cf. P. narcosli Piel 1971 rare
*Ulmus/*Zelkova sp. common
Myrica annulites Martin and Rouse 1966 common
?*Ilex* sp. rare
Pterocarya sp. common
Carya sp., heteropolar scarce
T.A.I.: 2, on *Alnus* sp.
Remarks: The age is probably Eocene to Miocene, based on the presence of Tsuga, Ulmus/Zelkova, Carya, Juglans, Liquidamber and Myrica annulites (Rouse *et al.*, 1970; Piel, 1971, 1977; Clague,1974; Rouse and Mathews, 1979; Mathews and Rouse, 1984)
Age: Eocene to Miocene

Map No.:F3 GSC Loc. No.: C-023488
UTM Coordinates:
FL0652900 E Latitude: 50°11'38"
FL5562000 N Longitude: 120°51'29"
NTS Sheet: 92I/2 Identified By: W.S. Hopkins
Location: At 695 metres (2275') elevation on the left bank of Guichon Creek 0.6 kilometres south of the mouth of Morgan Creek and4.75 kilometres at 019° from Lower Nicola.
Rock Unit: Princeton Group, Coldwater Formation, unit EPcp
Flora: *Baculatisporites* sp.
Bisaccate conifer pollen
Glyptostrobus sp.
Taxodiaceae - Cupressaceae
Taxodium sp.
Metasequoia sp.
Alnus sp.
Pistillipollenites sp.
Pterocarya sp.
Castanea - type
Carya sp.
Tricolpites spp.
Tricolporopollenites sp.
Triporopollenites spp.
Age: probably Middle Eocene

Map No.: F4 GSC Loc. No.: C-039525
UTM Coordinates:
FL0679250 E Latitude: 50°08'29"
FL5556740 N Longitude: 120°29'30"
NTS Sheet: 92I/1 Identified By: J.M. White
Location: At 740 metres (2425') elevation on the east side of QuilchenaValley 4.05 kilometres at 178o from the outlet of Robb Creekinto Nicola Lake.
Rock Unit: Princeton Group, Coldwater Format ion, unit EPcp
Lithology: Dark grey carbonaceous shale.
Flora: unsieved fraction:
Ctenosporites wolfei Elsik and Jansonius 1974 rare
Monoporisporites sp. common
Taxodiaceae - Cupressaceae - Taxaceae rare
Ulmipollenites undulosus Wolf 1934 very abundant
Alnus sp. rare
Carya sp. rare
T.A.I.: 2 to 2+ on Ulmipollenites
Age: Middle Eocene to Early Oligocene
Remarks: The stratigraphic range of Ctenosporites wolfei in the southern interior of British Columbia is Middle Eocene to EarlyOligocene (Rouse and Mathews 1979).

A3. CACHE CREEK AND TRANQUILLE RIVER (92I/14, 15)

A3.1. Nicola Group

Map No.:F6 GSC Loc. No.:C-158288
UTM Coordinates:
FM0644170 E Latitude: 50°56'47"
FM5645520 N Longitude:120°56'52"
NTS Sheet: 92I/15 Identified By: M.J. Orchard
Location: 2.50 kilometres at 120° from the junction of Gorge Creek and Deadman River at an elevation of 1130 metres (3700').
Rock Unit: Nicola Group, unit uTRv
Lithology: Dark grey limy argillite and argillaceous limestone
Fauna: *Epigondolella abneptis* subsp. A Orchard (12)
ramiform elements (7)
ichthyoliths
C.A.I.: 5
Age: Late Triassic, Early Norian

Map No.:F8 GSC Loc. No.: C-158290
UTM Coordinates:
FM0644270 E Latitude: 50°55'13"
FM5642630 N Longitude: 120°56'51"
NTS Sheet: 92I/15 Identified By: M.J. Orchard
Location: 4.65 kilometres at 151° from the junction of Gorge Creek andDeadman River at an elevation of 1135 metres (3725').

Rock Unit: Nicola Group, unit uTRc
Lithology: Light grey, unbedded limestone
Fauna: Budurovignathus ex gr. Mungoensis (Diebel) (6)
Neogondolella sp. (1)
ramiform elements (1)
C.A.I.: 5
Age: Middle Triassic, late Ladinian

Map No.: F17 GSC Loc. No.: C-158286
UTM Coordinates:
FM0640050 E Latitude: 50°47'43"
FM5628630 N Longitude: 121°00'46"
NTS Sheet: 92I/14 Identified By: M.J. Orchard
Location: 3.9 kilometres at 052° from Anglesey station on the CanadianNational Railway on the north side of the Thompson River eastof the town of Cache Creek.
Rock Unit: Nicola Group, unit uTRc
Lithology: Unbedded, medium grey crinoidal limestone
Fauna: Epigondolella triangularis (Budurov) (20)
ramiform elements (6)
ichthyoliths
C.A.I.: 3-3.5
Age: Late Triassic, early Norian

Map No.: F18 GSC Loc. No.: C-158285
UTM Coordinates:
FM0640200 E Latitude: 50°47'36"
FM5628400 N Longitude: 121°00'39"
NTS Sheet: 92I/14 Identified By: M.J. Orchard
Location: 3.9 kilometres at 056° from Anglesey station on the Canadian National Railway on the north side of the Thompson River east of the town of Cache Creek.
Rock Unit: Nicola Group, unit uTRc
Lithology: Unbedded, medium grey crinoidal limestone
Fauna: *Epigondolella* abneptis subsp. A Orchard (5)
ramiform elements (2)
ichthyoliths
C.A.I.: 3-4
Age: Late Triassic, early Norian

A4. BONAPARTE TO DEADMAN RIVERS (92P/2, 3)

A4.1. Silverquick Formation

Map No.:F6 GSC Loc. No.: C-210059
UTM Coordinates:
FM0647920 E Latitude: 51°02'05"
FM5655450 N Longitude: 120°53'26"
NTS Sheet: 92P/2 Identified By: G.E. Rouse
Location: In a roadcut on the Deadman Valley road at 785 metres (2575') elevation, 1.0 kilometre south of the north end of Mowich Lake on the east side of the lake.
Rock Unit: Silverquick Formation, luKs
Lithology: Minor carbonaceous siltstone and shale partings from an interbedded lithic wacke, siltstone and shale sequence
Flora: Fern spores:
Cicatricosporites imbricatus
Klukisporites foveolatus
cf. *Tricolpites micromunus*
Foveosporites labiosus
Leptolepidites verrucosus
Deltoidospora diaphana
Kuylisporites lunaris
Cicatricosporites exilioides
Dinocysts:
Gonyaulacysta cassidata
Ovoidites sp.
Pareodinia - 1
Canningia minor
Remarks: This assemblage correlates with those from the Spences Bridge Group reported from the Nicola and Coldwater rivers by Thorkelson and Rouse (1989).
Age: Albian

A4.2. Chilcotin Group, Deadman River Formation

Map No.: F1 GSC Loc. No.: C-210060
UTM Coordinates:
FM0644200 E Latitude: 51°12'20"
FM5674350 N Longitude: 120°56'09"
NTS Sheet: 92P/2 Identified By: G.E. Rouse
Location: At 1065 metres (3500') elevation on the west wall of Deadman Valley, 4.7 kilometres at 331° from the village of Vidette.
Rock Unit: Chilcotin Group, Deadman River Formation
Lithology: Grey-brown carbonaceous siltstone
Flora: Palynomorphs:
Picea grandivescipites
Carya juxtaporipites
C. viridifluminipites
Tilia vescipites
T. crassipites
Tsuga viridifluminipites
Ilex infissa
Abies sp.
Cedrus perialata
Quercus shiabensis
Remarks: This assemblage correlates with that of the Fraser Bend Formation extending from the Nechako River to Quesnel to theGang Ranch to Big Bar region on the Fraser River.
Age: Middle Miocene

Map No.: F2 GSC Loc. No.: C-210061
UTM Coordinates:
FM0644850 E Latitude: 51°11'35"
FM5673000 N Longitude: 120°56'09"
NTS Sheet: 92P/2 Identified By: G.E. Rouse
Location: At 1060 metres (3475') elevation on the east wall of Deadman Valley, 3.25 kilometres at 331° from the village of Vidette.
Rock Unit: Chilcotin Group, Deadman River Formation
Lithology: Dark grey carbonaceous shale and siltstone
Flora: Palynomorphs:
Inapertipollenites irregularis
Liquidambar sp. 1
Laevigatosporites ovatus
Cupressacites sp.
Laricoidites "minor"
Remarks: This assemblage correlates with that of the Fraser Bend Formation from Prince George to Quesnel to Gang Ranch and Big Bar.
Age: Middle Miocene

A5. HAT CREEK (92I/12 to 14)

Because 135 palynology collections from Hat Creek are unpublished, and are part of a detailed structural and stratigraphic investigation by Rouse and Read (in preparation), the palynology table (OF 1990-23) summarizes only those aspects of the collections necessary for the unravelling of the stratigraphy and structure of the area.

A6. FRASER RIVER (92I/5, 12, 13, 16; 92O/1, 8; 92P/4)

A6.1. Jackass Mountain Group

Map No.:n/a GSC Loc. No.: C-162590
UTM Coordinates:
EM0565330 E Latitude: 51°04'27"
EM5658270 N Longitude: 122°04'03"
NTS Sheet: 92O/1 Identified By: A.R. Sweet
Location: At 655 metres (2150') elevation in an irrigation ditch on thesouth side of Watson Bar Creek 2.1 kilometres at 080° from theconfluence of Watson Bar and Madson creeks.
Rock Unit: Jackass Mountain Group
Lithology: Carbonaceous shale lenses in sandstone
Flora: Selected flora:
*Appendicisporites s*p.
Cicatricosisporites spp.
Clavatricolpites prolatus Pierce 1961
Distaltriangulisporites perplexus Singh 1964
Eucommiidites minor Groot and Penny 1960
Gleicheniidites sp.
Phimopollenites psuedocheros Ward 1986
Sestrosporites pseudoalveolatus (Couper) Dettman 1963
Vitreisporites pallidus (Reissinger) Nilsson 1958
Remarks: Preservation and recovery good. The above combination ofspecies favours a middle to late Albian age although an Early-Late Cretaceous age cannot be completely excluded. A maximum age of middle Albian is based on the common occurrence of tricolpate angiosperm pollen (Clavatricolpitesprolatus and Phimopollenites pseudocheros)
Age: Middle to late Albian

A6.2. Spences Bridge Group

Map No.:n/a GSC Loc. No.: C-162588
UTM Coordinates:
EM0579500 E Latitude: 50°50'13"
EM5632070 N Longitude: 121°52'16"
NTS Sheet: 92I/13 Identified By: A.R. Sweet
Location: On the left bank of the Fraser River about 10 metres aboveriver level 3.4 kilometres downstream from the mouth of Pavilion Creek.
Rock Unit: Spences Bridge Group, unit lKsBs
Lithology: Dark grey carbonaceous shale
Flora: Bisaccate pollen
Taxodiaceae-Cupressaceae pollen
Remarks: Organic residue highly carbonized and dominated by woody fragments. Bisaccate and Taxodiaceae-Cupressaceae pollen are recognizable.
Age: unrefined Mesozoic or Tertiary

A6.3. Unnamed Eocene Unit

Map No.: n/a GSC Loc. No.: C-162591
UTM Coordinates:
EM0562230 E Latitude: 51°08'01"
EM5664840 N Longitude: 122°06'38"
NTS Sheet: 92O/1 Identified By: A.R. Sweet
Location: At 1005 metres (3300') elevation on the north side of WardCreek, 5.05 kilometres upstream of its confluence with theFraser River.
Rock Unit: Unnamed Eocene unit Etfs
Lithology: Carbonaceous siltstone
Flora: Ulmipollenites undulosus Wolff 1934
Remarks: Preservation good. Residue dominated by cuticles and algalcysts (one dinoflagellate). Based on the presence of Ulmipollenites undulosus this sample is younger than mid-Paleocene in age.
Age: younger than mid-Paleocene.

APPENDIX B

RADIOMETRIC AGE DETERMINATIONS

The radiometric age determinations listed are for localities established during the fieldwork of this investigation (Table B.1). The details of all other localities of radiometric age determinations appear in the references given in the appropriate tables of the map areas (Maps 1 to 7). The data are organized from oldest to youngest within each map area, starting with the southeasternmost area and ending with the northwesternmost.

B1. PRINCETON AND TULAMEEN BASINS (92H/7 to 10)

B1.1.Princeton Group

Map No.: R1 NTS Sheet:92H/9

UTM Coordinates:
FK0681850 E Latitude: 49°35'08"
FK5494950 N Longitude: 120°29'03"
Material Dated: Whole rock Dating Method: K-Ar
Location: A roadcut at 1120 metres (3675') elevation, 2.45 kilometres at160o from the confluence of Rampart and Summers creeks,north of Princeton.
Rock Unit: Princeton Group, Jura andesite
Lithology: Porphyritic (hypersthene, augite) basaltic andesite
Geological Setting: The sample comes from a flow remnant a few square kilometresin area that overlies sediments of the Allenby Formation. These are the only volcanics, the Miocene at Blakeburn excepted, which overlie the arkose-rich Middle Eocene sediments in southwestern British Columbia.
Analysts: D. Runkle, J. Harakal
Analytical Data:
K = 1.15±0.02; n =2
40*Ar/Total 40Ar = 39.6%
40*Ar (x 10-6 cc/g) = 2.261
40*Ar (x 10-10 mol/g) = 1.009
Age: 49.4±2.0 Ma (Middle Eocene)

Map No.:R3 NTS Sheet:92H/10

UTM Coordinates:
FK0680649 E Latitude: 49°34'20"
FK5493850 N Longitude: 120°30'05"

Material Dated: Biotite Dating Method: K-Ar
Location: On the east side of Summers Creek about 30 metres above the creek and 50 metres south of the east end of the road bridge.
Rock Unit: Princeton Group, Summers Creek sandstone
Lithology: A crystal-rich (biotite, quartz, feldspar) vitric tuff and tuffaceous sandstone.
Geological Setting: The sample comes from close to the northern margin of the basin where the sediments are dominantly tuffaceous.
Analysts: D. Runkle, J. Harakal
Analytical Data:
K = 7.63±0.20; n = 2
40*Ar/Total 40Ar = 85.1%
40*Ar (x 10-6 cc/g) = 13.8
Age: 46.2±1.9 Ma (Middle Eocene)

TABLE B.1
RADIOMETRIC DATES IN STRATIGRAPHIC ORDER

Map No.	UTM Coordinates Easting	Northing	NTS Sheet	Rock Unit	Age (Reason for anomalous date)
CHILCOTIN GROUP					
R**	EM0555200	EM5686900	92O/8	MPvb	1.16±0.06 Ma
R3	FM0642150	FM5633550	3450	Mvb	10.4±0.4 Ma
R1	FM0602150	FM5628800	92I/13	Mvb	29.7±2.7 Ma(reset or contaminated)
Princeton and Kamloops groups and unnamed Eocene volcanics					
R**	EM0582005	EM5622980	92I/13	Evr	46.4±1.6 Ma
R**	EM0579500	EM5638090	92I/13	Evdx	48.1±1.7 Ma
R2	FK0681850	FK5494950	92H/9	EPAa	49.4±2.0 Ma
R2	FM0625420	FM5678250	92P/3	Evdx	50.9±1.8 Ma
R1	FM0625430	FM5678550	92P/3	Evb	52.1±1.8 Ma
SPENCES BRIDGE GROUP					
R**	EM0570850	EM5650150	92P/4	lKSBv	89.7±3.1 Ma (reset by burial metamorphism)
R**	EM0577170	EM5634900	92I/13	lKSBv	81.0±2.4 Ma (reset by burial metamorphism)

B2. CACHE CREEK AND TRANQUILLE RIVER (92I/14, 15)

B2.1. Chilcotin Group

Map No.:R3 NTS Sheet:92I/15
UTM Coordinates:
FM0642150 E Latitude: 50°50'21"
FM5633550 N Longitude: 120°58'52"
Material Dated: Whole rock Dating Method: K-Ar
Location: At 1050 metres (3450') elevation on the west side of the Deadman River valley, 4.7 kilometres at 190° from the mouth of Criss Creek.
Rock Unit: Chilcotin Group, Chasm Formation, unit Mvb
Lithology: Medium grey, porphyritic (olivine 15%, titaniferous augite 30%) nepheline basanite composed of olivine and titaniferous augite phenocrysts lying in a matrix of 36% plagioclase (An63),15% nepheline and 4% opaque minerals. The rock is free of alteration.
Geological Setting: The sample comes from near the base of a 400-metre-thick residual of basalt flows.
Analysts: D. Runkle, J. Harakal
Analytical Data:
K = 0.828æ0.002% n = 2
40*Ar/Total 40Ar = 40.3%
40*Ar (x 10-6 cc/g) = 0.334
40*Ar (x 10-10 mol/g) = 0.149
Age: 10.4±0.4 Ma (Late Miocene)

B3. BONAPARTE TO DEADMAN RIVERS (92P/2, 3)

B3.1. Kamloops Group, Skull Hill Formation

Map No.: R1 NTS Sheet:92P/3
UTM Coordinates:
FM0625430 E Latitude: 51°14'49"
FM5678550 N Longitude: 121°12'11"
Material Dated: Whole rock Dating Method: K-Ar
Location: At 975 metres (3200') elevation on the east valley-wall of Fly Creek, 1.1 kilometres at 001° from the confluence of Fly Creek and Bonaparte River.
Rock Unit: Kamloops Group, Skull Hill Formation, unit Evb
Lithology: Olivine-bearing (completely pseudomorphed by iddinsgite) augite basalt with a flat-stage plagioclase determination of An50.
Geological Setting: An olivine basalt flow, which has the outcrop characteristics of the Miocene Chasm Formation of the Chilcotin Group but is of Eocene age and therefore part of the Kamloops Group.
Analysts: J. Harakal, D. Runkle
Analytical Data:
K = 1.75±0.01
40*Ar/Total 40Ar = 67.0%
40*Ar (x 10-6 cc/g) = 3.593
40*Ar (x 10-10 mol/g) = 1.603
Age: 52.1±1.8 Ma (Early Eocene)

Map No.: R2 NTS Sheet:92P/03
UTM Coordinates:
FM0625420 E Latitude: 51°14'39"
FM5678250 N Longitude: 121°12'12"
Material Dated: Whole rock Dating Method: K-Ar
Location: At 930 metres (3050') elevation in the dry bed of Fly Creek,0.8 kilometres upstream from its confluence with Bonaparte River.
Rock Unit: Kamloops Group, Skull Hill Formation, unit Evdx
Lithology: Porphyritic (hypersthene, augite) basaltic andesite
Geological Setting: In a volcanic breccia near the top of the Kamloops Group which in this locality has been mapped as Miocene plateau basalt by Campbell and Tipper (1971).
Analysts: J. Harakal, D. Runkle
Analytical Data:
K = 1.93±0.00
40*Ar/Total 40Ar = 74.3%
40*Ar (x 10-6 cc/g) = 3.871
40*Ar (x 10-10 mol/g) = 1.727
Age: 50.9±1.8 Ma (Middle Eocene)

B4. HAT CREEK (92I/12 to 14)

B4.1. Chilcotin Group

Map No.:R1 NTS Sheet:92I/13
UTM Coordinates:
EM0602150 E Latitude: 50°48'14"
EM5628800 N Longitude: 121°33'01"
Material Dated: Whole rock Dating Method: K-Ar
Location: At 1335 metre (4375') elevation on the east side of the Upper Hat Creek valley, 4.60 kilometres at 193o from the confluence of Robertson and Hat creeks.
Rock Unit: Chilcotin Group, unit Mvb
Lithology: Porphyritic (titaniferous augite, olivine) basalt
Geological Setting: Sample collected from the base of a basalt flow remnant 50 metres thick. Church (1977) has a single whole-rock date from basalt in the Hat Creek valley. Unfortunately his sample was from basalt boulders from an unknown source.
Analysts: J. Harakal, D. Runkle
Analytical Data:
K = 0.627±0.006
40*Ar/Total 40Ar = 11.2%
40*Ar (x 10-6 cc/g) = 0.712
40*Ar (x 10-10 mol/g) = 0.318
Age: 29.0±2.7 Ma (Late Oligocene)
Remarks: The sample may not be suitable for K-Ar dating. Possible leaching, low K(?) and high atmospheric argon content raise doubts regarding the K-Ar age. Similar K-Ar dates have been obtained for basalts south of Kamloops, as for example Ewing(1981b); [Mv9-1] 25.5±0.4 Ma (Monger, 1989b), and Mathews (1989,p. 973) at Summit Lake in 93J.

B5. FRASER RIVER (92I/5, 12, 13, 16; 92O/1, 8; 92P/4)

B5.1. Spences Bridge Group

Map No.: R NTS Sheet:92P/4**
UTM Coordinates:
EM0570850 E Latitude: 51°00'02"
EM5650150 N Longitude: 121°59'25"
Material Dated: Whole rock Dating Method: K-Ar
Location: At 1160 metres (3800') elevation in a roadcut on the Slok Creek Forestry Access Road on the north side of Leon Creek,5.5 kilometres at 263° from the mouth of Leon Creek.
Rock Unit: Spences Bridge Group, unit lKsBv
Lithology: Medium grey-green to slightly maroon porphyritic (plagioclase) latite flow composed of 20% slightly sericitized, carbonated and laumontitized albite (An2) phenocrysts set in a matrix (72%) composed of plagioclase and finely disseminated opaque minerals (hematite?). Amygdules(4%) composed of carbonate. The altered rock contains 2% carbonate, 2% laumontite and 5% chlorite-montmorillonite.

Geological Setting: In the fault sliver between Slok Creek and Fraser faults.
Analysts: J. Harakal, D. Runkle
Analytical Data:
K = 1.18
40*Ar/Total 40Ar = 92.1%
40*Ar (x 10-6 cc/g) = 4.218
40*Ar (x 10-10 mol/g) = 1.882
Age: 89.7±3.1 Ma (Late Cretaceous)

Map No.: R NTS Sheet:92I/13**
UTM Coordinates:
EM0577170 E Latitude: 50°51'45"
EM5634900 N Longitude: 121°54'13"
Material Dated: Whole rock Dating Method: K-Ar
Location: At 695 metres (2275') elevation on the left bank of Slok Creek, about 100 metres upstream from the Slok Creek Forestry Access Road, 2.4 kilometres at 258o from the mouth of Pavilion Creek.
Rock Unit: Spences Bridge Group, unit lKsBv
Lithology: Medium grey, platy jointed rhyodacite flow containing 1% plagioclase phenocrysts which are slightly sericitized and replaced by carbonate and 4% biotite phenocrysts completely pseudomorphed by chlorite and minor carbonate which lie in a matrix of 86% flow-oriented plagioclase microlaths and 5% opaque minerals. The rock contains 2% chlorite and 2% carbonate as alteration minerals.
Geological Setting: In the fault sliver between Slok Creek and Fraser faults in a sequence of volcanics which presumably unconformably overlies the Pavilion Group.
Analytical Data: J. Harakal, D. Runkle
K = 1.62±0.01 n = 2
40*Ar/Total 40Ar = 92.3%
40*Ar (x 10-6 cc/g) = 5.218
40*Ar (x 10-10 mol/g) = 2.329
Age: 81.0±2.8 Ma (Late Cretaceous)

B5.2. Unnamed Eocene Volcanics

Map No.:R NTS Sheet: 92I/13**
UTM Coordinates:
EM0579500 E Latitude: 50°53'28"
EM5638090 N Longitude 121°52'11"
Material Dated: Whole rock Dating Method: K-Ar
Location: At 425 metres (1400') elevation on the west side of Fraser River 2.65 kilometres at 360o from the mouth of Pavilion Creek.
Rock Unit: Eocene, unit Evdx
Lithology: Medium grey porphyritic (augite, plagioclase) andesite volcanic breccia composed of 35% plagioclase phenocrysts (An47) and 20% augite phenocrysts lying in a matrix composed of 41% plagioclase microlaths and optically irresolvable material which contains celadonite (3%) and carbonate (1%) as alteration products.
Geological Setting: In the fault wedge between Slok Creek and Fraser faults, from a sequence which unconformably overlies the Pavilion Group.
Analysts: J. Harakal, D. Runkle
Analytical Data:
K = 3.11±0.01 n = 2
40*Ar/Total 40Ar = 69.9%
40*Ar (x 10-6 cc/g) = 5.888
40*Ar (x 10-10 mol/g) = 2.627
Age: 48.1±1.7 Ma (Middle Eocene)

Map No.: R NTS Sheet:92I/13**
UTM Coordinates:
EM0582005 E Latitude: 50°45'17"
EM5622980 N Longitude: 121°50'15"
Material Dated: Whole rock Dating Method: K-Ar
Location: A roadcut on Highway 12 north of Lillooet and 0.4 kilometres southwest of the highway bridge across Gibbs Creek, Fraser Canyon.
Rock Unit: Eocene, unit Evr
Lithology: Light pinkish grey, aphanitic felsite composed of 50% fine (0.2 mm) quartz, 48% fine, untwinned, slightly dusty potash feldspar, 2% unidentified opaque minerals and 0.5% dawsonite.
Geological Setting: In a fault sliver between Slok Creek and Fraser faults.
Analysts: J. Harakal, D. Runkle
Analytical Data:
K = 3.51±0.01 n = 2
40*Ar/Total 40Ar = 93.0%
40*Ar (x 10-6 cc/g) = 6.409
40*Ar (x 10-10 mol/g) = 2.860
Age: 46.4±1.6 Ma (Middle Eocene)

B5.3. Chilcotin Group

Map No.:R NTS Sheet:92O/8**
UTM Coordinates:
EM0555200 E Latitude: 51°19'58"
EM5686900 N Longitude: 122°12'28"
Material Dated: Whole rock Dating Method: K-Ar
Location: Located on the north end of Crows Bar Ridge about 150 metres north of survey station 3492' on the east side of the Fraser River south of China Gulch.
Rock Unit: Chilcotin Group, unit Pvb
Lithology: Dictytaxitic olivine basalt flow
Geological Setting: Taken from near the base of an erosional remnant of olivine basalt flows close to the trace of the Fraser fault.
Analysts: J. Harakal, D. Runkle
Analytical Data:
K = 0.455±0.006, n = 2
40*Ar/Total 40Ar = 16.3%
40*Ar (x 10-6 cc/g) = 0.0202
40*Ar (x 10-10 mol/g) = 0.0090
Age: 1.16±0.06 Ma (Pleistocene)