cop. 1

CACHE CREEK AND NICOLA GROUPS NEAR
ASHCROFT, BRITISH COLUMBIA

by

JOAN FRANCES GRETTE

B.A., Middlebury College, 1974

A THESIS SUBMITTED IN PARTIAL FULFILLMENT OF

THE REQUIREMENTS FOR THE DEGREE OF

MASTER OF SCIENCE

in

THE FACULTY OF GRADUATE STUDIES

(Department of Geological Sciences)

We accept this thesis as conforming
to the required standard

THE UNIVERSITY OF BRITISH COLUMBIA
November, 1978

In presenting this thesis in partial fulfilment of the requirements for an advanced degree at the University of British Columbia, I agree that the Library shall make it freely available for reference and study. I further agree that permission for extensive copying of this thesis for scholarly purposes may be granted by the Head of my Department or by his representatives. It is understood that copying or publication of this thesis for financial gain shall not be allowed without my written permission.

Department of GEOLOGY

The University of British Columbia
2075 Wesbrook Place
Vancouver, Canada
V6T 1W5

Date APRIL 27, 1979

Frontispiece. Venables Valley and Thompson River valley, background. The photograph is taken looking southeast.

ABSTRACT

Detailed mapping near the type area of the Cache Creek Group in southern British Columbia has led to significant changes in the distribution of Cache Creek and Nicola rocks. Much of what was called Cache Creek Group is now considered to be part of the Upper Triassic Nicola Group. Several criteria can be used to distinguish the two groups. These include: 1) lithologic differences, 2) fossil information, 3) structural style, and 4) metamorphic history.

The Cache Creek Group is subdivided into three mappable, fault-bounded units and appears to be a tectonic melange over much of its extent. A deformational event produced isoclinal folds, a phyllitic foliation in some lithologies, and was accompanied by metamorphism with variable pressure-temperature conditions. Mineral assemblages support conditions from temperatures less than 250°C and pressures of 4 kb or less to transitional blueschist conditions: T = 350° C and P = 6 kb.

In contrast, the Nicola Group is characterized by hydrothermal alteration and the lack of a pervasive secondary fabric. It does not have the blocks in a sheared matrix tectono-stratigraphic style typical of the Cache Creek Group.

The two units were brought together along the Martel Fault, probably a thrust, during late Lower or early Middle Jurassic time. Deformation and melange development in the Cache Creek Group predates this event. Distribution of Cache Creek and Nicola rocks and their relationship to each other during Upper Triassic time are still not clear.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

Figure | Page

ACKNOWLEDGEMENTS

First I would like to thank Peter B. Read who helped me find this problem and who gave invaluable assistance in the field and with petrology. Also, thank you to Karen Massey who suffered the 42° C temperatures of Venables Valley as my field assistant. Krista Scott provided technical expertise for Rb/Sr geochronology. Lee Pigage, besides leading me by the hand on the microprobe, was always happy to answer any questions he could help with. Valuable discussions were provided by W.R. Danner, Bill Travers, Jim Monger, Bill McMillan, Randy Parrish and Ian Duncan. Bruce Cameron helped me through microfossil traumas, and the Geology Department technicians assisted in most other crises. R.L. Armstrong supervised the thesis, provided financial support, and critically read the manuscript. Special appreciation to Stack and Pat Stackhouse for their part in my summer in Venables Valley.

INTRODUCTION

Purpose

Rocks of the Upper Paleozoic Cache Creek Group and Lower Mesozoic Nicola Group have figured significantly in models of the tectonic history of the Canadian Cordillera (Monger and others, 1972). Yet, especially within the type area, near Cache Creek, British Columbia, little detailed work has been published. There has been uncertainty in distinguishing Cache Creek Group rocks from the Nicola Group as lithologies are quite similar. The contact relations between the two have not been described.

The goals of this study are: 1) to describe the Cache Creek Group near its type locality in terms of lithology, stratigraphy, structure and metamorphism; 2) to determine what criteria can be used to distinguish the Cache Creek and Nicola Groups; 3) to study the contact between the two groups; and 4) to provide constraints on tectonic interpretations of the Late Paleozoic and Early Mesozoic history of the Intermontane Belt.

Field Area

The southernmost exposure of the Cache Creek Group was selected for detailed mapping. The area lies west of the Thompson River midway between the towns of Ashcroft and Spences Bridge, approximately $50^{\circ}30'$ N, $121^{\circ}20'$ W (Figure 1). Approximately 30 square miles were mapped during June, July, and August of 1975.

Access to the area is easy. It is situated along and west of the Trans-Canada Highway and is crossed by several ranching and logging roads. Quality and quantity of outcrops depend strongly on lithology and elevation. Limestone, chert, and greenstone are resistant to weathering in the dry climate and tend to be best exposed while phyllite, other clastic sedimentary rocks, and serpentinite are poorly exposed. Below about 1300 feet the terrain is

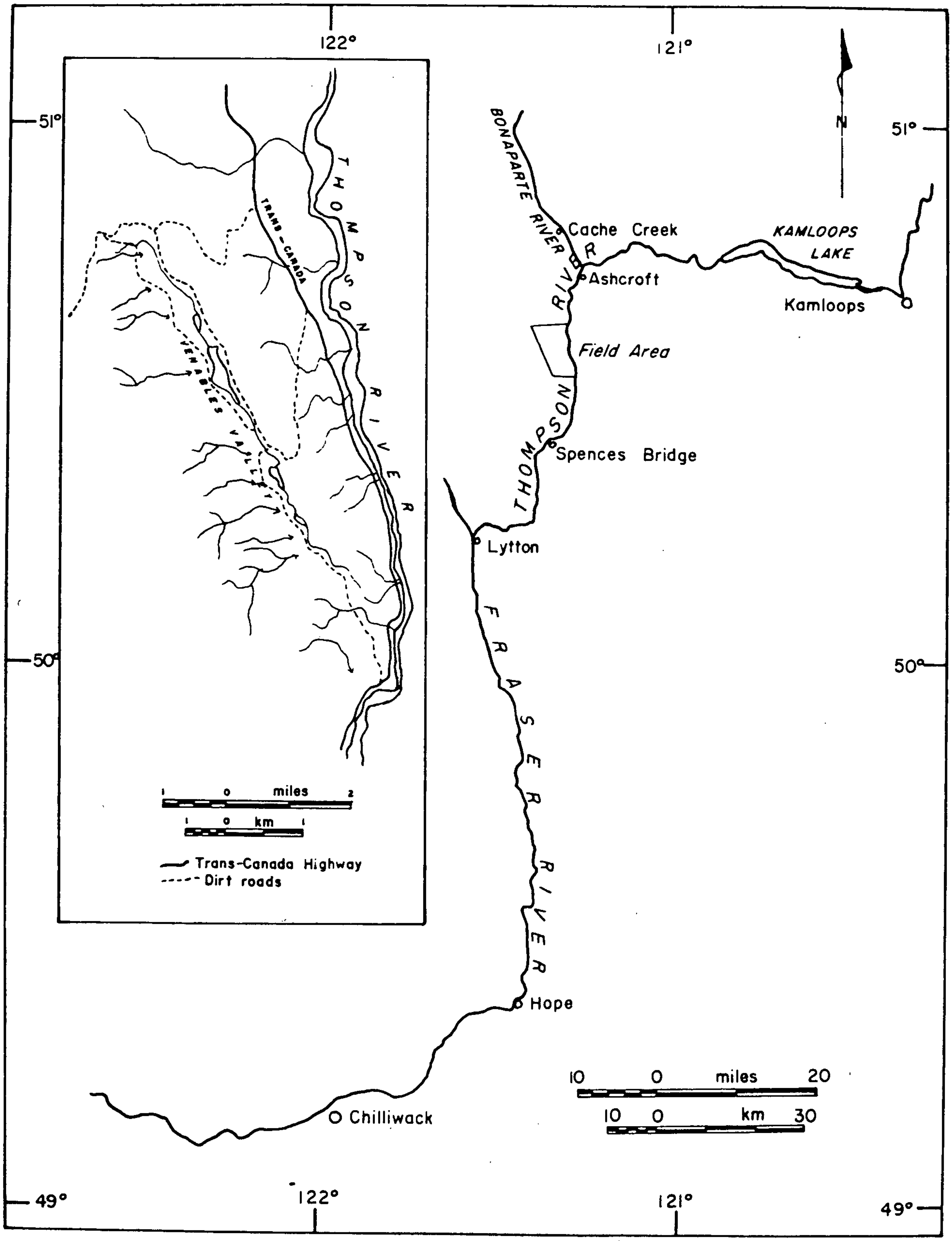


Figure 1. Location and access of field area.

quite flat, and sagebrush, cactus, and shortgrass are the dominant plant life. Sparse rock exposures are limited to small knobs, stream gullies, road cuts, and some cliffs near the river. At higher elevations, up to about 2400 feet, Ponderosa Pine dominates. Slopes are steeper, but outcrop quantity is not much better. Above 2400 feet on the slopes west of Venables Valley, spruce-fir forest and long grass undergrowth cover much of the hillside. Best outcrop or float is found on the north side of small gullies since these south-facing slopes are drier and have less cover. Game trails which cut through the heavy turf can be useful in exposing float. Above elevations of about 3500 feet the slope flattens and outcrop becomes extremely sparse. Only occasional carbonate, greenstone, or chert masses stick out, though logging cuts reveal the more prevalent phyllites and serpentinites.

Previous Work

Selwyn (1872) first described the Cache Creek and Nicola rocks along the Thompson River. He found fossils just north of Venables Creek which were then thought to be Devonian to Permian. He therefore classified all rocks along the west side of the river as Cache Creek.

Dawson (1894) published the first map that includes the present study area. All rocks west of the river with the exception of a small area north of Venables Creek was considered to be Cache Creek Group. The Cache Creek itself was divided into a lower unit of clastic sedimentary rocks and greenstones and the upper Marble Canyon Formation with the contact between the two lying along the west side of Venables Valley. Drysdale (1912) changed the location of this contact to the next valley west, but otherwise his map is identical to Dawson's in this area. The next work was done by Duffel and McTaggart (1952). Their map reverts to that of Dawson. Carr (1962) was the first to map in detail along the highway and river. He delineated some lithologies but did not make changes in the major units.

More recently, Danner (1965, 1975, 1976) has done considerable work on the carbonates in the Cache Creek Group and has established their age and probable environment of deposition. Across the Thompson River the Nicola Group has been mapped in detail by McMillan (1974). He includes detailed descriptions of several measured sections. To the north of this study area, near Ashcroft, work is in progress by Ladd (in press) and Travers (1978) on the Cache Creek, Nicola and Ashcroft Groups.

Detailed work in the Cache Creek elsewhere in British Columbia has been mainly by Monger (1969, 1975a, 1977a) in the Atlin Area and by Paterson (1973, 1974, 1977a, 1977b), Monger and Paterson (1974) and Paterson and Harakal (1974) in the Pinchi-Stuart Lake area.

REGIONAL GEOLOGY

General - North America

A eugeosynclinal belt containing Upper Paleozoic and Lower Mesozoic rocks that include the Cache Creek and Nicola Groups runs the length of the western North America Cordillera. In British Columbia part of this eugeosynclinal region is called the Intermontane Belt (Figure 2), a region of low-grade to unmetamorphosed rocks that lies between high-grade crystalline belts - the Omineca Crystalline Belt to the east and the Coast Plutonic Complex to the west (Monger and others, 1972).

The Intermontane Belt is characterized by the remnants of an Upper Paleozoic - Triassic (Monger, 1977b; Paterson, 1977a, 1977b; Travers, 1978) oceanic terrane of ribbon chert, alpine ultramatic rocks, and basic volcanic rocks (Monger, 1972, 1977b) allochthonous to North America, and a Lower Mesozoic arc terrane of calc-alkaline to alkaline volcanic rocks and related sedimentary rocks. Upper Paleozoic rocks of oceanic affinity belong to the Cache

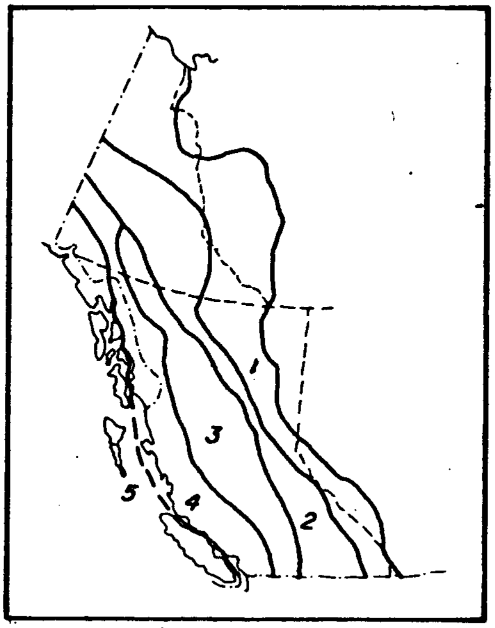


Figure 2. Geologic and physiographic belts of the Canadian Cordillera (from Monger and others, 1972). The belts are 1) Rocky Mountain Belt, 2) Omineca Crystalline Belt, 3) Intermontane Belt, 4) Coast Plutonic Complex, and 5) Insular Belt.

Creek Group in British Columbia and are characterized by a distinctive Tethyan fusilinid fauna (Danner, 1965; Monger and Ross, 1971; Monger, 1975b) and a pod-like tectono-stratigraphic style, suggesting severe deformation and dismemberment. Travers (1978) calls the Cache Creek near its type locality a melange. Blueschist metamorphism of eugeosynclinal strata has been dated in several localities as Late Triassic (Paterson and Harakal, 1974; Monger, 1977b). No basement for the Cache Creek has been found and most contacts with Lower Mesozoic and other Paleozoic rocks are faults.

Upper Paleozoic eugeosynclinal terranes extend discontinuously from Alaska to California. In Alaska the Uyak Formation on Kodiak Island and rocks near Anchorage have Tethyan faunal affinities (Connelly and others, 1976; Jones and others, 1972). Similar rocks are found in the western Yukon Territory, along the length of British Columbia, and in the San Juan Islands of Washington (Danner, 1974,1976, 1977). In British Columbia the Fergusson and Hozameen Groups have been suggested to be the southern extension of the Cache Creek Group (Monger, 1975b, 1977b). Bits of similar rocks are preserved in the western Cascades of Washington, in northeast Oregon, in the Western Paleozoic and Triassic Belt of the Klamath Mountains, and along the western edge of the Sierra Nevada - Calaveras Formation (Monger, 1975b). Oceanic assemblages in Alaska and Washington include rocks as young as Jurassic and early Cretaceous (Monger, 1977b).

Mesozoic volcanic and plutonic arc rocks within the Intermontane Belt range from mafic through silicic in composition. The Upper Triassic rocks of British Columbia are known as Nicola Group in the south and Takla Group in the north where volcanism continues into Lower Jurassic time. In southern British Columbia these predominantly volcanic rocks lie to the east of the oceanic terrane while to the north Takla rocks are found to the west of the Cache Creek Group.

British Columbia

Cache Creek Group

Monger (1975a) describes the following lithologies as characteristic of the Cache Creek: ribbon chert, abundant pelitic sediment, altered basic volcanic rocks, massive lensoid carbonate, minor clastic sediment, and alpine ultramafic rocks. In British Columbia there are three areas where Cache Creek rocks are exposed: the Atlin Terrane, the Pinchi-Stuart Lake Area, and the type area at Cache Creek (Figure 3).

Cache Creek rocks of the Atlin Terrane range in age from Missippian through Permian (Monger, 1975a) with recent reports of Middle Triassic radiolarian chert (Monger, 1977b).

Monger (1977a, 1977b) suggests the depositional environment to be one of

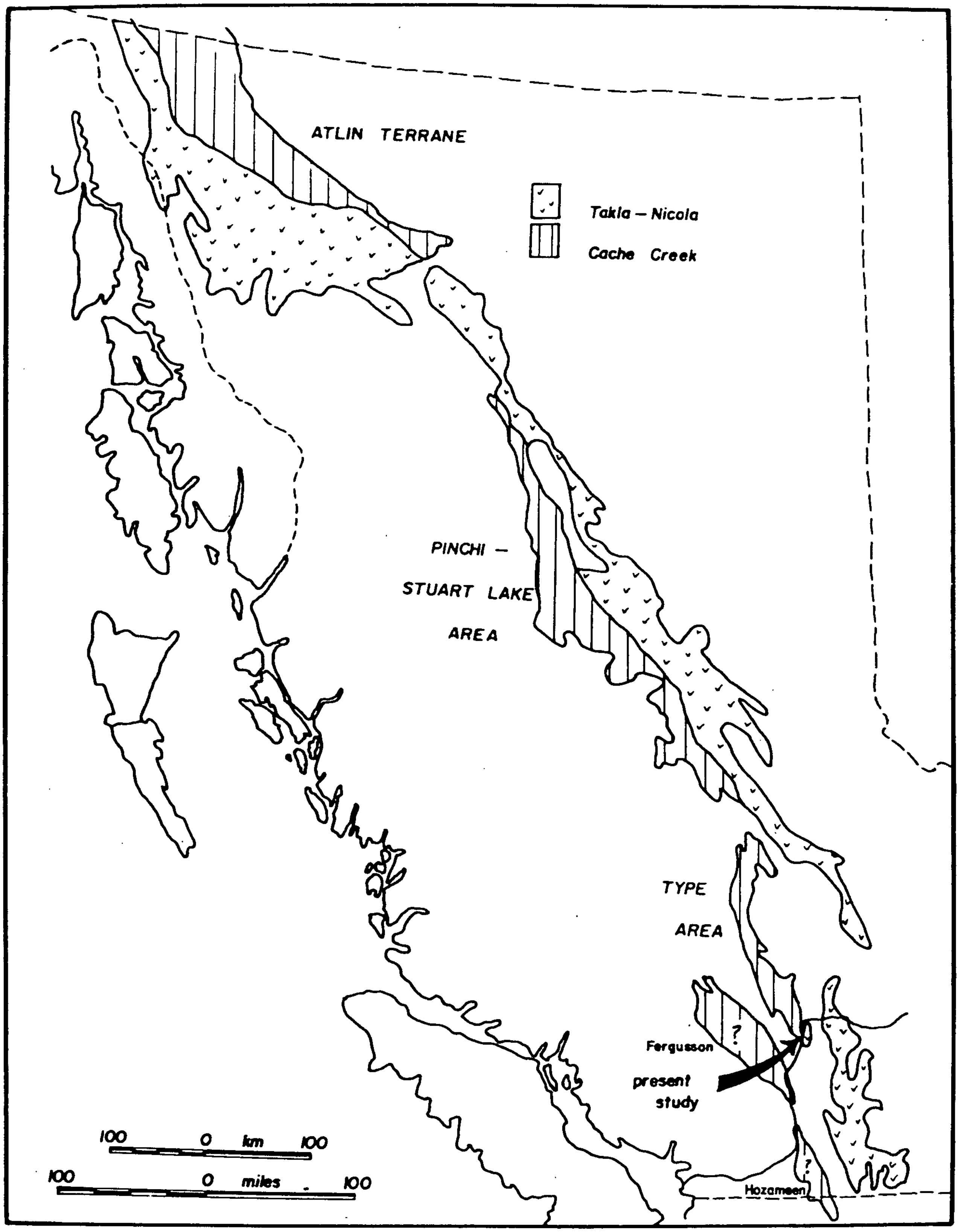


Figure 3. Areas of exposure of Cache Creek and Nicola-Takla in British Columbia. Regions with question marks are tentatively correlated with Cache Creek Group (Monger, 1975b).

volcanic pediments (atolls) on which reefs have formed. These reefs broke off from time to time and blocks slid into deeper water coming to rest among fine-grained sediments.

The structural history consists of early isoclinal folding and a later brittle folding event (Monger, 1977a, 1977b). Low grade to blueschist metamorphism accompanied the earlier deformation which has been traditionally considered post Late Permian and pre Late Triassic (Monger, 1977a). If the new radiolarian ages are valid, timing of deformation may need revision. In the later event, during or after late Middle Jurassic time, late Middle Jurassic and older strata were involved in thrusting (Monger, 1975a).

The Atlin Terrane is fault-bounded. On the northeast the Thibert Creek Fault separates Cache Creek from more deformed and metamorphosed Paleozoic rocks and farther south from less deformed Mesozoic rocks. To the southwest the Atlin Terrane is thrust over Mid-Jurassic and older rocks along the Nahlin Fault (Monger, 1977a, 1977b).

In the Pinchi-Stuart Lake Area in the center of British Columbia, typical Cache Creek lithologies are exposed in a belt approximately 450 kilometers long (Armstrong, 1949). Though Paterson (1977b) considers some Cache Creek lithologies to be very similar to rocks in the nearby Takla Group, fossils in carbonate rocks range from Pennsylvanian through Permian (Monger, 1975a). In the same region an ophiolite sequence is overlain by Upper Triassic sediments that locally contain aragonite (Paterson, 1977b). Thus Upper Triassic rocks have been deformed and metamorphosed with the Cache Creek. On the other hand, detrital chromite, presumably derived from ultramafic rocks in the Cache Creek, is found in nearby Upper Triassic sediments (Paterson, 1974). Therefore the tectono-stratigraphic setting of the Cache Creek and Takla rocks is not clearly defined in the Pinchi-Stuart Lake Area, and their ages overlap.

Three deformational events are recognized by Paterson (1977b). First to develop are east - west isoclinal folds with axial planes parallel to compositional layering accompanied by blueschist metamorphism K-Ar dated at 211-218 Ma (Paterson and Harakal, 1974). Later north-south trending, concentric folds are overprinted by still younger Cretaceous to Tertiary warps and kinks.

Like the Atlin Terrane the Pinchi-Stuart Lake Cache Creek is fault bounded. To the east is the Pinchi Fault separating oceanic terrane from the Hogem Batholith of Jurassic age (Paterson, 1974). There may have been significant right-lateral movement along the Pinchi Fault (Paterson, 1977b). To the west, northeast dipping faults place Cache Creek over Upper Triassic to Lower Jurassic rocks of the Sitlika Formation (Paterson, 1974).

In the type area (Figure 4), including this study, the Cache Creek is bounded by the Fraser River Fault Zone to the west, beyond which lies the Coast Plutonic Complex. In fault contact to the east are Triassic Nicola and younger rocks including the Guichon Batholith. Other Upper Paleozoic rocks farther east are not closely related to the Cache Creek Group. The Eastern Paleozoic Belt appears to be a different depositional realm with a different foreign fauna less tropical then the Tethyan fauna in the Cache Creek Group (Danner, 1976). Lithologies resemble those of the Cache Creek (Monger, 1975b) and these rocks were mapped as Cache Creek in earlier works (Cockfield, 1948; Dawson, 1894).

Between the Fraser Fault Zone and the Cache Creek Group are rocks of the Pavilion Group, lithologically similar to the Cache Creek but of uncertain stratigraphic position. It is likely they are a younger facies of the Cache Creek, but no younger than Middle Triassic (Campbell and Tipper, 1971). Their contact with the the Cache Creek is a fault. Of similar Middle Triassic age and west of the Fraser River Fault Zone is the Fergusson Group (Cameron and Monger, 1971), associated with ultramafic rocks of Permo-Triassic

LEGEND FIGURE 4

T	Tertiary - volcanic rocks, some sedimentary rocks
uM	Upper Mesozoic - sedimentary and volcanic rocks
Js	Jurassic - sedimentary rocks
TR N	Triassic - Nicola Group
PTR um	Permo-Triassic - ultramafic rocks
PTR P, PTR F	Upper Permian, Lower Middle Triassic - Pavillion, Fergusson Groups
Pcc	Pennsylvanian - Permian - Cache Creek Group
IP	Eastern Paleozoic Belt
	Coast Plutonic Complex - Cretaceous and younger intrusive and metamorphic rocks
	Jurassic and Triassic(?) - intrusive rocks
	Field area location
	Fraser-Yalakom Fault System

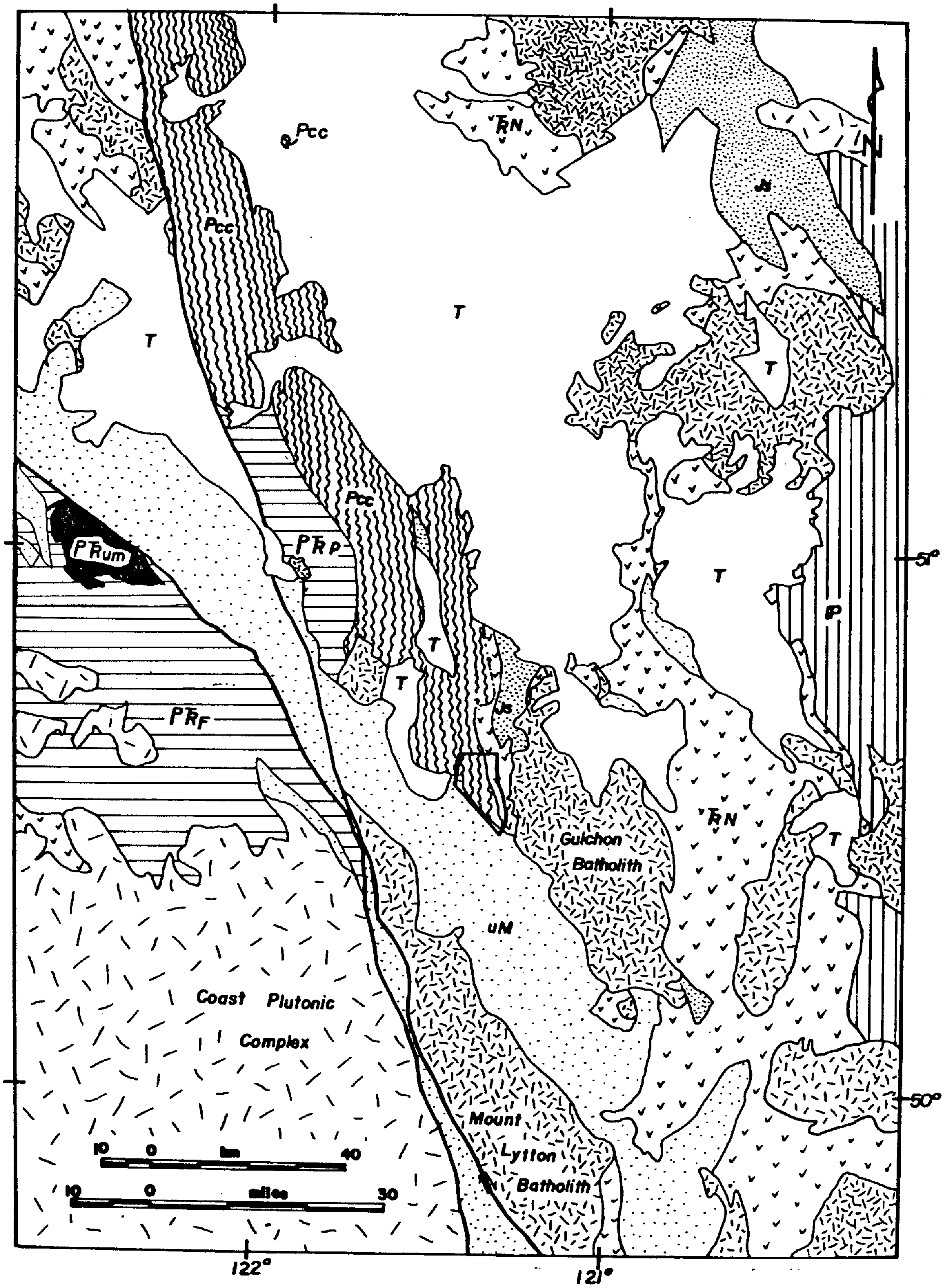


Figure 4. Regional geology of the southern Intermontane Belt.

age (Campbell and Tipper, 1971). Based on limited evidence, Monger (1975b, 1977b) and Cameron and Monger (1971) correlate both Pavilion and Fergusson Groups with the Cache Creek. Probable large-scale right-lateral strike-slip movement along the Fraser Fault Zone (Tipper, 1977) places the Fergusson and Cache Creek in closer proximity now than during their deposition. The Coast Plutonic Complex of dominantly Cretaceous intrusive rocks with screens and pendants of country rocks encloses Fergusson Group rocks on the west.

Cache Creek rocks within the type area contain a Middle Pennsylvanian through Permian fauna in limestone pods and within the massive Marble Canyon limestones (Danner, 1976). Travers (1978) has found Middle or Upper Triassic radiolaria in Cache Creek ribbon cherts. Lithologies are similar to those found further north - pelitic sedimentary rocks with pods of limestone, ribbon chert, basic volcanic rocks, and ultramafic rocks - all strongly deformed in most exposures. The pod-like occurrence of shallow water carbonates with radiolarian cherts is considered to be an original depositional pattern by Danner (1975). This implies that ribbon cherts are not necessarily restricted to deep water conditions. This environmental interpretation does not require movement of slide blocks and/or slumping of shallow water sediments into deeper water as was suggested by Monger (1977a, 1977b) for the Atlin region. Travers (1978) considers limestone blocks to be allochthonous.

Deformation in the type area has been described only in general terms. "Intensely sheared" (Campbell and Tipper, 1971) or "severely deformed with internal structures impossible to sort out though with generally northwest trends and southwest dips" (Duffell and McTaggart, 1952) are the only descriptions available. Similarly the low grade regional metamophism has not been studied.

Contact relationships with lower Mesozoic rocks are poorly known; much of this contact is covered by Tertiary and younger rocks. The eastern margin of the Cache Creek Group near Cache Creek is strongly sheared along what Danner (1975) has termed the "Bonaparte Disturbed Zone". Within this zone Travers (1978) has identified a fault contact between Cache Creek and Nicola which has apparently had some Tertiary left-lateral movement but whose earlier movement history is unknown.

The Guichon Batholith dated at 205 Ma by Rb/Sr (R.L. Armstrong, personal communication, 1978), intrudes Nicola rocks. Its setting is similar to that of the Hogem Batholith of the Pinchi-Stuart Lake Area. Lowest Jurassic strata are preserved in remnants of small basins, the largest of which is the Ashcroft basin, centered on the town of Ashcroft. In this basin a basal conglomeratic facies containing clasts of probable Guichon Batholith provenance is unconformable to disconformable on Nicola volcanic and sedimentary rocks (Frebold and Tipper, 1969). Travers (1978) reports an apparently complete Upper Triassic through Lower Jurassic section near the town of Cache Creek.

Nicola Group

Upper Triassic rocks which run the length of British Columbia are known as the Nicola Group in the south and Takla Group in the north. Nicola Group rests unconformably on older rocks (Danner, 1976; Campbell and Tipper, 1970) and consists of shallow marine to subareal calc-alkaline and alkaline volcanic rocks, reefoidal limestone, and clastic rocks derived from these. The depositional environment has been interpreted to be a volcanic island arc (Monger and others, 1972) with fringing carbonate reefs and small basins (Schau, 1968, 1970). Some workers have suggested that alkaline chemical trends favor a rift environment interpretation (Preto and others, 1975).

Nicola rocks of the type area in the Nicola map sheet (Cockfield, 1948) have been described in detail by Schau (1968, 1970). The age there spans

Late Karnian to Late Norian and possibly as young as Pleinsbachian (Preto, 1974). No base is seen, but to the east Nicola is unconformable on Upper Paleozoic. Schau has divided the Nicola into two assemblages which he has named P and A based on the dominant phenocryst, plagioclase or augite. In the lower assemblage (P) plagioclase porphyry flows with andesitic to dacitic compositions dominate. Interbedded with and above the flows are sediments derived from the volcanics - tuff, greywacke, argillite, conglomerate, breccia, and some limestone. Dacite plugs intrude these and tend to lie along faults. The upper assemblage (A) is composed of flows with abundant large augite phenocrysts and sediment derived from them.

Deformation of the Nicola in the type area is typically gentle, upright, cylindroidal folds and abundant faulting. A few overturned folds are found locally (Schau, 1968, 1970). A foliation is developed in fault zones. Low-grade metasomatic and hydrothermal alteration is common. Higher grades of metamorphism are attained close to intrusive bodies.

Granitic rocks similar to the Nicola and Takla rocks in chemistry and only slightly younger in age (Travers, 1978; McMillan, 1975) intrude Nicola and Takla rocks. The Guichon Batholith and the Hogem Batholith are two of the best known. These plutons are not seen to cut the Cache Creek, though Travers (1978) has mapped small stocks cutting Cache Creek that may be related to the Guichon.

Ashcroft Formation

The Ashcroft Formation of Lower Jurassic age unconformably overlies the Nicola Group and the Guichon Batholith. Usually there is a basal conglomerate containing abundant granitic detritus, probably from the Guichon, and fragments of Nicola volcanic and sedimentary rock. Most of the section is black, carbonaceous shale with some siltstone, sandstone and minor, impure limestone (McMillan, 1974).

Except for one questionable block described by Travers (1978), no detritus of Cache Creek origin have been identified in the Ashcroft Formation. This is in contrast to Lower Jurassic boulder conglomerates which contain Cache Creek detritus in the Quesnel-Prince George area (Tipper and Richards, 1976).

GEOLOGY OF THE STUDY AREA

General Distribution of Rock Units

Five rock groups are represented within the map area. General bedrock distribution is shown on Figure 5. Figure 6 (in pocket) is the detailed geologic map and Figures 7 and 8 (also in pocket) are cross sections from this map. The oldest rocks are those of the Cache Creek Group, the focus of this study. Many lithologies are present and stratigraphy is complicated by tectonic disruption. The age of the Cache Creek here is probably Late Permian. Upper Triassic rocks are found along the eastern part of the area where various lithologies of the Nicola Group are exposed. Lower Jurassic rocks which can be correlated with the Ashcroft Formation further north crop out in two small areas near the south end of the map area. A fourth unit is the Lower Cretaceous Spences Bridge Group which underlies the western edge of the map area. Covering large amounts of the bedrock are Quaternary deposits of various origins.

Cache Creek Group

Cache Creek stratigraphy is obscure because of three factors: 1) poor exposure, 2) lenticular nature of original bedding, and 3) tectonic disruption. The group is divided into three map units. Figure 9 is a diagrammatic

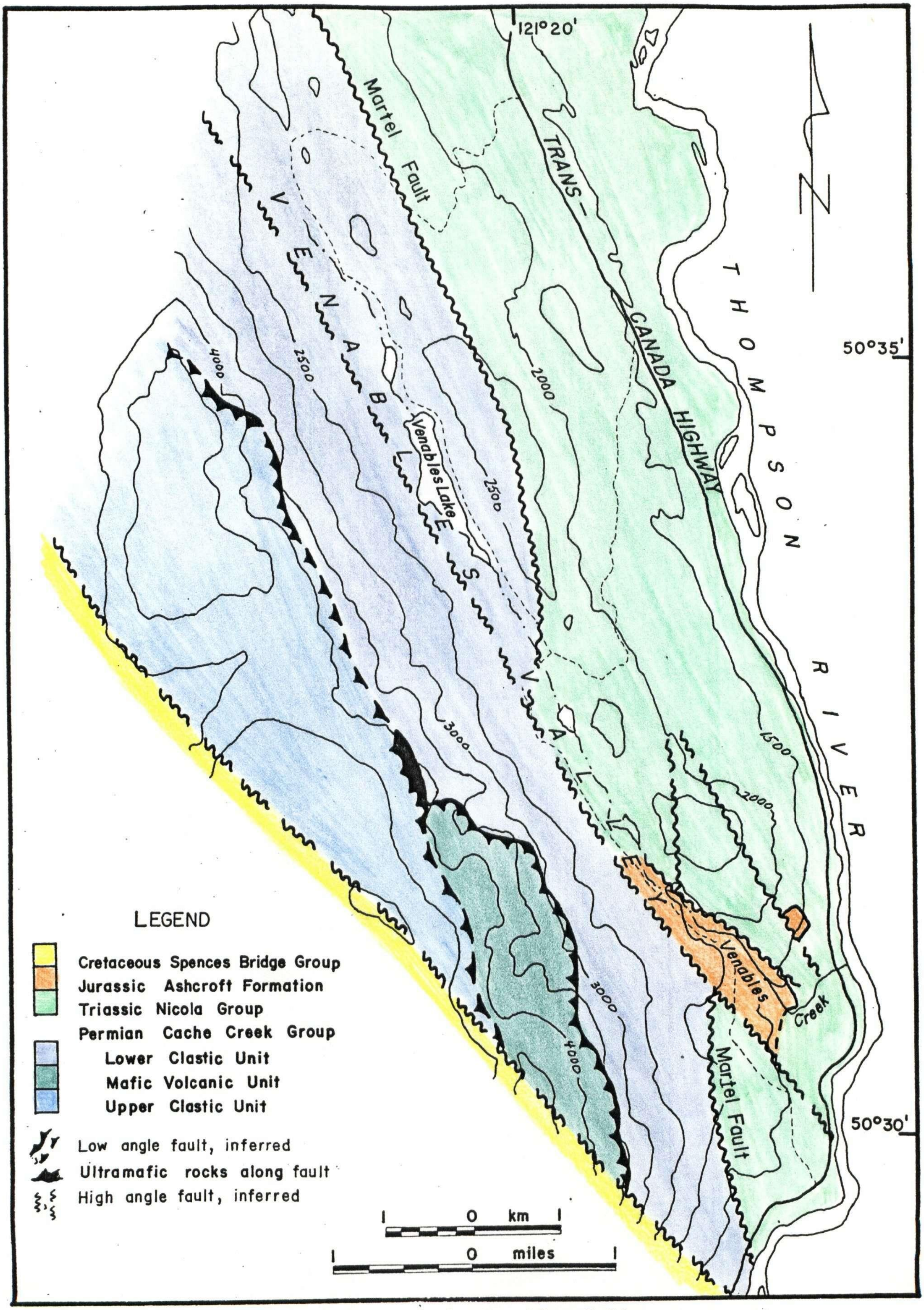


Figure 5. Generalized geology of the Venables Valley area.

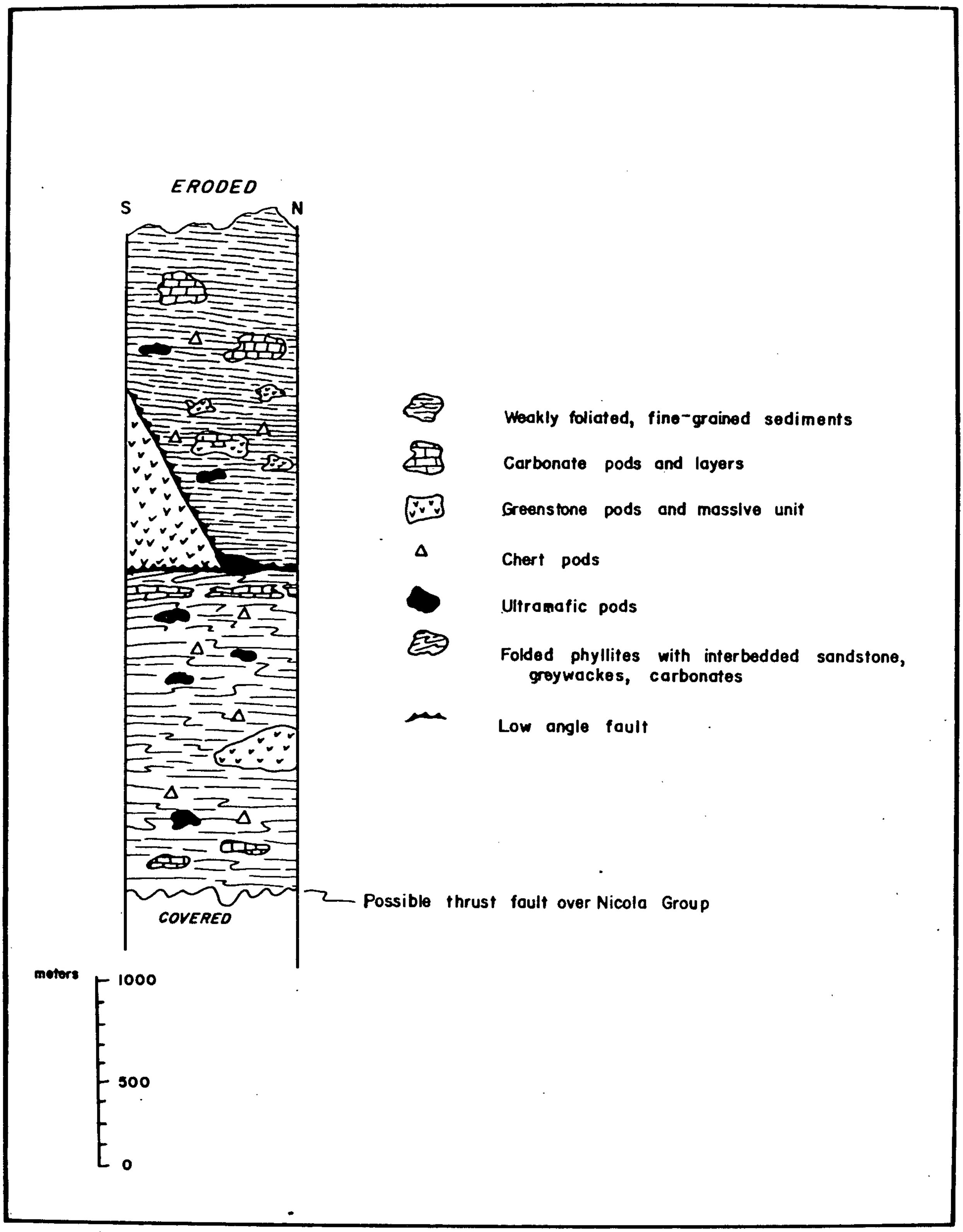


Figure 9. Diagrammatic stratigraphic section of the Cache Creek Group.

section showing these units and their relation to each other. Lowest, but not necessarily oldest, is a strongly deformed, clastic unit consisting chiefly of phyllite with minor greywacke and sandstone. Volcanic rocks, limestone layers and pods, ribbon chert and serpentinite masses are present but less abundant. In the south the overlying unit is composed of altered basaltic flows. This unit thins to the north, probably as a result of faulting. Above the wedge of basalt is a second clastic-dominated unit that has previously been mapped as part of the Marble Canyon Formation (Duffell and McTaggart, 1952). Present work indicates that limestone is a minor component, present as small pods in a sheared pelitic matrix. Just north of the field area, along strike, massive limestone, probably Marble Canyon Formation, is exposed on White Mountain.

Lower Clastic Unit (Pp, Pvcl. Ppl. Pls on Figure 6)

Lithologies present in this unit in order of abundance are phyllite, greywacke, ribbon chert, limestone, volcanic rocks, volcaniclastic sedimentary rocks and serpentinite.

Though phyllite is very poorly exposed, it probably underlies most of the area mapped as lower clastic unit. Some good exposures can be found in gullies of road cuts, but outcrops of the lower clastic unit on hillsides are usually of coarser-grained clastic rocks, chert, or limestone. Phyllite, however, makes up most of the float in the area where float is visible, in game trails or on drier, more open slopes.

The phyllites are grey to black, in some places greenish and weakly banded. Thin stringers less than 2-3 mm thick of lighter colored, coarser-grained material, usually silt or very fine sand, give the phyllite its banded appearance. Though these stringers may be related to original bedding, they no longer can be called bedding since they are discontinuous and occasionally form small, rootless folds. Banding parallels the phyllitic foliation in most exposures, but at several outcrops, probably fold hinges, original bedding can be seen in a crosscutting relationship to the foliation. Usually these exposures are in coarser-grained rocks.

In thin section the phyllites are seen to be strongly foliated and recrystallized. The phyllites are dominantly very fine-grained with up to 50% plagioclase feldspar (albite) and very little to no quartz. Feldspar and quartz often occur in separate patches of interlocking grains with chlorite, $\pm$ stilpnomelane, and sericite wrapping around the patches producing a flaser texture (Figure 10). This texture supports field evidence that present layering is secondary, a result of alignment of the platy minerals, except where bedding is preserved in fold hinges.

A different sort of phyllite is exposed at the southern end of the area just north of the contact with the Spences Bridge Group and about thirty meters above the highway. Here the phyllites are much more disrupted and contain abundant but scattered clasts of variable lithologies. The term "melange" could be used to describe rocks at this exposure. The clasts, up to several centimeters across, include mainly greenstones, but chert and other sediments are present. The phyllitic foliation is well developed and is in turn deformed into sharp chevron folds with variable axes and axial plane orientations. Figure 11 is a photograph of some of these structures. The location is shown as I on Figure 6. Many of the folds are refolded in the same manner as the earlier ones. This seemingly chaotic deformation may be a result of proximity to the fault contact with Nicola strata or more likely, could be characteristic of much of the lower clastic unit and just poorly exposed elsewhere.

Only two other exposures, both in logging cuts, show similar deformation styles within the phyllites. Natural outcrops of the phyllites tend to expose

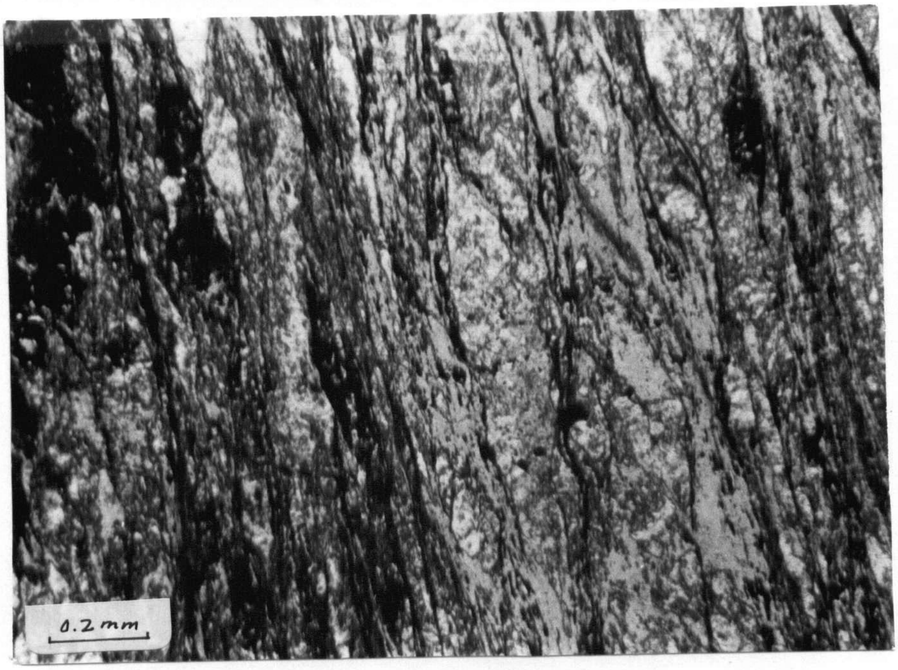


Figure 10. Photomicrograph of typical phyllite in the lower clastic unit of the Cache Creek Group. Note cataclastic fabric. Augen-like patches of feldspar and quartz are surrounded by chlorite, sericite and stilpnomelane. Plane polarized light.

Figure 11. Chaotic folding in Cache Creek phyllite at southern end of the area, locality I on Figure 6. The photograph is taken looking north-northwest; note hammer near top of outcrop for scale.

less deformed parts. Sketches of the deformation style in the two artificial exposures are shown in Figure 12. In both cases drag folds are associated with steeply dipping shear zones. The phyllitic foliation is irregularly folded and sheared. Average strike of foliation is N 25^{o} W at location II and N 60^{o} W at III. Fold axes parallel the strike but axial planes are curved.

Greywacke crops out more than phyllite in the lower clastic unit. Occasionally it is seen interbedded with the finer grained sediments, but more often greywacke occurs as pods amidst phyllite float. Interbedded greywacke and phyllite were seen in layers as thin as 3 cm, but the greywackes may be quite thick in areas where contacts with the phyllite are not exposed.

In the field the clastic nature is not always evident - greenstone and greywacke are easily confused. Greywacke is usually green and varies from massive to deformed, with a well-developed chlorite schistosity. Grain size is usually less than 2 mm. Occasionally larger clasts, several centimeters in length, sit in the finer matrix. These clasts are best observed on cut surfaces.

The greywackes are feldspathic. Some contain as much as 75% plagioclase grains, euhedral to subhedral in shape (Figure 13). At least 30% of every greywacke is plagioclase. Most of the feldspars are now strongly saussuritized or completely altered to albite. The original andesine composition is preserved in a few grains. Zoning and twinning show up in many grains.

Lithic fragments make up most of the remainder of the detrital material. Volcanic rocks are the dominant lithic fragments; chert is present in one sample; and another contains abundant carbonate clasts. Volcanic clasts include porphyritic flow rocks and pieces of palagonite (Figure 14). It is rather unusual to find a piece of glass preserved in a Permian rock, especially since the rock is altered and deformed, but the fragment is isotropic, brown

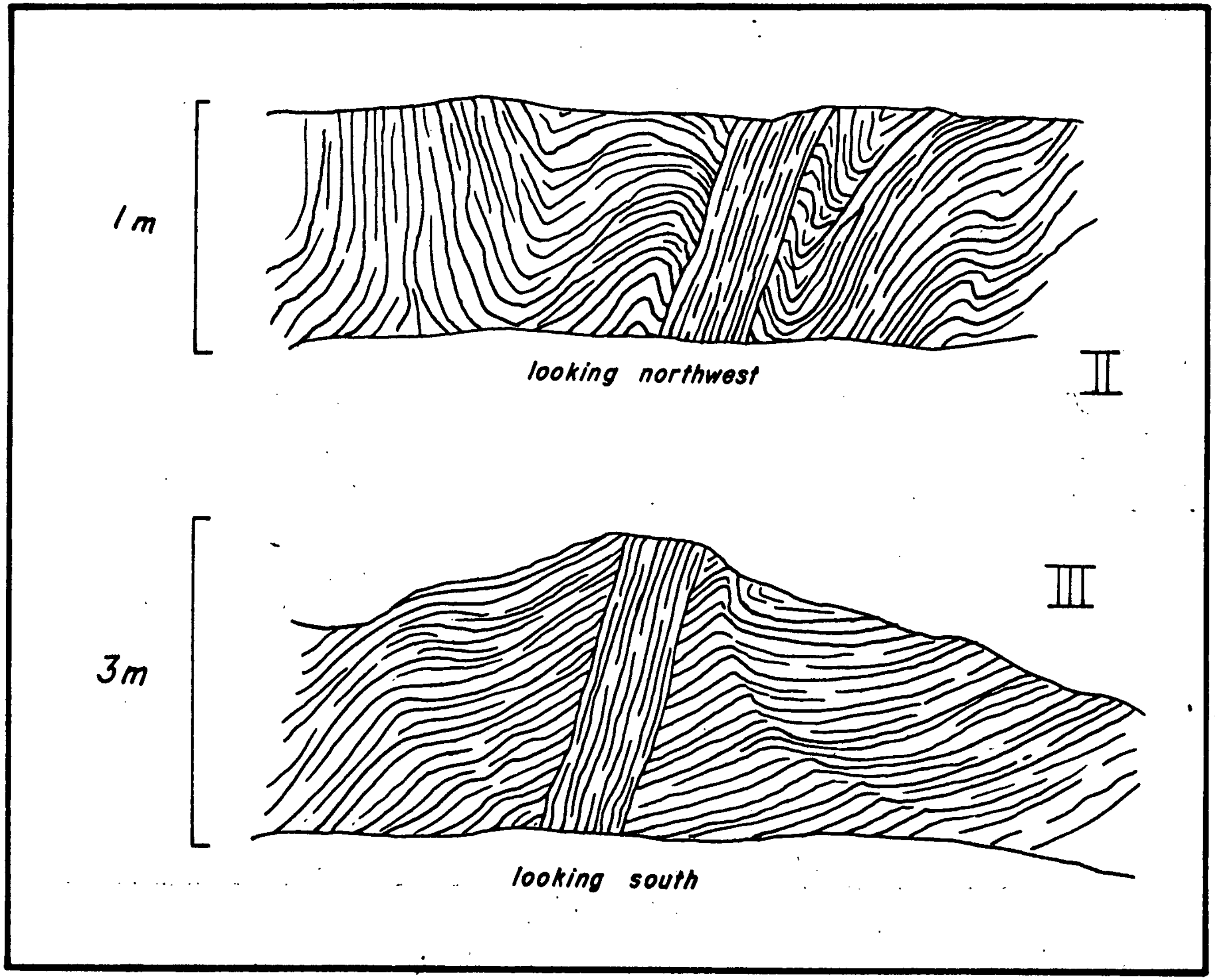
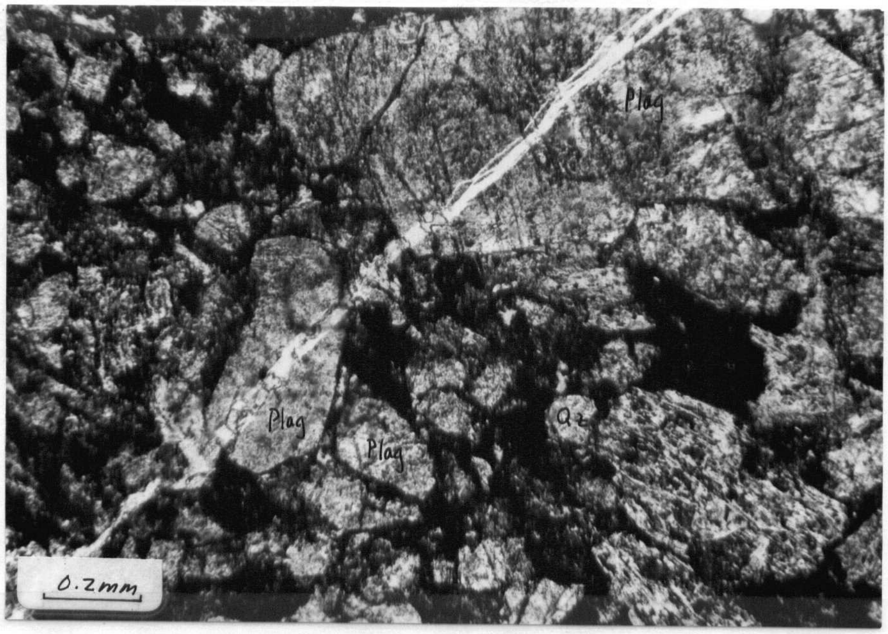
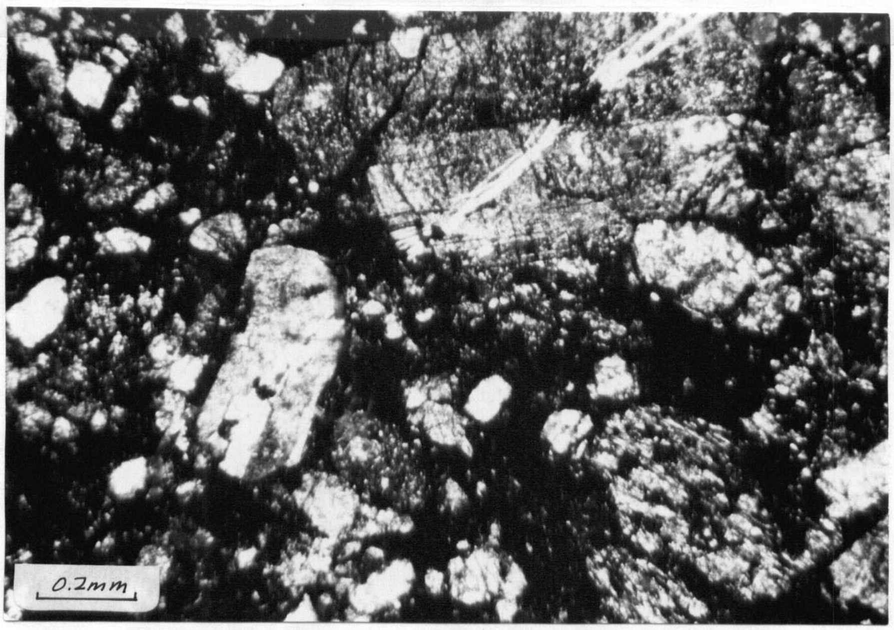


Figure 12. Field sketches showing folding and shearing of phyllitic foliation at two road cuts in the Cache Creek Group. Roman numerals designate locations shown on Figure 6.

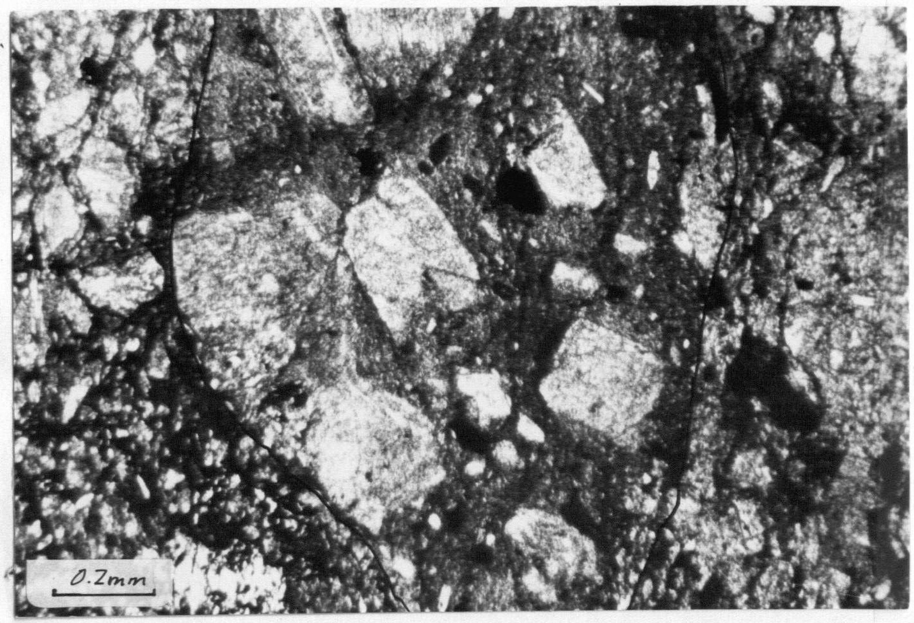


a.

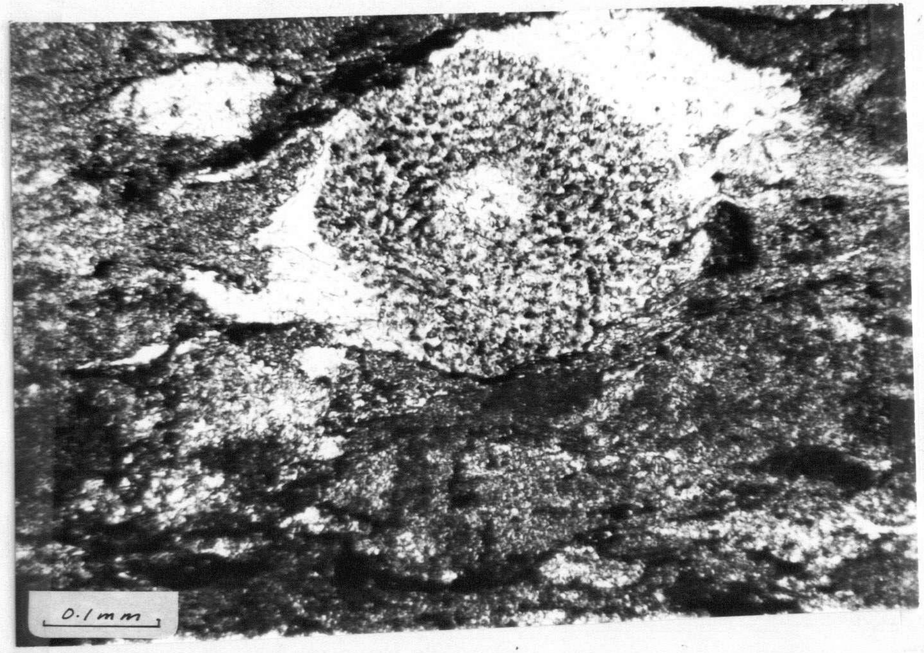


b.

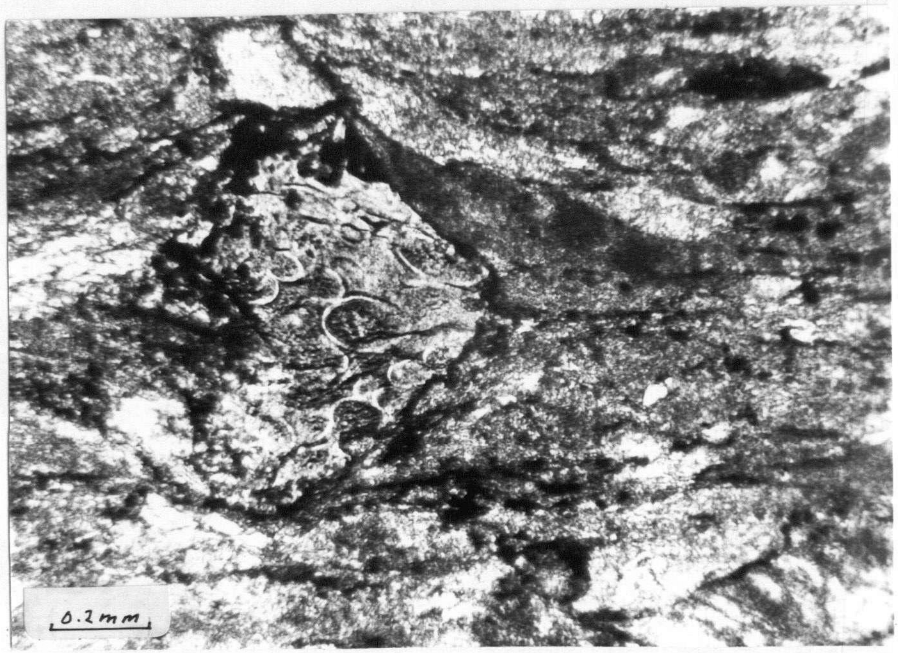
Figure 13. Photomicrograph of undeformed plagioclase-rich greywacke. a) Plane polarized light; b) crossed polars. Plag-plagioclase, Qz-quartz.



a.



b.



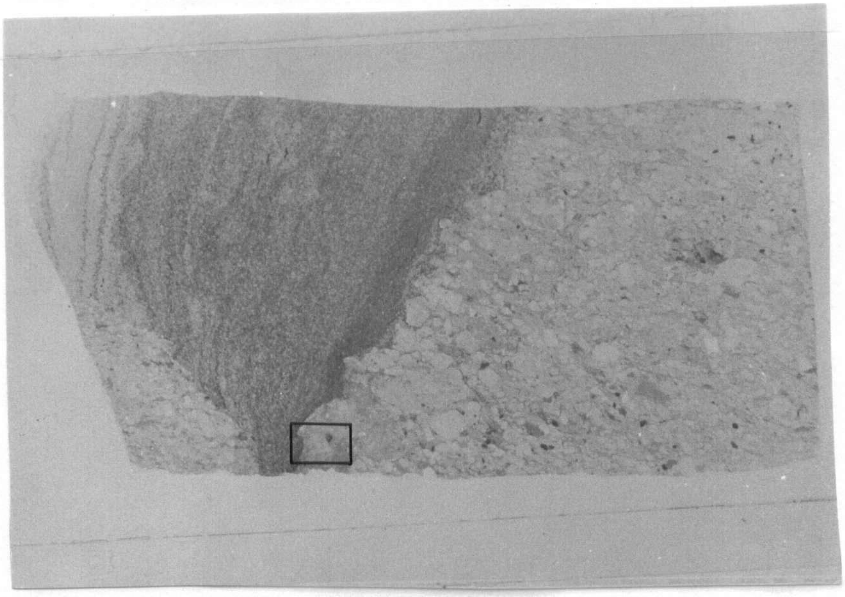
c.

Figure 14. Photomicrographs of lithic fragments in Cache Creek Group greywackes. a) Feldspar porphyry fragment, outlined, b) limestone fragment with fossil and c) palagonite fragment. All are taken with plane polarized light.

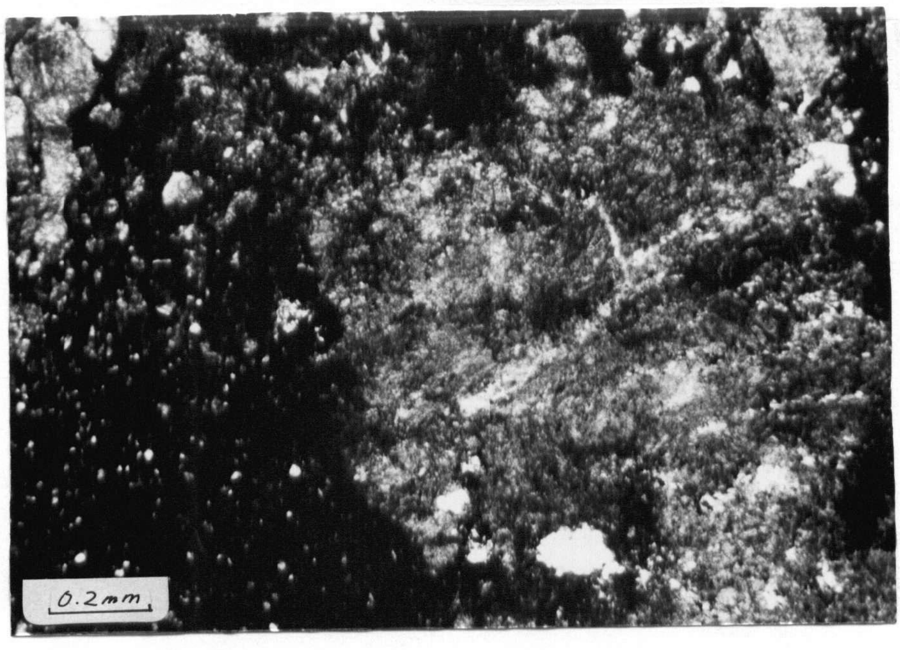
and has an apparent eliptical banded structure common to palagonite. In one sample a piece of finer grained greywacke occurs as a clast (Figure 15). Quartz is very rare, usually only 2-3 grains per thin section. A brownish amphibole was observed in one sample. Though the greywackes themselves have been metamorphosed, there appear to be some clasts derived from a low-grade metamorphic terrane. Figure 15 shows a detrital grain which is almost completely bowtie prehnite. Another section comtains detrital epidote.

The semi-opaque matrix is usually very fine grained and made up of secondary minerals. Metamorphic minerals include chlorite (found in all samples in both the matrix and replacing detrital fragments), white mica. calcite (more prevalent in the finer grained greywacke), sphene (making up much of the semi-opaque matrix and replacing volcanic fragments), stilpnomelane (occurring with chlorite in the matrix of deformed greywacke), pumpellyite and/or epidote (found both in the fine grained matrix and replacing detrital grains). Pumpellyite is brightly green pleochroic and is therefore of the iron rich variety. Except for the detrital prehnite mentioned earlier, prehnite occurs in veins and is rarely developed within the body of the rocks. Table I shows mineralogy of the greywackes.

Deformation in the greywackes varies from negligible to strong, in the form of a cataclastic foliation. Figure 13 is a photomicrograph of one of the relatively undeformed greywackes. Matrix is composed of finer and finer grains similar in composition to the larger clasts. A weakly foliated greywacke is shown on Figure 16. The foliation is defined by the development of chlorite in the matrix and recrystallized detrital grains. Figure 17 shows a more extreme cataclastic fabric, protomylonite, with an almost opaque, recrystallized and broken fragment zone of fine grained material around the shattered and tectonically eroded feldspar grains. This variation in deformaion within the same lithology is typical of the structural style of the Cache Creek



a.



b.

Figure 15. a) Thin section of a Cache Creek Group greywacke showing large rip-up clast of siltstone re-deposited while soft. Box is around approximate location of b) photomicrogragh of a detrital prehnite grain. Crossed nicols.

Sample #	Lithology	Augite	Plagioclase	Quartz	Chlorite	Albite	Pumpellyite	Prehnite	Actinolite	Stilpnomelane	Sodic amphibole	Epidote	Calcite	Sphene	White mica	Devitrified glass
Lower Clastic Unit																
6-18-1	Greywacke		f	f	a	a			a	a		a	a	a	a	f
6-18-2	Greywacke		f	f	a	a				a			fa	a	a	f
6-18-3	Greywacke		f	f	a	a	a			a			a	a	a	
7-8-2	Greywacke		f	f	a	a	a	a		a		a	a	a		
7-20-1	Greywacke		f	fq	aq	a	a						aq	a	a	f
7-20-6	Greywacke		f	f	a	a	q					a	fa	a	a	
7-20-8	Greywacke		f	a	a	a	a	f					a	a	a	
7-5-4	Augite porphyry	r		a	av	a	a		a	a	a		av	a	a	
7-5-3B	Basalt	r		a	a	a			a	a	a	a		a	a	
7-5-3A	Tuff	fr			av	a			a	a	a			a	a	f
7-6-5	Augite porphyry	r		q	a	a			a				a	a	a	
7-22-5	Basalt		r	rvq	av	a	v			a			q	a		
7-20-9	Greywacke	f	f	fq	a	a	a	q					q	a		f
Greenstone Unit																
6-9-3	Tuff	r			av	a			a				av	a	a	r
7-20-3	Basalt	r	r	q	a	a	aq	q					q	a		r
7-20-2	Basalt	r	r	vq	vq	a	avq			vq			vq	a		r
7-20-4	Basalt	r	r		a	a	a							a		r
7-19-3	Basalt	r	r	q	aq	a	av						q	a		
6-18-6	Basalt		r		a	a		a	a			a	aq	a		
6-18-5	Basalt	r	r	q	q	q	v					aq		a		
Upper Clastic Unit																
7-25-2	Tuff	r	r		a	a							av		a	r
7-12-3	Tuff	r			a	a	av						a			r
7-25-3C	Lithic sandstone	f	r		a	a							a		a	f
7-25-3B	Greywacke	f			a	a	f						a		a	f

TABLE I. Mineralogical Data for Greywackes and Greenstones in the Cache Creek Group.

Key to Mineral Occurrences

r - relict mineral
f - detrital fragment
a - alteration mineral
v - vesicle filling
q - vein mineral

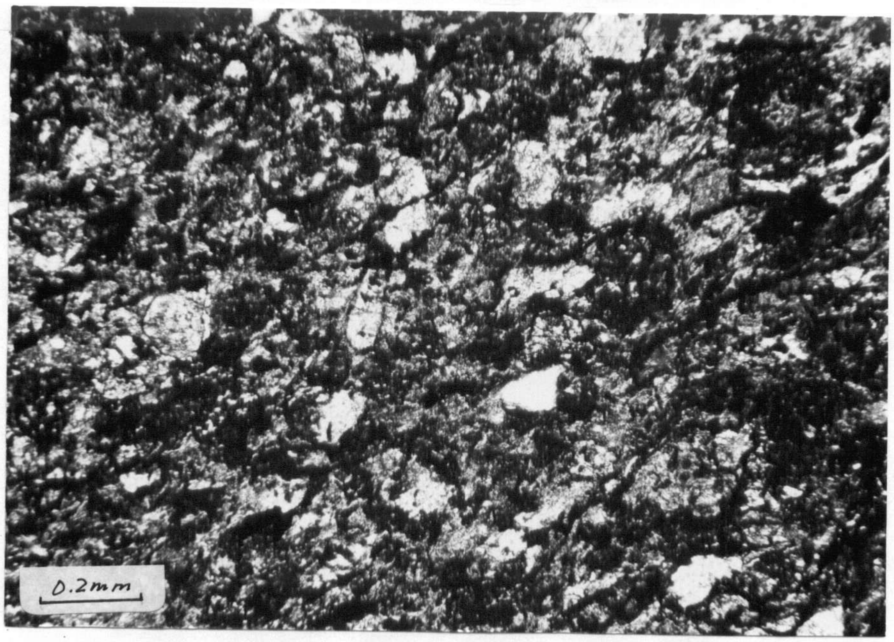


Figure 16. Photomicrograph of a weakly foliated Cache Creek Group greywacke. Plane polarized light.

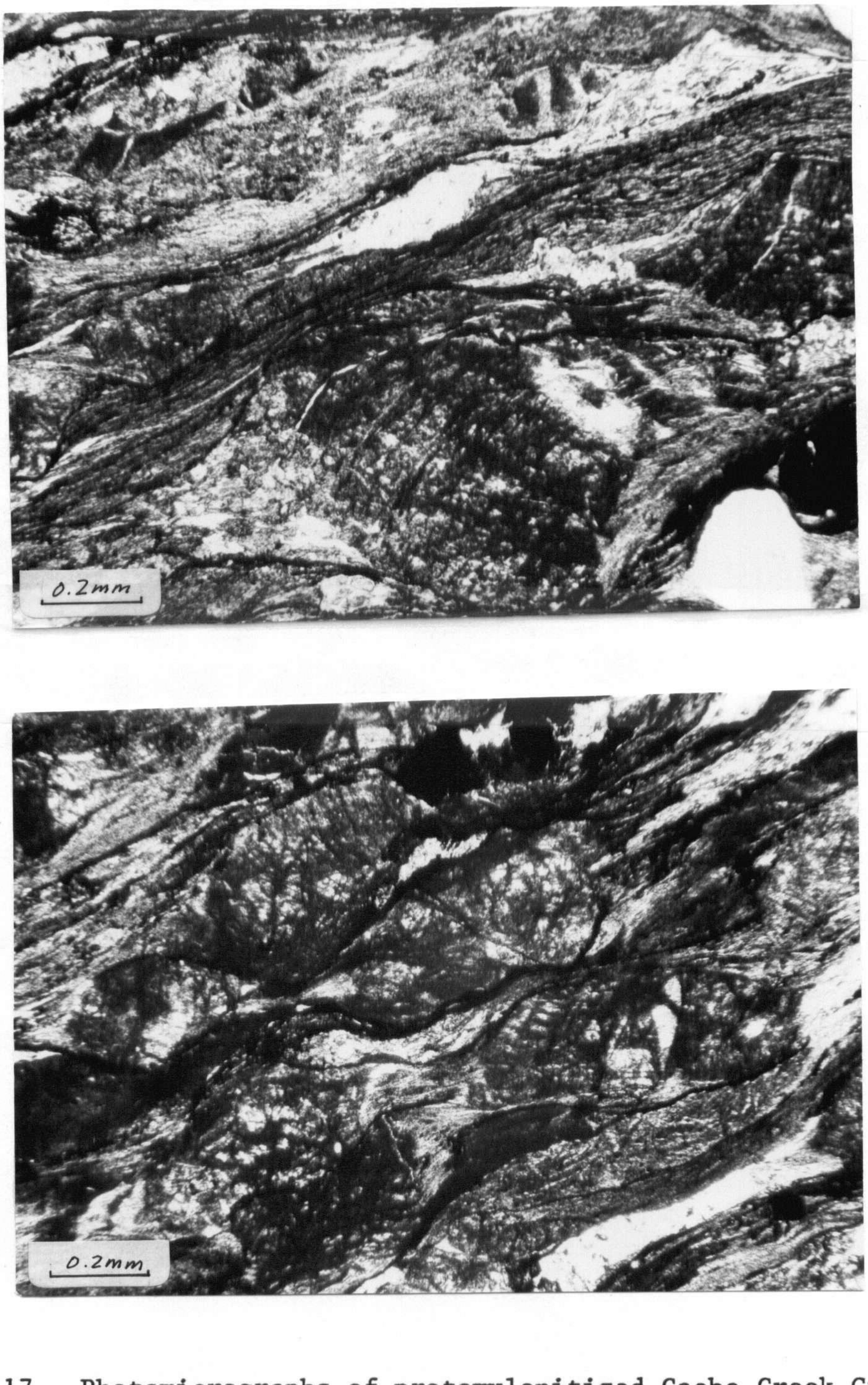


Figure 17. Photomicrographs of protomylonitized Cache Creek Group greywacke. Note shattered feldspar grains and fluxion texture in much of the matrix. Plane polarized light.

and will be discussed later.

Chert, the third most plentiful lithology within the lower clastic unit, varies from light grey to nearly black in color and is interbedded with thin layers of black argillite (ribbon cherts). The argillite is usually quite deformed and frequently squeezed out from between chert layers.

Chert outcrops are usually small, 6 meters or less in largest dimension. Invariably the chert is boudined and occasionally chevron type folds of several tens of centimeters amplitude are visible. Alignment of a large number of chert outcrops in the south end of the field area suggests there may have been larger scale boudinage of a single horizon. Brecciation and mylonitization are also prevalent in the cherts on macroscopic and microscopic scales (Figures 18 and 19).

Thin sections show some of the cherts to contain radiolaria and probable sponge spicules, but these are too recrystallized to be identified and show up as circles or ellipses of slightly coarser quartz within the finer grained matrix (Figure 20). Hydrofluoric acid etching techniques were used in an attempt to recover radiolaria (Pessagno,1972), but recrystallization has effectively destroyed the fossils. The etching did expose tiny folds of thin argillaceous layers within the chert.

Generally the cherts are impure. They contain minor amounts of chlorite with some sericite, scattered pyrite, and occasional clinozoisite. The platy minerals, if they are sufficiently abundant, lend a foliation to the chert.

Carbonates occur as semi-continuous layers and as pods. The best example of a carbonate layer is found along the top of the lower clastic unit and can be traced intermittently for 4.5 km. It is a silty to sandy limestone with a well-developed foliation. No fossils were found. Thin sections show detrital material to be similar to that in the greywackes - plagioclase grains, some andesine but mostly altered to albite, and lithic fragments, usually

Figure 18. Brecciated Cache Creek Group chert. Scale is 5 cm.

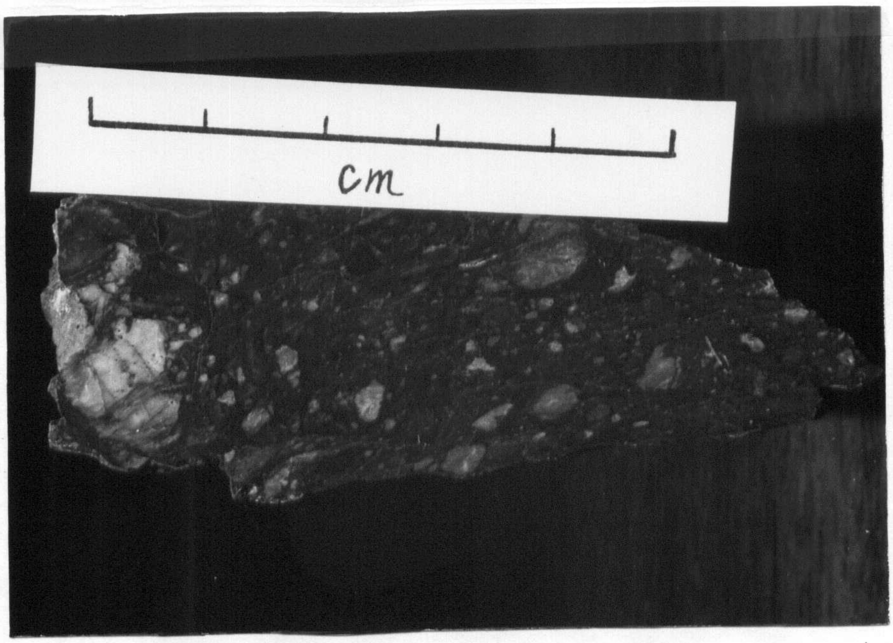
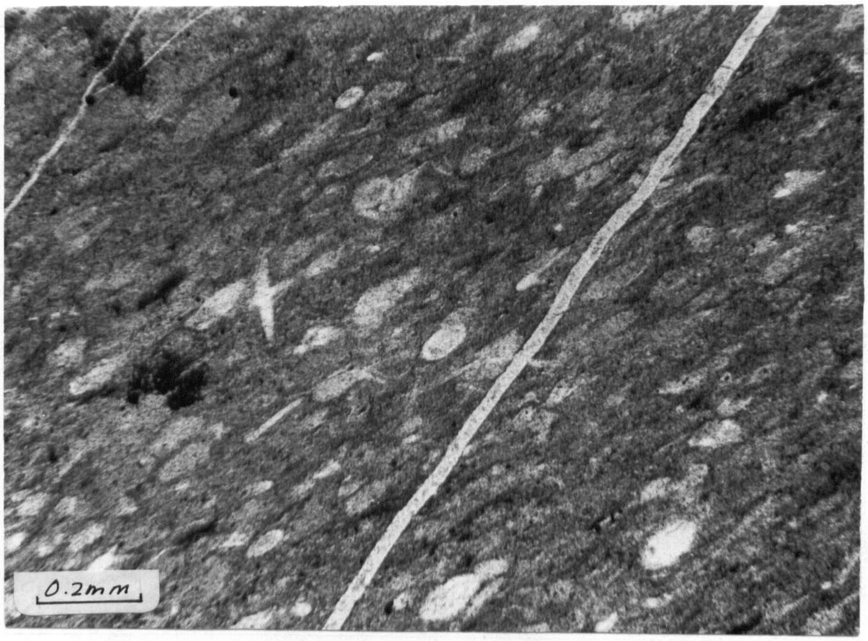
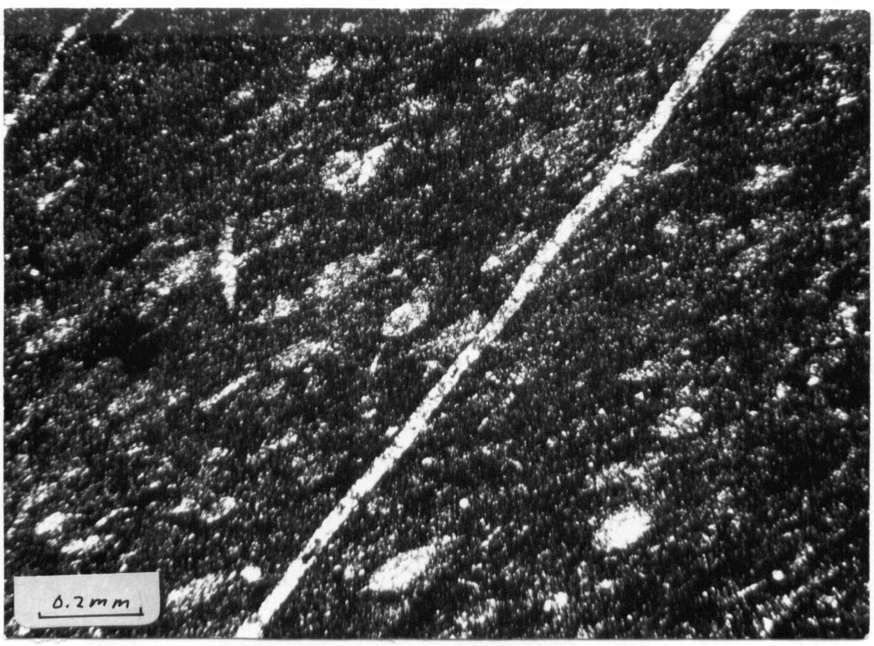


Figure 19. Mylonitized Cache Creek chert.



a.



b.

Figure 20. Recrystallized radiolaria and probable sponge spicules in Cache Creek chert. Photomicrograph "a" is plane polarized light and "b" with crossed polars.

volcanic rocks, occasional chert and calcite grains. The clasts are surrounded by calcite which is recrystallized into long grains and defines the foliation. Most of the calcite is probably of sedimentary origin, sand grains and cement, but some occurs as a replacement of plagioclase. Minor epidote and chlorite are present.

The carbonate pods are much purer limestone and are strongly recrystallized and foliated. The foliation parallels the length of the pods which in turn parallels the foliation in the surrounding rocks. These pods vary in size from a meter or less in length to a kilometer. Unfortunately no fossils are preserved in the pods within the field area, though Danner (pers. comm., 1975) finds Permian fusilines in pods to the north.

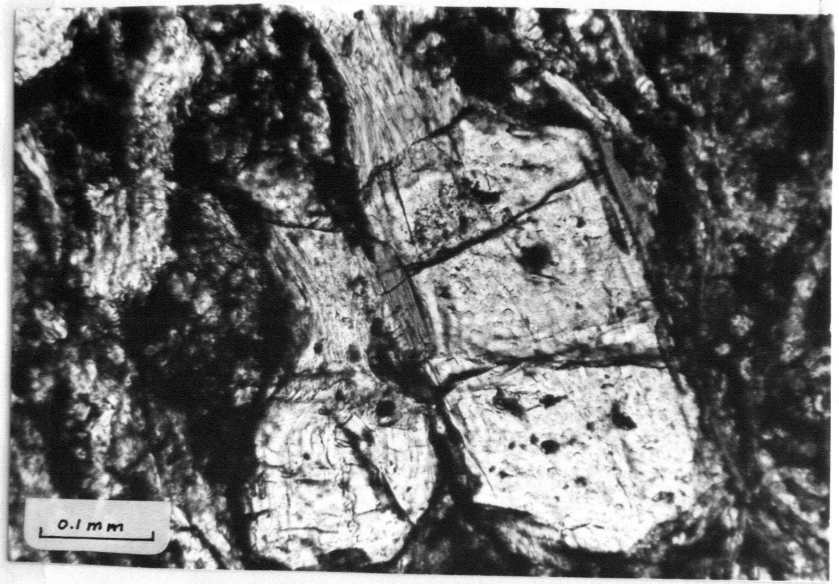
Contact relationships of the pods with the clastic rocks surrounding them are not very clear. In some places it appears as if the fringes of the pod are interbedded with the sediments, though infolding is another possibility. Usually the margins of the pods are more highly sheared than their interiors suggesting movement along the contact. However, sheared margins would occur if the blocks are tectonically emplaced or if they were present prior to tectonism, and deformation was concentrated along the contact zone.

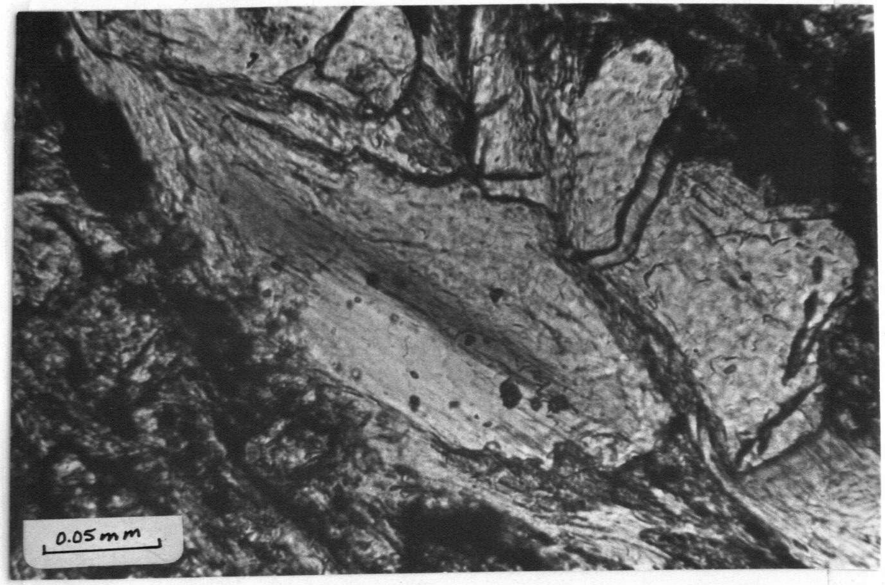
Minor volcanic and volcaniclastic rocks are present within the lower clastic unit. One 2 km long pod is mapped separately. This pod lies along the east side of Venables Valley and is composed of augite porphyry, some as crystal and lithic tuffs. Phenocrysts occur as small as 1 mm and less but usually are several millimeters across. Also present are coarser volcaniclastic rocks with clasts derived from augite porphyry. Original textures are in large part destroyed by later deformation and recrystallization.

A well-developed schistosity (chlorite, also talc?) is present in some of the greenstones of this pod and parallels foliation in the surrounding phyllite, while other greenstones are hardly foliated. Metamorphic minerals besides chlorite include albite, pumpellyite, epidote, stilpnomelane, sphene, white mica, actinolite, and a blue amphibole. The occurrence of this amphibole is at locality IV on Figure 6, just northeast of Venables Lake. The grey-blue to bluish-green, pleochroic amphibole grows parallel to the foliation on the edges and interiors of augite grains and in patches in the matrix (Figure 21). Microprobe analyses were run on several of these grains to determine their composition. Oxide weight percentages of nine elements and the number of ions of each element in the mineral formula are presented in Table II. Two OH molecules were assumed to complete the amphibole structure. An average formula representing these analyses is:

$$(Na_{.9-1.1},Ca_{1.1-1.4})_2\ (Mg_{2.7-3.2},Fe_{1.6-1.8},Al_{.2-.5})_5Si_8O_{22}(OH)_2.$$

On the standard sodic amphibole rectangle (Figure 22a) this composition plots within the magnesioreibekite field along the crossite-magnesioreibekite boundary. The presence of Ca implies an actinolitic component. A miscibility gap between Na- and Ca-amphiboles has been suggested by Coleman and Papike (1968) who find glaucophane and actinolite coexisting in carbonate rich sedimentary rocks. The blue amphibole of the present study, however, plots directly in the center of their compositional gap (Figure 22b). Brown (1977b) claims that continuous solid solution between crossite and actinolite exists and all compositions are stable within the greenschist facies and lower pressure part of the blueschist facies. The gap may exist at higher pressures. Amphiboles nearly identical in composition to those in the present study are found in a blueschist grade ophiolite from the melange zone in northern New Caledonia (Black and Brothers, 1978). There riebeckitic amphiboles rim relict igneous pyroxene grains. The blue amphiboles are frequently strongly zoned; sodic-actinolite cores grade out to riebekitic rims. The analysis which most closely resembles the present study is a sodic actinolite (analysis 13541, p.75 in Black and Brothers, 1978) listed on Table II. In





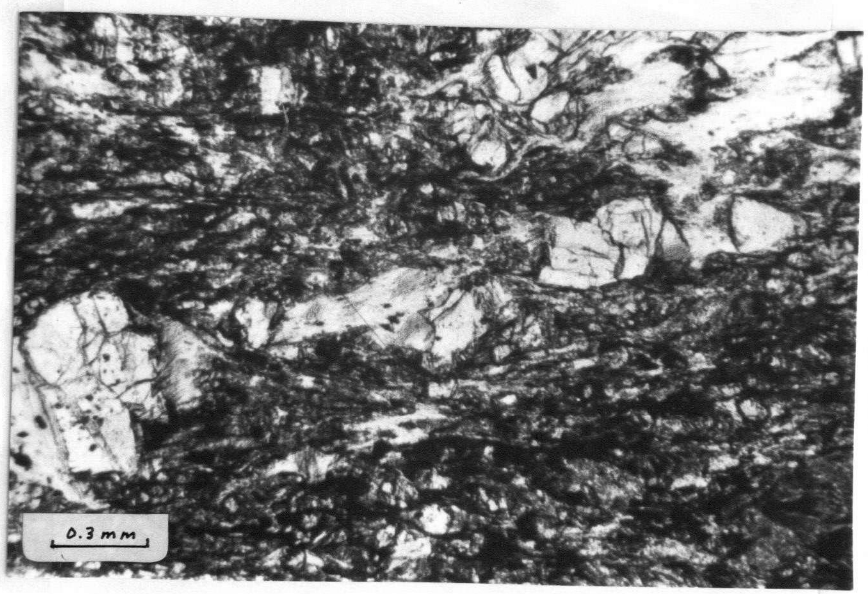


Figure 21. Photomicrographs of blue amphiboles in augite porphyry volcanic rocks. The amphiboles rim or form within relict augite grains. Some occur in the groundmass. Plane polarized light. The blue amphiboles are colored to show their distribution.

TABLE II

Blue Amphibole Probe Analyses**

Oxide Weight % / Ions Per Formula Unit of Element

Na_2O	3.27 / 0.89	3.17 / 0.85	3.52 / 1.00	3.99 / 1.14	3.04 / 0.86	3.20 / 0.9***
MgO	14.49 / 3.04	14.35 / 2.97	12.68 / 2.77	12.15 / 2.67	14.43 / 3.15	14.70 / 3.17
Al_2O_3	0.99 / 0.16	1.20 / 0.2	1.37 / 0.24	3.07 / 0.53	1.14 / 0.2	2.40 / 0.41
SiO_2	57.96 / 8.06	58.71 / 8.14	54.43 / 7.98	53.76 / 7.92	55.52 / 8.14	53.60 / 7.76
K_2O	0.07 / 0.01	0.06 / 0.01	0.07 / 0.01	0.06 / 0.01	0.07 / 0.01	0.05 / 0.01
CaO	7.44 / 1.12	8.23 / 1.22	7.44 / 1.17	8.62 / 1.36	7.29 / 1.15	8.70 / 1.35
TiO	0.14 / 0.02	1.07 / 0.11	2.57 / 0.28	0.21 / 0.02	0.13 / 0.01	0.05 / 0.01
MnO	0.14 / 0.01	0.12 / 0.01	0.12 / 0.02	0.14 / 0.02	0.16 / 0.02	0.30 / 0.04
FeO*	15.05 / 1.77	13.58 / 1.57	13.54 / 1.66	13.63 / 1.68	13.34 / 1.64	15.20 / 1.84
Total (less OH)	99.55	100.49	95.26	95.64	95.11	98.25

*Total Fe computed as FeO

** acceleration potential - 15kv
specimen current - .25 μamp
beam size - 10 μ
Bence-Albee data reduction (Bence and Albee, 1968)
α factors from Albee and Ray (1970)
Analyses conducted on University of British Columbia microprobe

*** Analysis 13541 from Black and Brothers (1978)

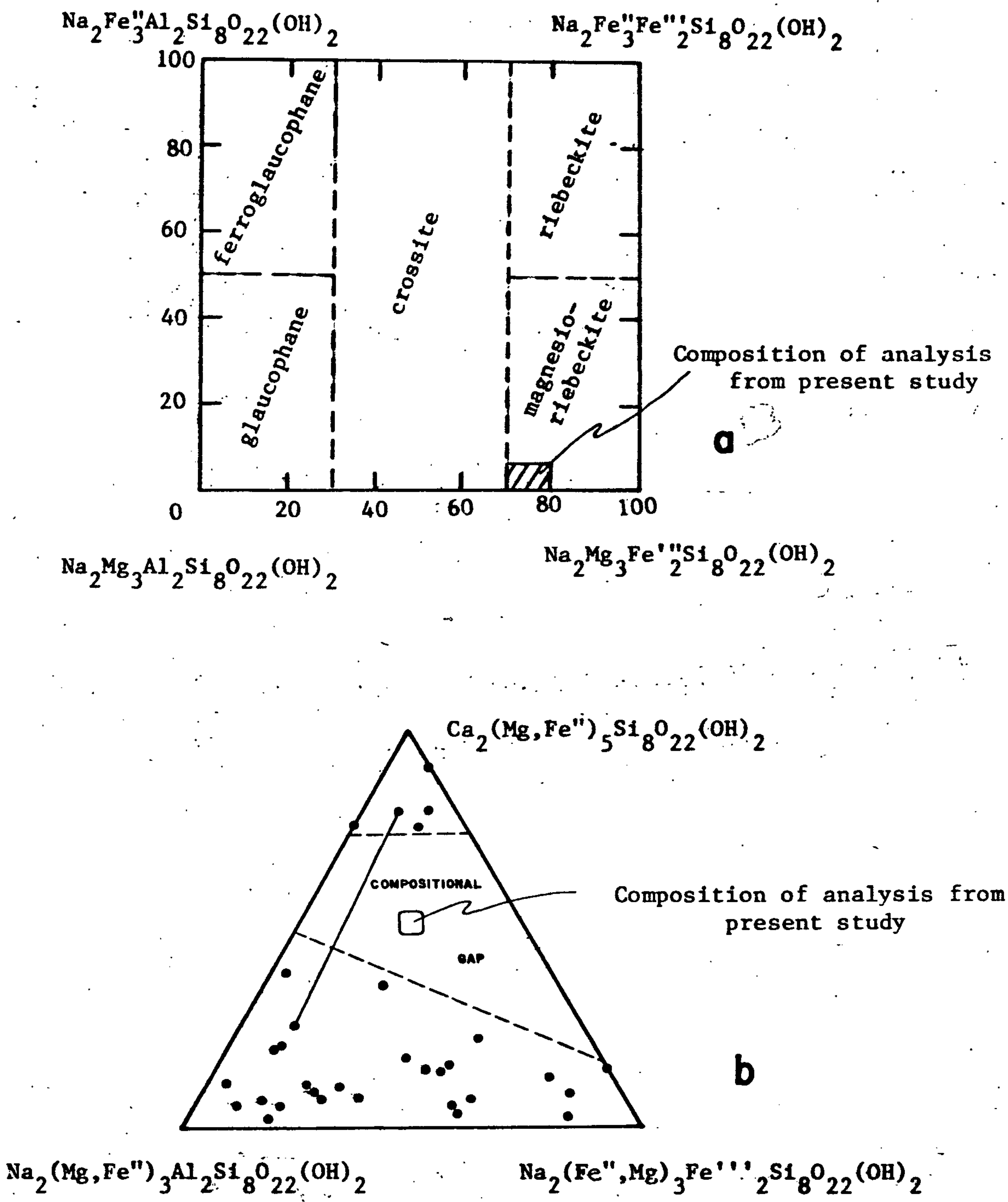


Figure 22. Sodic amphibole compositions plotted on a) standard glaucophane-crossite-riebeckite rectangle (Deer and others, 1966) and b) an actinolite vs.sodic amphibole triangle from Coleman and Papike (1968).

New Caledonia the sodic amphiboles are greenish rather than blue. Colorless to pale green amphiboles occurring with blue amphiboles in the present area were not analysed; additional microprobe work is necessary to fully describe the nature of amphiboles in this part of the Cache Creek Group.

Small pods of volcanic rocks are found in the lower clastic unit as well as the large pod already described. The small pods are basaltic and include augite porphyry with zoned and twinned augite phenocrysts in a very fine-grained, recrystallized groundmass with abundant actinolite, and amygdaloidal flows with tiny plagioclase crystals set in an extremely fine grained, devitrified glass groundmass. Vesicles are chlorite filled. Contact relationships of these greenstones with the surrounding phyllites are not exposed and it is not evident whether these greenstones are flows within the section, dikes or tectonic inclusions.

Ultramafic rocks, mainly serpentinite, are scattered throughout the lower clastic unit as small pods, and are found more continuously along the northern part of the upper contact of the unit. A large pod pinches out northward to a thin layer generally found only in float. Although relict clinopyroxenes are occasionally visible in thin section, the ultramafic rocks are almost totally altered to serpentine with magnesite, magnetite and minor chromite.

A foliation due to the alignment of serpentine similar to the foliation in the phyllites is developed in the smaller serpentine pods. Part of the larger ultramafic block along the contact between the lower clastic unit and the greenstones, however, is more massive and includes some porphyritic basalt. The basalt contains altered plagioclase phenocrysts set in a finer mass of feldspar laths and devitrified glass.

Contacts of the lower clastic unit are unexposed or poorly exposed. No base for the unit is seen. The upper contact is defined by a serpentinite zone in the north and greenstones to the south. Shearing has occurred along the contact which appears to dip parallel to the regional foliation. The contact is probably a low-angle fault.

To the south and along the west and southwestern margin of the Cache Creek is a probable fault contact with rocks of the Lower Cretaceous Spences Bridge Group. The contact is not exposed within the area, but Pearson (1974) documents truncation of zeolite facies boundaries within the Spences Bridge by the contact with the Cache Creek Group. Also, low angle faults in the Cache Creek are truncated by the contact.

Massive Mafic Volcanic Unit (Pv on Figure 6)

Lying topographically above and in fault contact with the lower clastic unit is a great thickness of altered mafic volcanic rocks. In the field these rocks can only be identified as massive, aphanitic greenstones and resemble the green clastic sedimentary rocks of the other units. Fresh surfaces are nearly impossible to produce as these rocks tend to break only along weathered surfaces. Occasionally a weak foliation can be observed, but fracturing is much more prevalent. In the field these were grouped by the massive weathering character, the greenish color, and the lack of sedimentary features that sometimes show up in the greywackes.

All of the greenstones in this unit are basaltic. In porphyritic members phenocrysts are euhedral augite with or without plagioclase. In one sample a serpentinized olivine phenocryst can be recognized along with augite and plagioclase. Plagioclase of composition An_{47} is relict in one rock, but generally all the feldspar is altered to albite. The groundmass is an interlocking mass of fine plagioclase and augite. Table I contains mineralogical details. Vesicles filled with calcite, chlorite, or pumpellyite are surrounded by devitrified glass in several samples, and the very fine grain size of others makes a flow origin for most of the greenstones seem reasonable. Crystal and lithic tuffs are present in smaller quantities. Flow structures, pillows, or individual flow units could not be distinguished in the field.

Alteration varies from one sample to another. Chlorite, albite and sphene are present in all the greenstones while prehnite, pumpellyite, calcite, white mica, and actinolite are variably developed. As stated above, the greenstones are usually massive, but immediately above the contact with the underlying unit a protomylonite fabric is developed. Round grains of augite sit in a very fine grained, almost opaque, foliated matrix (Figure 23). This cataclastic foliation at the base of the greenstone unit supports the low-angle fault interpretation for the lower contact. The upper contact is not exposed anywhere but is probably faulted, since the greenstone unit is cut off to the north.

Upper Clastic Unit (Ps, Pls)

As a result of very poor exposure due to thick grass, trees and low relief, rocks in the area mapped as the upper clastic unit can not be well defined. The unit lies above the greenstone unit to the south and to the north it is separated from the underlying clastics by a thin serpentinite belt.

Lithologies are much the same as in the lower clastic unit, but deformation and metamorphism seem to be less. Blocks of limestone, greenstone, coarse clastic rocks - greywacke and breccia - and occasionally chert are best exposed. They appear to be surrounded by a shale, chert-argillite, and serpentine matrix which is only exposed in float or in scattered logging road cuts. No traceable layers or structures are visible.

Limestone, one of the best exposed lithologies, is different from carbonates in the lower clastic unit. It occurs as pods, but the pods are not sheared and original structures such as bedding in some places, abundant

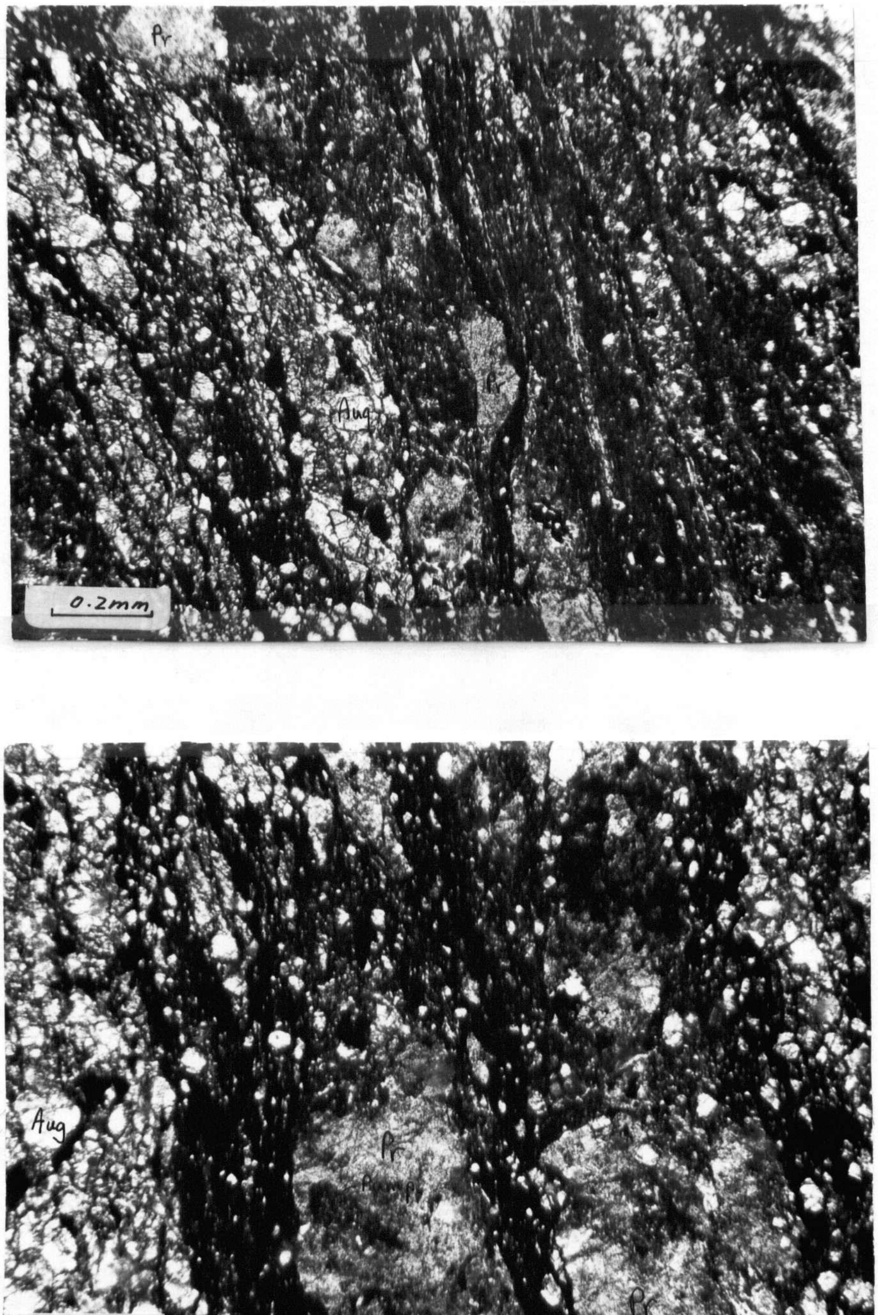


Figure 23. Cataclastic textures in altered augite porphyry which lies along the contact of the mafic volcanic unit and the lower clastic unit. Pr-prehnite, Pump-pumpellyite, Aug-augite. Plane polarized light.

oolites, and fusilinids are preserved. The carbonates are typical Marble Canyon limestone, light grey weathering and coarsely crystalline. Two pods of this type are exposed on the west side of the high ridge.

Other limestone exposures are much smaller and are closely associated with greenstone in breccias. These are probably slide breccias and will be discussed under sedimentary structures.

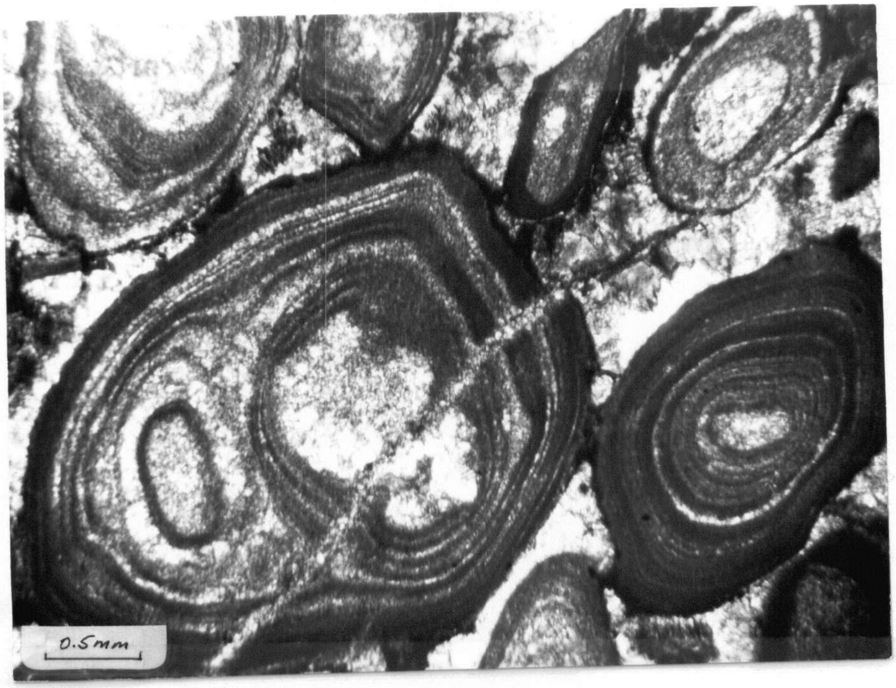
Clastic rocks coarser than argillite resemble similar lithologies in the lower clastic unit. Detritus in these greywackes and fine sandstones is composed of volcanic fragments and augite and feldspar crystals set in a very fine grained matrix of argillaceous material, feldspar, chlorite, carbonate and sericite. Pumpellyite occurs in a fragment in one sample. Bedding is not disrupted and is defined by alternating bands of coarser and finer material. Layers are 2-10 cm thick in the few exposures seen.

Welded crystal lithic tuffs appear to be the major volcanic component of the upper clastic unit. Augite and plagioclase crystals sit in a groundmass of devitrified, welded glass shards. Volcanic fragments are mostly very fine grained basalt or nearly opaque pieces of devitrified glass. Albite, chlorite, sericite, calcite and minor pumpellyite are the only alteration minerals.

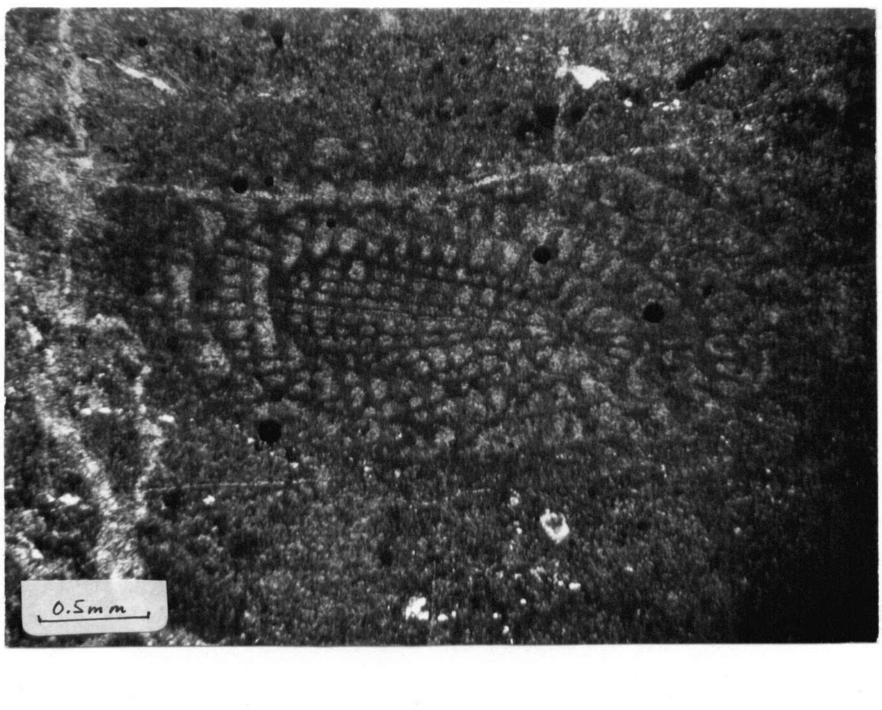
The chert-argillite and serpentinite matrix surrounding the blocks of carbonate, greenstone, and coarse clastic rocks is exposed only as float and in rubble in logging road cuts. Chert and argillite are grey to black and black respectively and very weakly foliated. Contacts between the blocks and matrix are not exposed.

Age of the Cache Creek Group

Fusilinids found in limestone pods of the upper clastic unit (Figure 24) were identified by W.R. Danner as Yabeina minuta of Late Permian probably Late



a.



b.

Figure 24. Photomicrographs of limestone in the upper clastic unit, Cache Creek Group: a) oolites and b) Upper Permian, probably Late Guadalupian, fusilinid Yabeina minuta, identified by W.R.Danner.

Guadalupian. This age is typical of limestone masses in this part of the Cache Creek (Danner, 1976). No information is available for other lithologies or for limestones of the lower clastic unit.

Sedimentary Structures and Environment of Deposition

Two models of depositional environment have been presented to explain the pod-like occurrence of shallow water carbonates within sediments usually interpreted to be of deeper water origin. From his work in the Atlin Terrane, Monger (1977a, 1977b) has developed a model of a deep ocean basin in which seamounts have formed. Fringing reefs are formed on seamounts and atolls and these shallow water carbonates break off from time to time and slide into deeper water. They come to rest amongst deeper water rocks. Danner (1967, 1975), on the other hand, suggests that these carbonate blocks in chert are not exotic, but that the cherts and carbonates are interbedded. This requires that ribbon cherts are of very shallow water origin within the Cache Creek Group. In this model lensoid masses of carbonates are interpreted to be algal mounds.

Sedimentary structures, locally preserved in areas of less intense deformation, reflect a variety of depositional environments within the Cache Creek Group. Fine to coarse grained clastic sedimentary rocks show the most structures. Rhythmic layering in siltstones and greywackes and other structures typical of the Bouma sequence - graded bedding, laminar bedding, convolute laminations - suggest turbidite sedimentation for much of the clastic material. Soft sediment slump folds (Figure 25) and rip-up clasts (Figures 15 and 26) support grain flow movements. One outcrop at the top of the ridge in the upper clastic unit is a breccia containing limestone and amygdaloidal and tuffaceous basalt fragments (Figure 27). Chunks of limestone are several centimeters across while greenstone fragments are less than 2 cm

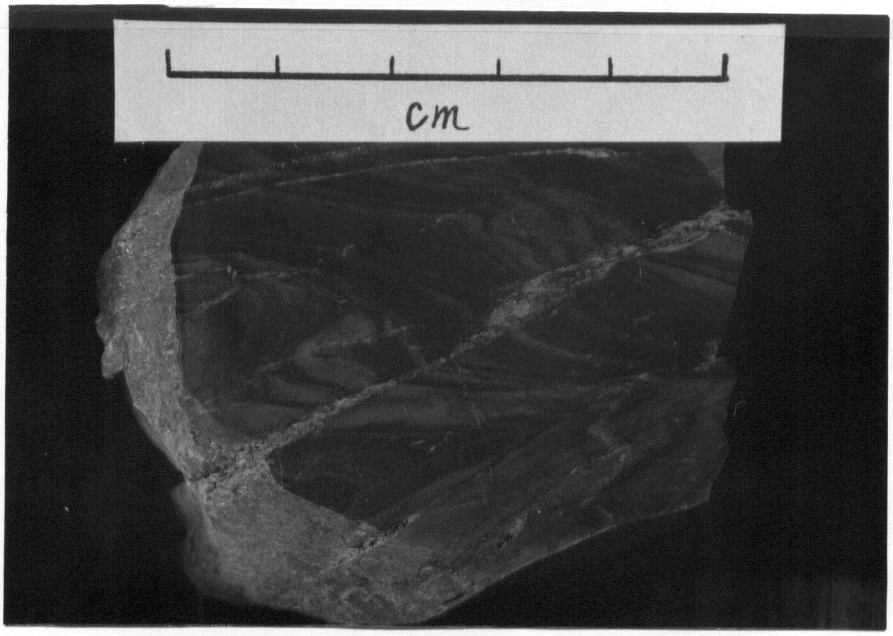


Figure 25. Soft sediment folds in fine grained sediments of the lower clastic unit, Cache Creek Group.

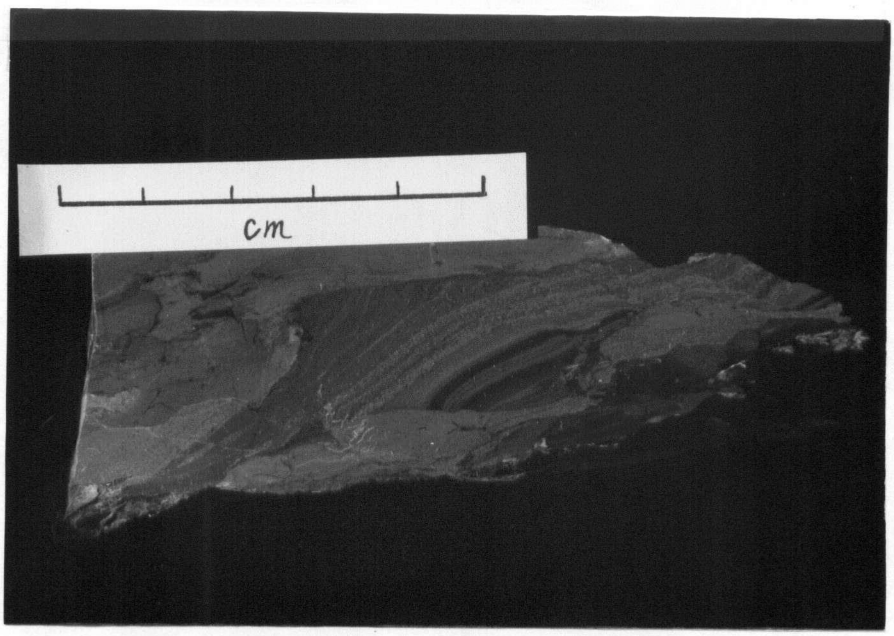


Figure 26. Rip-up clasts in sediments of the upper clastic unit, Cache Creek Group.

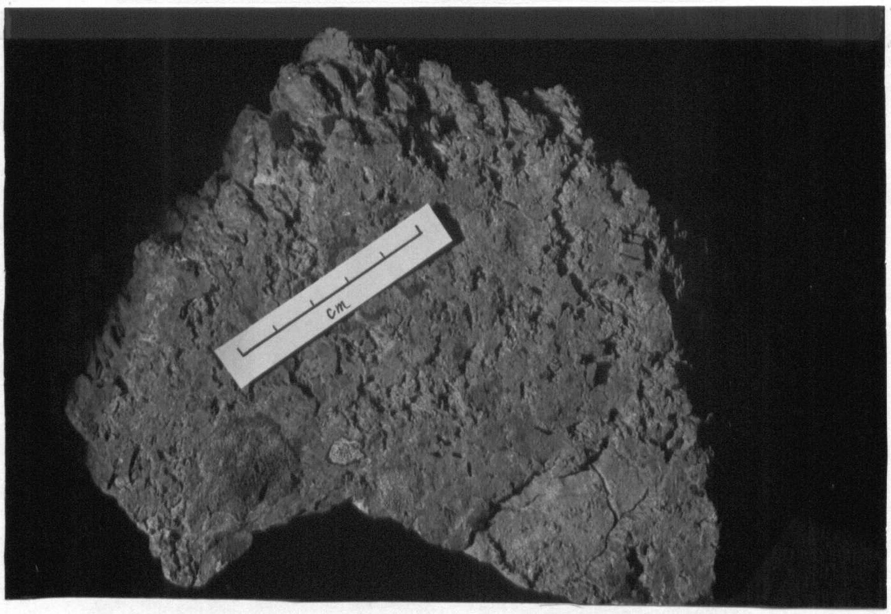


Figure 27. Slide breccia in the upper clastic unit of the Cache Creek Group. Light grey, recessive weathering fragments are limestone. The remainder is volcanic material.

in diameter. This is also thought to be a debris flow off a shallow carbonate and basaltic platform.

There is abundant evidence for shallow water conditions in the limestone masses of the upper clastic unit. Oolites, fusilinids and what may be algal structures are present and represent water depths of less than 30 meters.

Although very deep water conditions are not necessary for the formation of turbidites, lack of shallow water structures implies they were deposited at levels below wave base. Apparently interbedded with the debris flows are ribbon cherts. The environment of formation of ribbon cherts is a function of many factors, but carbonate free radiolarites are thought to be restricted to depths below the carbonate compensation depth, probably 2000-3000 meters in Permian time (Bosellini and Winterer, 1975). No shallow water limestones were observed directly interbedded with ribbon cherts in this area. Contacts of these carbonates are usually strongly sheared. Carbonate rocks clearly interbedded with the turbidite and ribbon chert sequences are calcarenites, some weakly graded, which are probably turbidites themselves.

From evidence in this area a depositional environment similar to Monger's model is reasonable. Shallow water carbonates form on basaltic volcanic seamounts that are surrounded by deeper water. The basin is dominated by chert and argillite sedimentation with influxes of coarser material derived from the volcanic and carbonate terrane. Exotic blocks of limestone within the fine grained sediments must be slide blocks. In support of this model are preliminary Mesozoic ages for Cache Creek radiolaria (Travers, 1978; Monger, 1977b). Thus the slide blocks may be much older than the matrix in which they presently sit. More fossil data from the non-carbonate rocks are needed to conclusively define the depositional environment in this area.

Structure

A strong phyllitic foliation in the clastic rocks, best developed in finer grained rocks, is the earliest and dominant structure in the Cache Creek Group. This foliation is of variable intensity in coarser clastic rocks and absent in most greenstones. In most cases bedding has been transposed to parallel the foliation, and tiny rootless folds, with amplitudes less than a few centimeters, found in finer grained lithologies suggests the foliation parallels the axial planes of isoclinal folds. No large early folds were found, but several outcrops clearly demonstrate cross-cutting bedding-cleavage relationships. A bedding-cleavage intersection lineation is developed on foliation surfaces in the clastic members.

Carbonate and chert responded differently to this deformation. Cherts are strongly boudined and brecciated with the argillite layers almost squeezed out. The long axis of the boudins parallels the other lineation. Chert layers are probably boudined on a larger scale. This is reflected in the discontinuous outcrop pattern of the cherts. Carbonate, greywacke and greenstone layers may also have been boudined on a large scale; in some of the carbonate-greenstone breccia of the upper clastic unit, carbonate clasts have been strongly elongated. Chevron folds of one to two meter amplitude are developed in ribbon cherts in a few localities. No axial plane cleavage cuts these folds, and their timing is unknown.

Despite the extreme deformation in much of the Cache Creek, some portions seem to have been left completely undeformed. Greywacke pods, mostly in the upper clastic unit, are unfoliated and the sedimentary structures are well preserved, even though the pods are apparently surrounded by deformed phyllite. Some carbonate pods are strongly deformed while others are essentially pristine.

Figure 28 is an equal area stereonet plot of all structural elements measured in the Cache Creek Group. A northwest trend of all structural elements dominates. Foliations are clustered around a northwest strike with a moderate to steep southwest dip. Lineations plot along the northwest trend

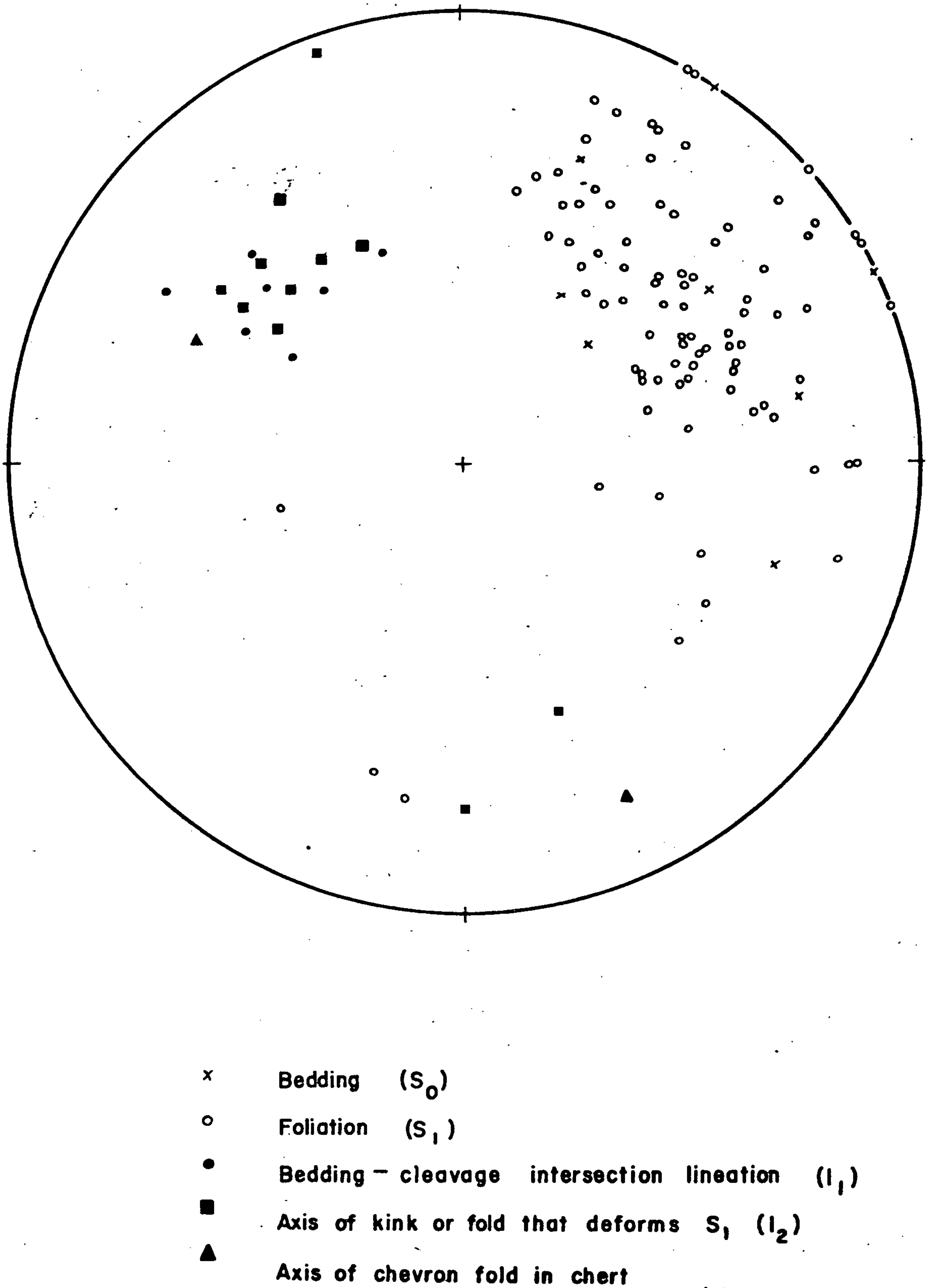


Figure 28. Equal area stereonet plot of structural elements in the Cache Creek Group.

and plunge moderately.

Scatter in the foliation plot is probably related to later subparallel folding which is only locally observed and deforms the earlier foliation and lineation. This event consists of brittle folding and warping with some fracturing along axial planes but no development of a penetrative axial plane foliation. Folds are flexural-slip, open, and of small (less than half a meter) amplitude and wavelength. The best exposure of these folds and their relationship to the earlier lineation and foliation is just west of the fault contact with the Nicola Group at the north end of the area. The folds may be related to movement along that fault. Chevron folds deforming the phyllite at the southern end of the map area (Figure 11) are similar and may be of the same age.

Macroscopically the Cache Creek Group appears to be composed of fault-bounded packages of rock. Quite clearly a low angle fault is the lower contact of the greenstone unit. The unit is truncated and a strong cataclastic foliation has formed in some of the lowermost greenstones (Figure 23) and the uppermost members of the lower clastic unit below. This fault parallels the foliation in the lower clastic unit. Further evidence for the fault is the presence of serpentinite along the projected trace to the north. It is possible that the two clastic units should be considered as repetition of a single unit enclosing the greenstone unit as a fault-bounded wedge. The discontinuous serpentinite belt, differences in the limestones and in degree of deformation and alteration between the upper and lower clastic units support the interpretation of a fault with large displacement. The only evidence for the fault mapped as the upper contact of the greenstone unit is the truncation of the greenstones at their northern end.

It is quite probable that there are similar faults throughout the Cache Creek Group. The large volcanic and volcaniclastic pod north and east of Venables Lake is probably fault bounded.

In many ways the structural style described above fits descriptions of tectonic melange as defined by Hsü (1974). Small packages of rock are shear-bounded and there is great variability in deformation within a small region. Most of the Cache Creek within the field area is typified by blocks of different lithology set in a pervasively sheared matrix. Block size ranges from a few centimeters, as exposed above the highway at the southern end of the area, to more than 5 kilometers, if the mafic volcanic unit is considered as a block within the deformed sediments. The next largest block is the 2 km long volcanic and volcaniclastic pod containing the blue amphibole metamorphic assemblage. Sedimentary processes have contributed to the discontinuous nature of many lithologies, but they do not explain the presence of serpentinite bodies in close proximity to shallow water carbonates that are mixed into the deformed pelitic matrix containing turbidite deposited clastic beds and bedded chert. The explanation is more likely tectonic than sedimentary.

At least two periods of faulting postdate isoclinal folding, shearing, and low angle faulting. The near vertical, north-northwest trending Martel Fault which separates Cache Creek and Nicola Groups is the earliest fault after the isoclinal folds. Sense of movement on this fault cannot be positively determined from this area. Later high angle movement along the Venables Valley fault and several smaller faults offset Lower Jurassic rocks. The Venables Valley fault cuts the Martel Fault. Some of this faulting must be post lower Cretaceous as Spences Bridge Group rocks are in contact with Cache Creek along a fault that parallels the Venables Valley fault. Landslides and slumps along the west side of Venables Valley further complicate structural interpretations in the Cache Creek. One major slide that is quite clear on areal photographs and in the topography is shown on the map (Figure 6). Rocks exposed in the slide are are limited to ground up phyllite and serpentinite.

Metamorphism

The matrix of greywackes and alteration of unstable glass and feldspar in basic volcanic rocks best reflect metamorphic conditions at low temperatures. Table III lists seven metamorphic mineral assemblages observed in Cache Creek rocks. Assemblages 1-6 are from rocks in the lower clastic unit, 5 and 6 from the volcanic and volcaniclastic pod (Pvcl), and assemblage 7 is from the greenstone unit. For determination of temperature the critical minerals are prehnite, pumpellyite, actinolite and the epidote family. Stilpnomelane and the sodic amphibole are the only minerals that assist in pressure estimates.

Miyashiro (1973), in reviewing several low grade metamorphic belts describes a sequence of zones from zeolite to greenschist facies. In Kii Peninsula, Japan, Zone II, prehnite-pumpellyite facies, includes the assemblage quartz, albite, prehnite, pumpellyite, epidote, and chlorite. Zone III, a transition zone, is marked by the appearance of actinolite and disappearance of prehnite, and in Zone IV, greenschist facies, pumpellyite is absent and stilpnomelane is present. The transition zone in the Panoche and Pacheco Pass areas of California contains the assemblage pumpellyite, actinolite, calcite, epidote and stilpnomelane. Under this classification system assemblages 5 and possibly 2 of Table III would be in the transitional zone. Assemblage 3 with prehnite and pumpellyite, no actinolite, falls below the transition zone in the prehnite-pumpellyite facies, and 7, with prehnite and actinolite co-existing, is probably on the boundary between the two zones. By Miyashiro's definition assemblages 1 and 6 fall in the greenschist facies. Assemblage 4 is not diagnostic.

Winkler (1974) marks the transition from very low grade to low grade rocks (greenschist facies) by the appearance of zoisite/clinozoisite instead of iron rich epidote. Figure 29 summarizes experimentally determined reaction equilibria at very low grade. The reaction pumpellyite + chlorite + quartz

TABLE III

Metamorphic Mineral Assemblages in the Cache Creek Group

Assemblage #	1	2	3	4	5	6	7
Quartz				X	X	X	
Chlorite	X	X	X	X	X	X	X
Albite	X	X	X	X	X	X	X
Calcite	X	X			X		X
Sphene	X	X	X	X	X	X	X
White mica	X	X	X		X	X	
Epidote	X		X			X	X
Stilpnomelane	X	X	X	X	X	X	
Actinolite	X				X	X	X
Subcalcic Amphibole					X	X	
Pumpellyite		X	X		X		
Prehnite			X				X

Sample number	Assemblage number
6-18-1	1
6-18-3	2
7-8-2	3
7-22-5	4
7-5-4	5
7-5-3B	6
6-18-6	7

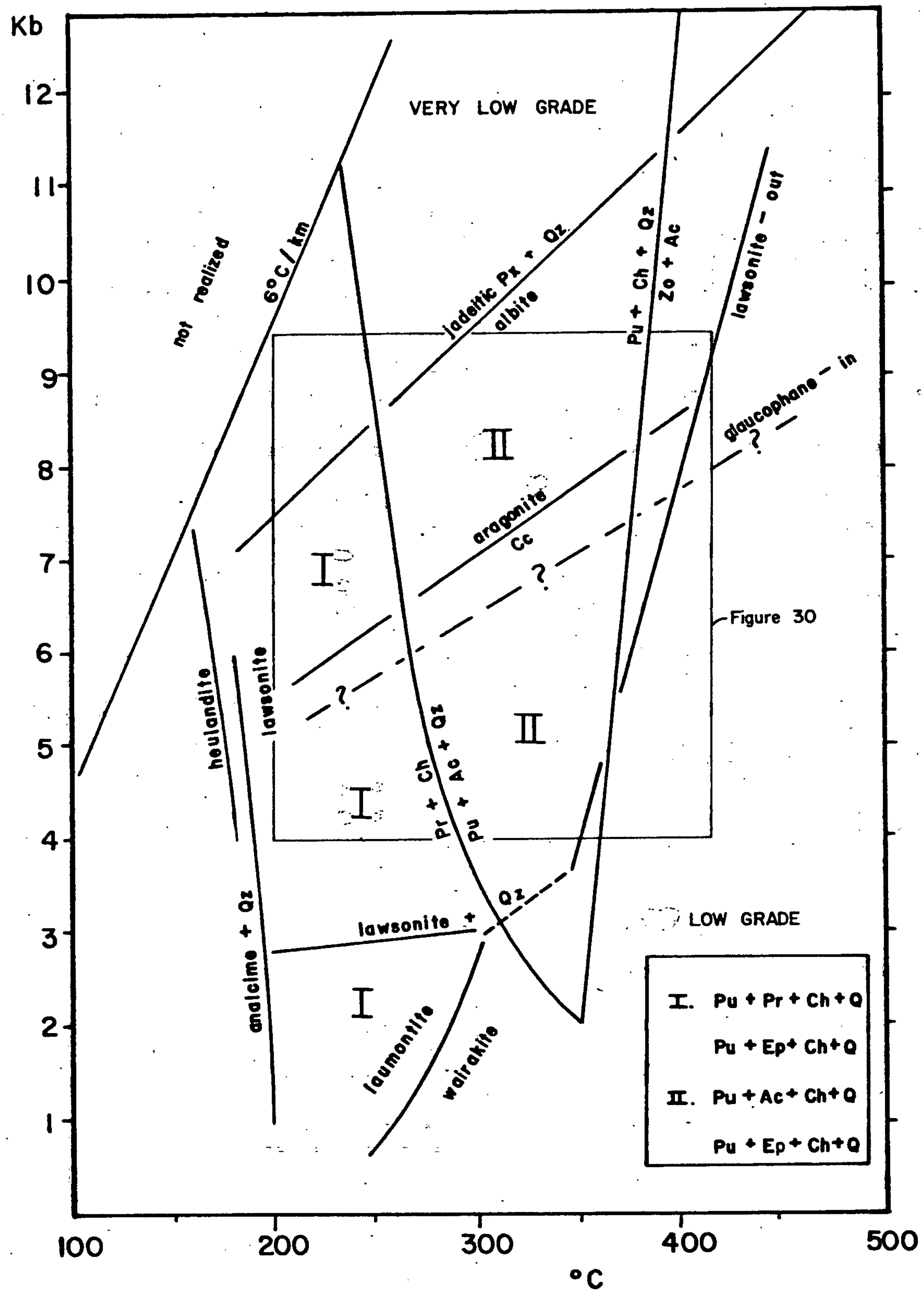


Figure 29. P-T equilibria at very low grade (after Winkler, 1974; p.188, 236). Mineral abbreviations are Px-pyroxene, Qz-quartz, Pu-pumpellyite, Ch-chlorite, Zo-zoisite, Ac-actinolite, Cc-calcite, Ep-epidote, Pr-prehnite.

goes to zoisite + actinolite can be used as a maximum temperature for Cache Creek rocks in Venables Valley. Assemblage 5 clearly lies on the low temperature side of that reaction, and 1 and 7 are on the low temperature side of the reaction prehnite + chlorite goes to pumpellyite + actinolite + quartz. Iron rich epidote rather than zoisite in other assemblages indicates those rocks also are below the boundary between rocks of low grade and very low grade.

In a more recent work, Brown (1977a) presents calculated reactions in this pressure and temperature range. Assumptions of fixed compositions for many of these minerals were necessary for the calculations, and the locations of the reaction curves are still estimates. Figure 30 enlarges the area of interest from Figure 29 and includes reactions from Brown. Several assemblages from Table III can be given estimated P-T fields based on these reactions. Assemblages 3 and 7, discussed earlier, are plotted below the prehnite + chlorite breakdown, with 7 at higher temperature due to the presence of actinolite. Co-existing calcite and epidote in assemblage 1 puts it below calcite + epidote + pumpellyite + actinolite + H_2O + CO_2. Lack of calcite and epidote together in 5 and 6 and co-existing pumpellyite and actinolite in 5 puts them above the same reaction.

Pressure conditions are not as well controlled. Stilpnomelane probably can be used as an indication of fairly high pressure as it is rare in mediun pressure rocks and very rare in rocks of low pressure metamorphism (Miyashiro, 1973). Sodic amphibole also can suggest high pressure conditions, but only the additional presence of aragonite or lawsonite is diagnostic for high pressure. Lawsonite is more prevalent in Al-rich rocks; those containing the blue amphiboles here are basic in composition, possibly even silica deficient, which favors blue amphibole at lower pressure. Brown (1977b) presents a tentative correlation of pressure to crossite component in Ca-amphiboles. In his model, the sodic amphiboles of this study, containing approximately one Na in the M_4 site, would occur at pressures of about 6 kb. These pressures are

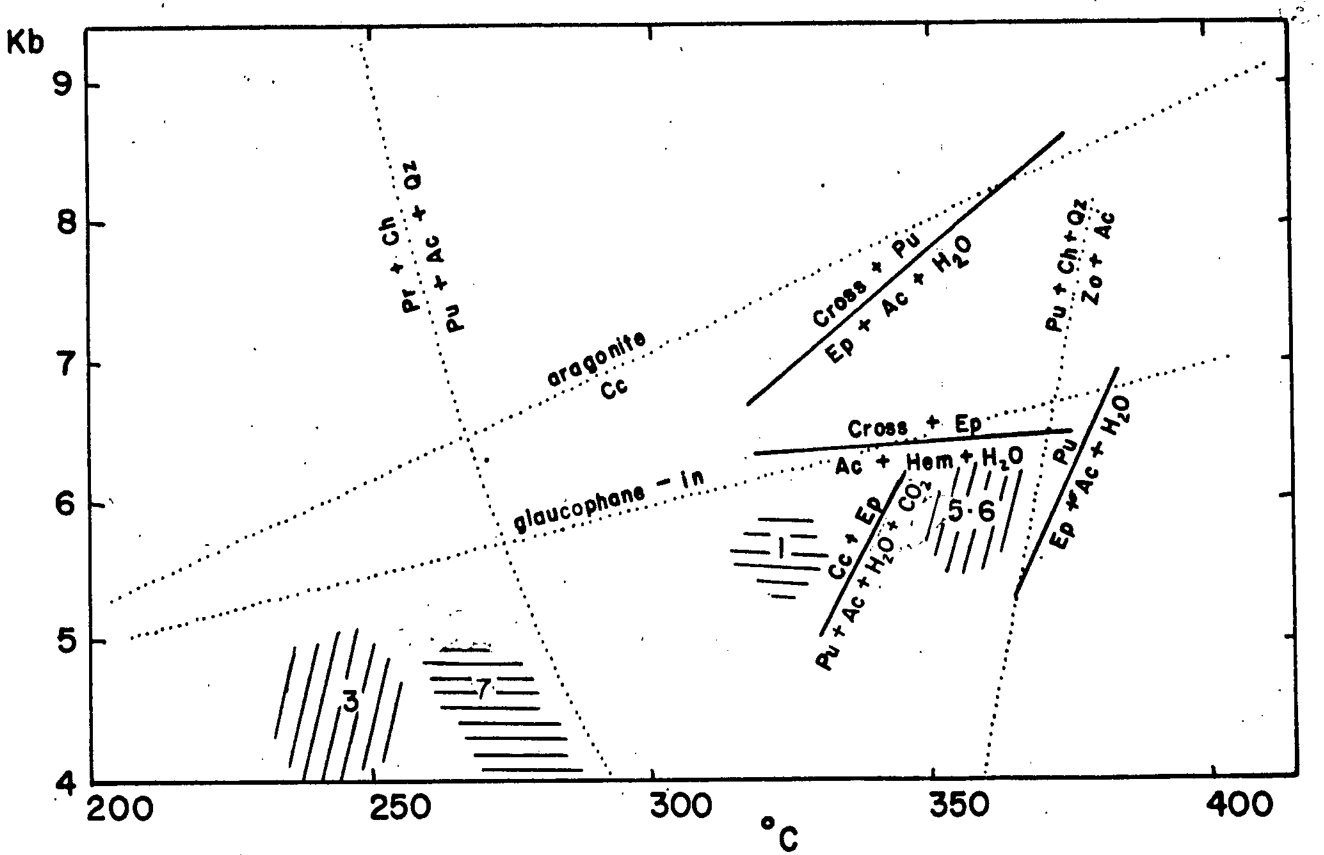


Figure 30. Enlarged P-T equilibria from Figure 29 with reactions from Brown (1977a). Mineral abbreviations as on Figure 29 with Hem-hematite and Cross-crossite.

conditional on the presence of iron oxide in the reaction assemblage; iron oxide is absent in the present study. Similar amphiboles found in the Northern New Caledonia melange zone are estimated to have formed at P-T conditions of 350°C and 7 kb (Black and Brothers, 1978), but jadeitic pyroxene is also in that mineral association. That indicates higher pressure than in the present study. Thus an estimate of 5 to 6 kb pressure for rocks in the Venables Valley area containing sodic amphiboles and stilpnomelane is considered reasonable. The assemblages of Table III are plotted on Figure 30 at pressures between 4 and 6 kb. Assemblages 2 and 4 do not contain diagnostic minerals for this plot.

From Figure 30 it is apparent that metamorphic conditions are not constant throughout even this small area of Cache Creek rocks. Different blocks within the sheared matrix contain metamorphic assemblages reflecting a temperature range of 100° C and a possible 1 to 2 kb pressure difference.

Nicola Group

In the Venables Valley area the Nicola Group can be divided into three map units. The first, dominantly greenstones, contains andesite, dacite, related high-level intrusive bodies and sedimentary rocks derived from the volcanic rocks. Thick, massive to bedded limestone makes up the second map unit and the third is a mixture of sedimentary rocks and some greenstones. The third unit includes argillite, thin bedded limestone, minor volcanic rocks, abundant green chert (siliceous tuff) and coarser clastic rocks. Figure 31 is a diagrammatic stratigraphic section of the Nicola and overlying Jurassic rocks.

The northern exposure of the second unit was mapped as Nicola, but most of the first and third units have previously been mapped as part of the Cache Creek Group (Carr, 1962; Duffell and McTaggart, 1952). Comparison of stratigraphic, structural and metamorphic characteristics with the Cache Creek Group, limited fossil evidence and a Rb/Sr isochron support an Upper Triassic age typical of the Nicola Group for this section.

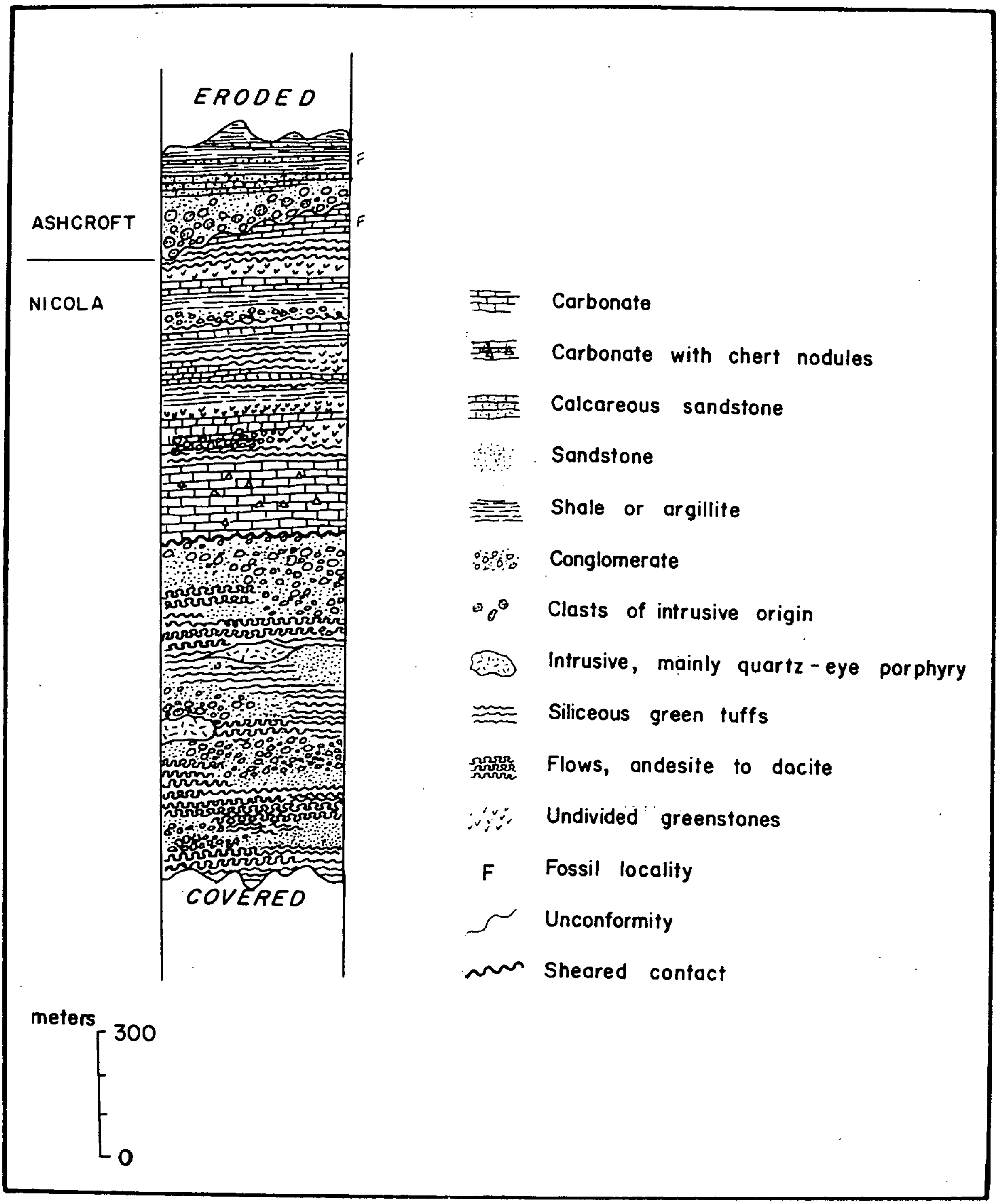


Figure 31. Diagrammatic stratigraphic section of the Nicola Group and Ashcroft Formation.

Greenstone Unit (TRv on Figure 6)

Flows, intrusive rocks, pyroclastic and epiclastic rocks of this unit are complexly interbedded and interfingering as sketched on Figure 31. Individual lithologies appear to have limited lateral extent. Poor exposure and minor faults contribute to the difficulty of tracing layers. It is often difficult to distinguish fragmental textures in the field unless a clean, smooth-weathered surface is present. Even then rocks types can be ambiguous.

Porphyritic andesite underlies much of the eastern part of the area and is best exposed in gullies above the Trans-Canada Highway. In outcrop the andesite is blue green to grey with white to pinkish, subhedral to globular feldspar phenocrysts. The aphanitic groundmass contains segregations of epidote or is cut by epidote veins. Structures such as pillows and flow tops were not observed, but occasionally large blocks of sedimentary rocks (one over a meter long) are caught up in flows.

Under the microscope plagioclase phenocrysts, original An_{35} composition preserved in some grains, are seen to be dominantly albite in composition with considerable epidote and sericite replacement. The phenocrysts comprise an average of 20% of the rock and sit in a very fine grained, interlocking mosaic of recrystallized feldspar, mainly albite with traces of K-feldspar, and other alteration minerals - chlorite, sericite, epidote, and sometimes calcite. No primary mafic minerals are preserved.

Though most of the andesites are not foliated, there is considerable evidence of strain in the rocks. Kinked twins in plagioclase grains are plentiful, and phenocrysts show polygonalization and recrystallization along old and new grain margins. Locally a weak fracture cleavage is developed.

Dacitic rocks are found throughout the greenstone unit but are most plentiful and best exposed along the ridge east of Venables Valley. In the field, rocks of this composition are easily identified by the presence of abundant quartz , usually in the form of spherical to ellipsoidal, clear to smoky phenocrysts (quartz eyes), 1-6 mm in diameter. Feldspar phenocrysts are absent to more plentiful than the quartz eyes. The groundmass, where unsheared, is aphanitic and siliceous, generally light green in color. Locally the groundmass is bleached to very pale green or white. These bleadhed zones are mineralized and contain abundant pyrite.

Ratios of phenocrysts to groundmass, size of phenocrysts, and other macroscopic textures reflect a variety of volcanic-plutonic processes involved in the formation of these quartz rich rocks. Numerous textures can be observed by traversing the ridge east of Venables Valley. Just south of the road crossing the ridge, volcanic breccia crops out. Fragments are almost exclusively quartz-eye porphyry and are surrounded by a matrix of similar material - quartz crystals and green aphanitic matrix/groundmass. This may be an explosion breccia deposited near a volcanic vent. Siliceous tuffs represent more distant deposits related to explosive volcanism. Quartz crystals in the tuffaceous rocks are usually less than 2 mm across and feldspar is absent. Aphanitic groundmass comprises more than 95% of these rocks, and in many places they look megascopically like pale green chert with scattered round quartz crystals and occasional fragments of similar aphanitic material.

Farther north along the ridge both feldspar and quartz phenocrysts are present and make up a larger percentage of the rock. Scattered fragments of quartz and quartz-feldspar porphyries occur in these rocks, but the general appearance is of flows rather than breccias. Still farther north rocks of apparently the some composition are definitely intrusive in origin. Two miles north of the northern edge of the field area, a coarsely crystalline quartz diorite crops out. Mafics are altered to chlorite, and epidote is abundant. This quartz diorite is probably the intrusive equivalent of the extrusive and pyroclastic quartz-rich rocks. Thus the quartz-rich rocks show in a small area the volcano-plutonic nature of the Nicola Group.

Along fault zones original igneous textures have been overprinted by a shear foliation. Locally a quartz-sericite schist is developed. The foliation wraps around the quartz phenocrysts and fragments. Rocks with this foliation have a rather lumpy appearance.

In thin sections of the dacitic rocks the round to elliptical quartz phenocrysts can be seen to have partially resorbed margins and some quartz overgrowths. In more deformed samples the crystals are internally shattered. Feldspar phenocrysts, if unaltered, are plagioclase with an average composition of andesine (An_{35}). Feldspar is generally altered to albite or pseudomorphed by epidote, calcite and fine grained albite. The groundmass, much the same as that in the andesites, is a mosaic of feldspar, quartz, chlorite and sericite with variable amounts of epidote, calcite, K-feldspar and some sphene. More altered varieties contain more K-feldspar. Included fragments show up as patches of slightly different grain size. Margins of the fragments are indistinct.

Epiclastic rocks derived from the volcanic and intrusive rocks make up the remainder of the greenstone unit. These include conglomerate, breccia, greywacke, lithic sandstone and siltstone.

One of the best conglomerate exposures is along the Trans-Canada Highway just north of the greenstone-limestone contact. Well rounded cobbles of porphyritic andesite are nearly indistinguishable from the finer grained, feldspar rich matrix. The rocks have been altered and the matrix is as resistant to weathering as the volcanic cobbles. Epidote occurs in veins and patches within both clasts and matrix. Another conglomerate, the only one within the greenstone unit containing clasts derived from a non-volcanic source, caps the 2700 foot high hill northwest of the limestone-greenstone contact. There 2-3 cm long fragments are limestone, black pelitic rocks and abundant light green to white tuff. The matrix is quartz and feldspar rich and well indurated.

Volcanic breccias are interbedded with the andesites and dacites. The angular to subrounded fragments are mainly pieces of volcanic rocks - quartz-eye porphyry, feldspar porphyry, silicified tuff, aphanitic greenstone - but elongate pieces of green sandstone and greywacke are also present. The breccias are poorly sorted but have little very fine material. Most of the fragments are at least several millimeters in diameter and range up to several centimeters across. In both conglomerates and breccias clasts do not weather out in relief.

Finer grained epiclastic rocks, sandstones and greywacke, are usually darker green than most of the volcanic rocks, but siltstones are fairly light green in color. Microscopic examination shows lithic fragments are clearly derived from volcanic rocks in the Nicola Group. Round quartz grains are plentiful; there is also considerable subrounded albite grains. Calcite, epidote, and sericite replace the feldspars, and chlorite and very fine feldspar comprise the matrix. No metamorphic minerals like prehnite, pumpellyite, or actinolite are present in any of the greenstones studied.

Contacts between the greenstone unit and other units are exposed in only two places, both with the overlying limestone. That contact appears to be depositional, as bedding orientations in the limestone are subparallel to the contact. Whether this is conformable is unknown because of lack of bedding in the greenstones. Exposures of the contact are in two prospecting pits. In both pits the rocks are sheared parallel to the contact. Chlorite forms a schistosity in the greenstone. This shearing probably represents later movement along a depositional contact rather than a large fault displacement. All other external contacts of the greenstone unit are steeply dipping faults.

Limestone Unit (TRls)

Two substantial bodies of massive limestone have been distinguished as a separate map unit within the Nicola. The largest caps the hill northeast of Venables Creek. The second forms cliffs in the next creek south. They are mapped on the basis of lithology and are not necessarily of precisely the same age or stratigraphic position. Thickness of the limestone is variable, and the northern body appears to pinch out towards the east.

The limestone is light grey weathering and dark blue to black on a fresh surface. Much is massive, fine to medium grained, but some is light and dark banded. Compositional variations include a range from almost pure carbonate to very sandy limestone. Scattered through much of these limestones are red-brown weathering chert nodules. In some places the nodules are aligned and may represent original interbedded layers, 2-3 cm thick. These layers are now disrupted and boudinaged and occasionally form small fold hooks of chert floating in carbonate.

Dark grey layers in the fine grained, laminated varieties are due to concentrations of carbonaceous material. As much as 15 to 20% of the banded limestones is quartz, usually of the same grain size as the carbonate but occasionally in patches which may have been larger grains now recrystallized. A few larger quartz grains remain, but the margins of those grains are polygonalized.

The limestone unit includes carbonate sands, easily identified in thin section. Detrital limestone grains 1-3 mm across have curved or bent twins and are darker in color than the recrystallized cementing material. A minor part of the carbonate sands is other detritus - quartz and feldspar grains, usually much smaller than the carbonate fragments.

Bioclastic limestones are present in the northern limestone mass down in Venables Creek. There limestones have been sheared and recrystallized, and crinoids are the only identifiable fossil preserved. Several samples from different sites in the unit were dissolved in an attempt to separate conodonts with no success. The general lensoid shape and the variety of lithologies - calc arenites to bioclastic to micrite with areas of organic laminae - suggest a probable reef-shelf origin.

The lower contact of the northern limestone has already been described as a sheared depositional contact. The basal contact of the southern limestone mass is a fault against younger rocks. The transition upwards from relatively pure limestone to interbedded clastic rocks, chert, and limestone of the overlying mixed unit is clearly exposed in both limestone bodies.

Mixed Sedimentary and Volcanic Rocks (TRs, TRsl, TRsv)

The remainder of the Nicola Group is lumped as one unit. Most of the lithologies found in the other units - limestone, siliceous volcanic rocks, volcaniclastic rocks, some andesite, conglomerate - are found in this unit. Black argillite is also present.

Typical of much of the upper unit is interbedded limestone and greenstone. The greenstone is largly siliceous, aphanitic, and pale green in color, probably tuff. Beds range from 5-15 cm in thickness and tuffaceous greenstone layers are commonly laminated. Limestone layers are usually medium grey weathering except in patches of skarn where they have been altered and recrystallized. Nearly white, sugary textured marbles with coarse grain size in these zones are associated with chloritized and/or silicified, bleached greenstones. Garnet and epidote have formed from interbedded pelitic rocks in one of these skarn zones.

Limestone layers, up to several meters thick, can sometimes be traced for several hundred meters before they pinch out or are truncated by faults. Layering within these carbonates on a 3-5 cm scale is defined by alternating coarse sandy and fine grained bands. Coarse layers can be bioclastic and may show grading. One of the best exposures of this lithology is a little over one kilometer up Venables Creek from the highway. There, bedded limestones and calc arenites are interbedded with a few tuff layers.

Greenstones in the upper unit are much the same as those already described in the lower unit. Some more extensive and better exposed greenstone bodies are mapped separately (TRsv). Pale green chert, typically in beds 5-10 cm thick with exceptions up to a few meters thick, is the most common. The chert is a siliceous tuff, very fine grained with no phenocrysts. Quartz, feldspar and minor amounts of chlorite and sericite are visible in thin section.

Greenstone conglomerates up to a meter thick contain andesite, dacite and tuffaceous fragments as well as some granitic detritus. The source for the granitic material may be the high level plutons described in the greenstone section. Generally the granitic fragments are very quartz rich. A few are much less altered; primary hornblende is preserved. These clasts could be derived from the Guichon Batholith. A conglomerate of this description is exposed along the highway south of Venables Creek.

North of Venables Creek, above the highway, the lower cliffs are predominantly very fresh andesite. Euhedral, white feldspar phenocrysts, 1-2 mm across, sit in an intermediate to dark green aphanitic groundmass. Upwards, more siliceous greenstones and altered andesites give way to banded sedimentary rocks and minor limestone pods.

Clastic rocks other than greenstone conglomerate and tuff include argillite, some sandstone and greywacke, and considerable amounts of conglomerate derived from non-greenstone terrane. Argillites are black, siliceous and well bedded. Sandstone and greywacke are green, volcanic-derived and very similar to those in the greenstone unit. Conglomerates reflect the variety of lithologies in the Nicola Group. Clasts include green siliceous tuff, aphanitic purple volcanic fragments, argillite, and limestone, with quartz, feldspar, and calcite grains and argillaceous material making up the smaller fraction. Nowhere was detritus of Cache Creek origin identified.

The upper contact of these bedded rocks is an angular unconformity with a Lower Jurassic basal conglomerate which can be correlated with the Ashcroft Formation to the north. The unconformity is best exposed in Venables Creek about one kilometer upstream from the highway. Small, open folds in bedded limestone are truncated by the conglomerate.

Age of the Nicola Group

Two age determinations support a Mesozoic rather than Paleozoic age for this map unit. A Rb/Sr date was obtained on a suite of 6 samples from the greenstone unit. Four of these are from within the field area and two are from the quartz diorite just north of the field area. Table IV lists analytical data for the samples. They have a good spread in Rb/Sr ratios and define an isochron (Figure 32). The calculated date is 196 ± 15 Ma with an initial ratio of .7043 ± 2 somewhat different from values obtained from the Guichon Batholith, 205 ± 10 and .7034 (R.L.Armstrong, pers comm. 1978). The initial ratio, .7043, is slightly higher than the mean value for arcs (Faure and Powell, 1972) and may indicate some contamination very likely with Sr from seawater. A 196 Ma age for the Nicola is a bit younger than expected for time of formation as the Nicola is dated by fossils as Karnian to Norian. The isochron date may reflect the hydrothermal alteration event. A Late Triassic age of formation and early Jurassic alteration is reasonable.

Only one fossil collection was obtained from the Nicola. It includes microfauna from the bedded limestones below the unconformity in Venables Creek. In a collection of conodont fragments, B.E.B. Cameron of the Geological Survey of Canada identified one specimen of *Enantiognathus ziegleri* (Diebel) which ranges in age from lower Triassic to Upper Karnian (Mosher, 1968) and three specimens of *Neospathodus* sp. cf. *N. newpassensis* Mosher found in Lower Karnian, possibly ranging down to lower Middle Triassic (Mosher, 1968). Cameron assigns the assemblage a probable Upper Triassic (Karnian) age.

Depositional Environment of the Nicola Group

Submarine volcanic rocks, abundant volcanic-derived clastic material and

TABLE IV

Rb/Sr Geochronology Data

Sample #	Lithology	Locality	Latitude	Longitude	ppm Sr	ppm Rb	Rb/Sr	Rb^{87}/Sr^{86}	Sr^{87}/Sr^{86}
6-5-4	Dacite	V	50°32'37"	121°19'5"	68.0	33.0	0.485	1.404	.7079
6-5-2	Altered dactie	VI	50°32'27"	121°19'1"	91.0	24.8	0.273	0.790	.7062
11-4-1	Quartz diorite	VII	50°33'7"	121°17'48"	82.1	13.5	0.164	0.476	.7063
6-13-4	Altered dacite	VIII	50°32'39"	121°17'50"	23.2	58.0	2.49	7.22	.7244
4-14I	Inclusion in 4-14R	off map	50°40'40"	121°22'50"	126	7.9	0.062	0.181	.7047
4-14R	Quartz diorite	off map	50°40'40"	121°22'50"	170	12.7	0.075	0.216	.7046

Analytical Techniques :

Rb and Sr concentrations were determined by replicate analysis of pressed powder pellets using X-ray flourescence. U.S. Geological Survey rock standards were used for calibration; mass absorption coefficients were obtained from Mo Kα Compton scattering measurements, Rb/Sr ratios have a precision of 2% (1 σ) and concentrations a precision of 5% (1 σ). Sr isotopic composition was measured on unspiked samples prepared using standard ion exchange techniques. The mass spectrometer (60° sector, 30 cm radius, solid source) is of U.S. National Bureau of Standards design, modified by H. Faul. Data aquisition is digitized and automated using a NOVA computer. Experimental data have been normalized to a $^{86}Sr/^{88}Sr$ ratio of 0.1194 and adjusted so that the NBS standard $SrCO_3$ (SRM987) gives a $^{87}Sr/^{86}Sr$ ratio of .71022±2 and the Eimer and Amend Sr a ratio of 0.70800 ±2. The precision of a single $^{87}Sr/^{86}Sr$ ratio is 0.00013 (1 σ). Rb/Sr dates are based on a Rb decay constant of $1.42 \times 10^{-11} y^{-1}$. The regressions are calculated according to the technique of York (1967).

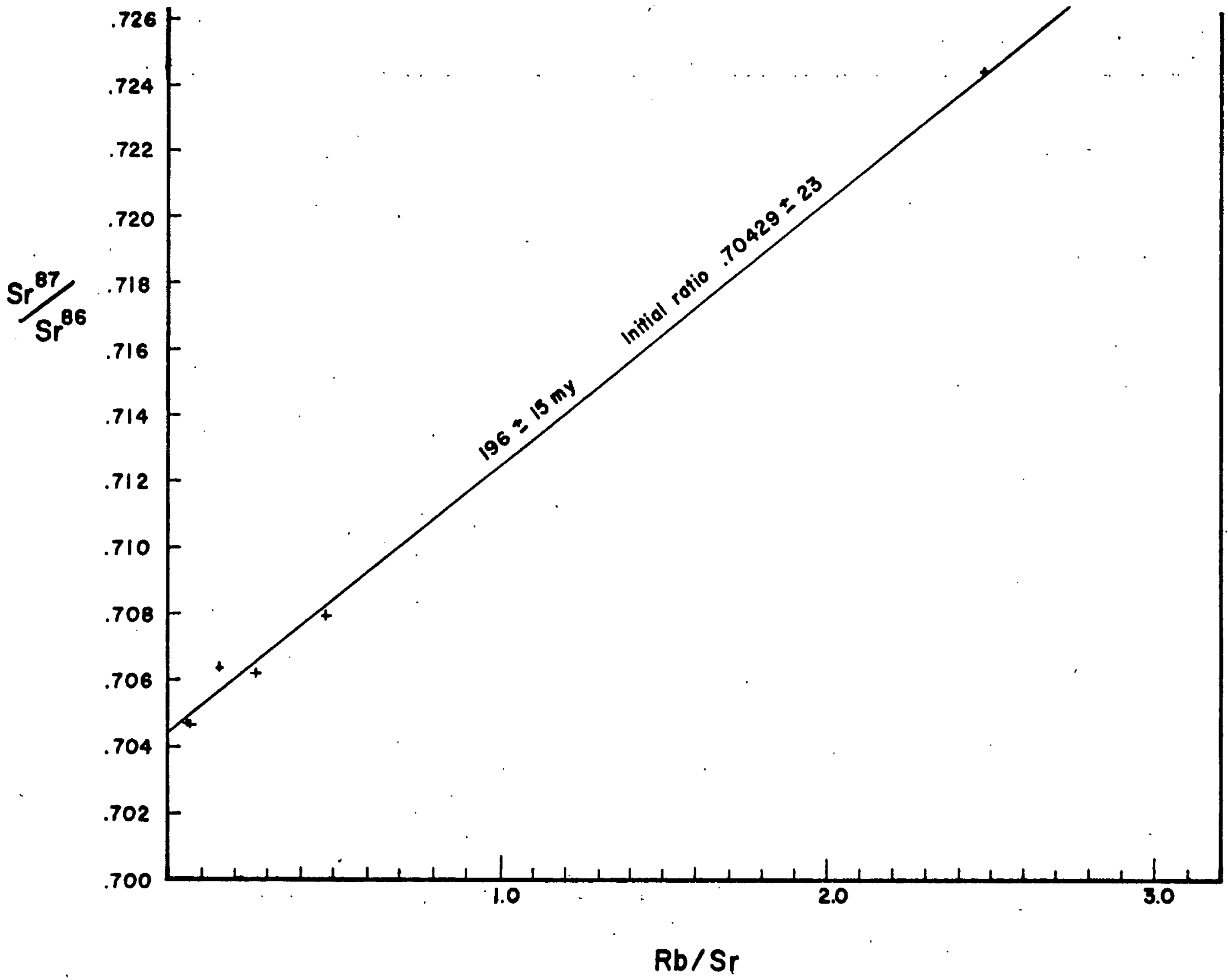


Figure 32. Rb/Sr isochron for greenstones of the Nicola Group.

carbonate shelf to reef facies rocks of the Nicola Group are typical of a volcanic island arc. Rapid facies changes and restricted lateral extent of most lithologies probably reflect small basins and rapid, irregular periods of uplift. No subareal volcanic rocks are present within the area, but clasts in conglomerates reflect subareal volcanism nearby. Rounded boulders in some conglomerates suggest some detrital material has had fluvial transport.

Influxes of detrital material, including tuffaceous layers, interrupted carbonate sedimentation. Turbidity currents redeposited clastic sediments and reef-derived fragments.

Structure

Faulting is the dominant deformation of the Nicola Group. Major faults trend north-northwest and are vertical. Most of these appear to be block faults with normal offset. The other major fault is the Martel Fault which forms the boundary between Cache Creek and Nicola strata. Near this fault and subparallel to it is a fracture cleavage to schistosity in the Nicola greenstone. Foliation is weakly developed or absent outside fault zones.

Figure 33 presents structural elements measured in the Nicola. Bedding attitudes are northwest trending and moderately southwest dipping. Small folds, usually drag folds along minor faults or ductile folds in limestone, have a fairly consistent northwest-southeast trend with moderate to shallow plunges. No axial plane foliation is developed. This southwest tilting of the Nicola section could be a result of intrusion of the Guichon Batholith. To the east across the Thompson River, large flatirons of Nicola dip to the west away from the Guichon contact. However, the Lower Jurassic Ashcroft Formation is also tilted to the southwest, so this tilting may be post lower Jurassic.

On the flatiron to the east, west vergent folds are developed in several-meter-thick bedded carbonate layers; contacts with over and underlying rocks are not folded. Apparently the carbonate behaved in a ductile fashion under

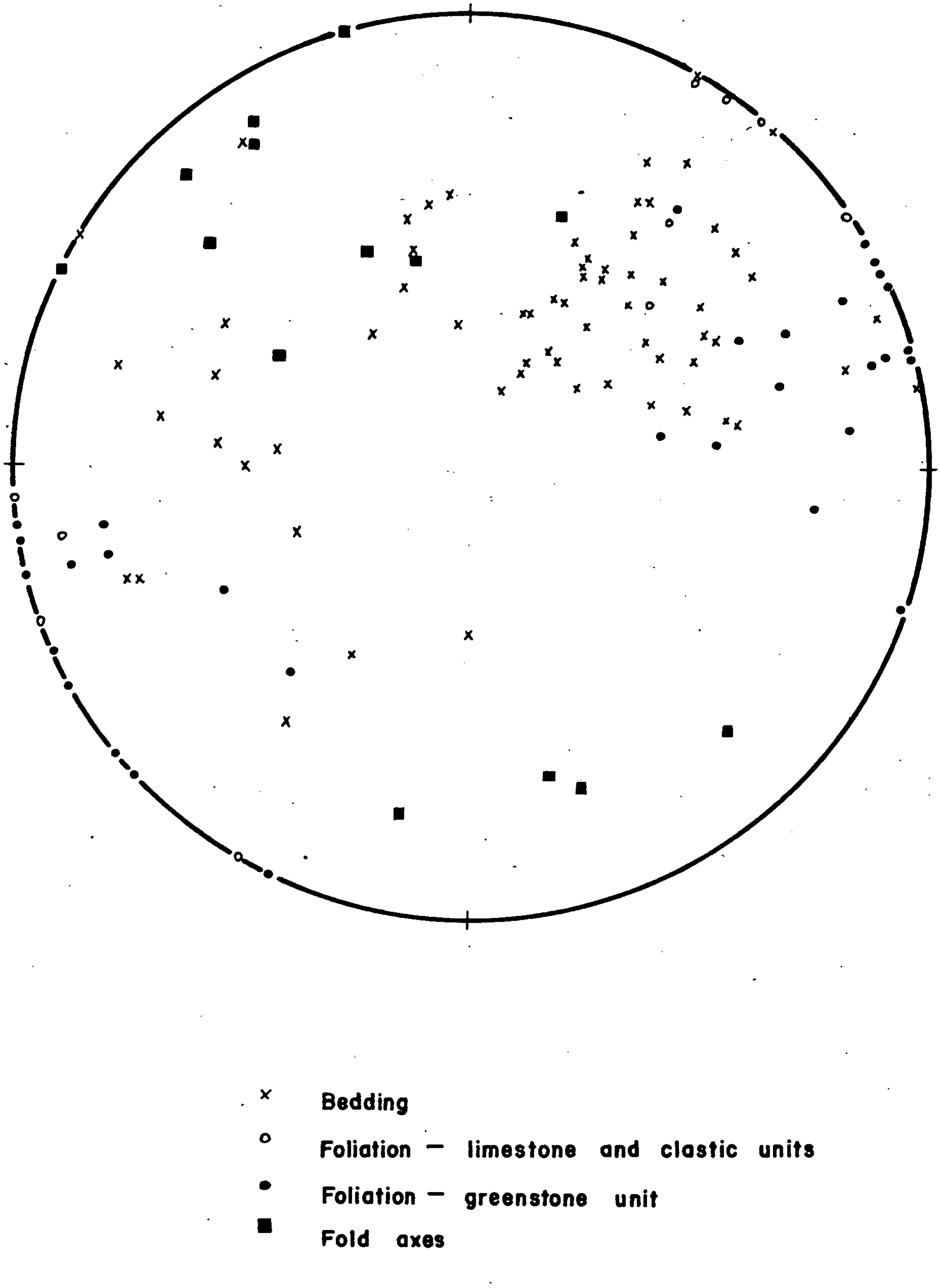


Figure 33. Equal area stereonet plot of structural elements in the Nicola Group.

shear stress which has allowed the overlying section to move downslope relative to the rocks underlying the carbonate. Movement was taken up in the limestone. Though not clearly demonstrated in the present area, folds in the limestones are thought to be of similar origin.

Alteration

Secondary minerals within the greenstones include epidote, albite, calcite, K-feldspar, and chlorite. Some areas are strongly silicified, bleached and usually pyritized. At one locality within the upper sedimentary unit a garnet-epidote skarn is developed. These are all hydrothermal alterations probably related to fluid movement during intrusion of the Guichon Batholith. Such alteration is similar to the feldspathization zone in the Wairaki geothermal field of New Zealand (Miyashiro, 1973). It is characterized by albitization and replacement of plagioclase by K-feldspar, local calcite alteration and abundant precipitation of silica. This occurs at temperatures of 230-250^{o} C.

Small skarns are also developed where dikes crosscut limestone layers. Epidote and more coarsely crystalline calcite replace the fine grained grey limestone.

Jurassic and Younger Rocks

Ashcroft Formation

Rocks of Jurassic age are exposed in two small areas, the larger along Venables Creek and the smaller patch slightly northeast (Figures 5 and 6). The Venables Creek exposure displays a more complete section. A basal conglomerate containing abundant granitic cobbles unconformably overlies folded Nicola sedimentary rocks. The granitic clasts, probably of Guichon provenance, are accompanied by Nicola detritus, principally greenstone fragments. There is no Cache Creek detritus. Clasts in the conglomerate are rounded to subrounded and range in size from 15 cm boulders to fine sand. The matrix and some sand grains are calcareous. This conglomerate resembles some of the Nicola conglomerates but is distinguished by the abundant granitic material and lack of alteration of matrix. Clasts weather out in relief as opposed to clasts within Nicola conglomerates.

Conglomerate grades rapidly upward into calc arenite and sandy, fossiliferous limestone. These are interbedded with and grade into black shale, common in the Ashcroft Basin (Frebold and Tipper, 1969; Travers, 1978). The entire exposed section is 200 meters thick.

Fossil collections from the sandy limestones and calc arenites were identified by T.P. Poulton of the Geological Survey of Canada. They include bivalves Weyla (?) sp. indet,. Camonectes (?) sp. indet., and Pleuromya (?) sp. indet. plus Terebratulid brachiopods, indet. and a solitary coral, indet. Poulton suggests a probable Lower Jurassic age.

The Jurassic rocks are preserved in two down-dropped fault blocks. In both cases the western contact is a fault which juxtaposes Jurassic strata against massive Nicola limestone. The strata dip southwest towards the faults. A fracture cleavage is developed in some of the sandstones. It is subparallel to the fault on the west side of the section and probably developed at the time of faulting.

Spences Bridge Group

The lower Cretaceous Spences Bridge Group is in fault contact with the Cache Creek Group along the western edge of the field area. It is very poorly exposed, but three outcrops of zeolitized, porphyritic andesite support the location of the contact drawn by Duffell and McTaggart (1952) and Pearson (1974). The group is made up of andesite, dacite and some rhyolite which have undergone zeolite alteration and gentle warping (Duffell and McTaggart, 1952).

Quaternary Deposits

Quaternary rocks of several origins cover much of the field area. Terraced glacial fluvial deposits fill the lower Thompson River valley. Quaternary is shown on the map (Figure 6) only in areas lacking outcrop or mappable float of older rocks.

DISCUSSION

Cache Creek Group, Nicola Group and Contact Relationships

In this area the Cache Creek Group appears to be a melange. It is a tectonic unit, rather than a stratigraphic unit, everywhere in fault contact with lower Mesozoic rocks. The group displays a sheared pelitic matrix containing blocks of varying size, lithology, age, and metamorphic grade. Blocks found within the the field area range in length from a few centimeters to greater than 5 kilometers. Lithologies represented as blocks include shallow water limestone, augite porphyry flows and tuffaceous rocks, ribbon chert, serpentinite and clastic sedimentary rocks. Within these blocks, primarily discernable in greenstones and greywackes, metamorphic conditions may vary from about 250^{o} C, 4 kb to conditions transitional to blueschist facies, T = 350^{o} C, P = 5.5-6 kb.

The relative importance of sedimentary vs. tectonic processes is not clear. There is abundant evidence of slumping and debris flows in the clastic rocks as coarser material was brought into proximity with pelagic sediments. This mechanism has been invoked to explain the presence of shallow water, reefoidal limestone masses amongst deeper water cherts (Monger, 1977b). If, as has been proposed, the reefs are developed on a volcanic pile, basalt blocks could also be largely slumped material. More difficult to explain are the differences in metamorphism within rocks of the same composition, especially the presence of transitional blueschist grade. There is some evidence of a low grade metamorphic source terrane since detrital prehnite and pumpellyite are found. Cache Creek Group rocks are probably the source rocks in this case. More highly metamorphosed rocks are likely tectonically emplaced. A similar mechanism is needed for serpentinite and other ultramafic bodies. The large ultramafic mass that forms the contact between the two clastic units is quite clearly emplaced along a fault, but smaller masses cannot be tied to known faults.

Structures in the Cache Creek Group, on the other hand, are not chaotic as they are in a typical melange. Over most of the area foliation maintains a fairly constant orientation, though it weakens upwards and to the west. The pods-in-matrix style does persist throughout.

In contrast, the Nicola Group, which has previously been mistakenly identified as Cache Creek Group in this area, does not have the same tectono-stratigraphic style. There are rapid lateral changes in lithology, and because of poor outcrop, some lithologies look like isolated blocks; but there is no sheared matrix. No regional foliation is developed; deformation is localized along fault zones. Shear foliation and schistosity parallel faults and are best developed in rocks near the Martel Fault. Hydrothermal alteration is also locally variable, but reflects differences in fluid movement rather than the wide P-T ranges found in the Cache Creek Group.

At outcrop scale clastic rocks in the Nicola Group are easily confused with weakly deformed Cache Creek rocks of the same lithology. However, if a large enough area is mapped, the contrasting tectonic style of these rocks should clearly separate the two groups. Other means for differentiation include fossil information, limited though it is, the absence of ultramafic masses in the Nicola Group, and isotopic data. More such data is needed for the volcanic rocks in the Cache Creek Group for comparison.

These distinctions between Nicola and Cache Creek Group rocks do not necessarily hold for other areas of the Cache Creek. In the Pinchi-Stuart

Lake Area, Paterson (1977b) finds Late Karnian to Early Norian Takla sediments containing metamorphic aragonite and speculates that augite porphyry volcanic rocks involved in blueschist metamorphisn could be correlated with the abundant augite porphyry of the Takla Group. Similar volcanic rocks with large augite phenocrysts are common in the Nicola Group outside the present study area (Schau, 1968, 1970; Campbell and Tipper, 1971; Preto, 1974). At the same time most of the volcanic and volcaniclastic rocks of the Cache Creek Group in this area are augite porphyry. In fact the higher pressure metamorphic assemblage is developed in a block of augire porphyry flows and tuffs. There are no data that require the age of these to be Paleozoic. They could be Triassic and part of the Nicola Group as well as involved with Cache Creek deformation and metamorphism. Also only 30 kilometers to the north Travers (1978) finds Triassic (Ladinian or Karnian) radiolaria in Cache Creek cherts.

As presently mapped the two groups are separated by a fault, the Martel Fault. It is now vertical to steeply west dipping, appears to truncate lithologies in the Nicola Group, but in some areas subparallels foliation in the Cache Creek Group. In other localities, notably the south end of the field area, this fault appears to cut the foliation of Cache Creek rocks. Its present steep dip could be a result of regional tilting in post lower Jurassic time since the entire Nicola and Ashcroft section is tilted to the southwest, subparallel to the average dip in the Cache Creek. If this tilting is removed and the Nicola and Ashcroft strata are returned to horizontal, the Martel Fault becomes a thrust fault placing foliated Cache Creek over Nicola and Ashcroft beds (as suggested by Ladd, in press).

On a larger scale, the Martel Fault juxtaposing Cache Creek in the west against Nicola is very similar to the Pinchi Fault which forms the eastern boundary of the Cache Creek Group in the Pinchi-Stuart Lake Area (Paterson, 1973, 1977b). Paterson (1977b) suggests large scale right lateral transcurrent movement in Late Triassic to Early Jurassic time on the Pinchi Fault. It has been suggested (P.B. Read, pers. comm., 1975) that the Martel Fault is the southern extension of the Pinchi Fault System. In that case one might propose strike-slip movement on the Martel Fault in early Mesozoic time using Paterson's idea. However, there is no concrete evidence in the Venables Valley area to support the presence of the Martel Fault in the early Mesozoic.

Tectonic Setting and History

Little hard data are available from this study on the timing of events in the type area of the Cache Creek Group. There is a lack of stratigraphic caontacts and fossil control. An approximate time-space plot can be drawn (Figure 34) by incorporating data from Paterson and Harakal (1974) for the time of blueschist metamorphism, and data from Travers (1978) for extension of Cache Creek deposition up into the Triassic. Timing of faulting events cannot be well documented but may be fairly continuous from Late Triassic to Tertiary.

From Mississippian time to as late as the Upper Triassic the Cache Creek oceanic assemblage was forming, presumably on oceanic crust (Monger, 1972, 1975a, 1977b) and during the Paleozoic it lay far from North America. In Upper Triassic (Karnian) time the Nicola arc became active, building up on Upper Paleozoic rocks which are thought to represent an earlier arc (Danner, 1977). At the same time Cache Creek Group rocks were probably being deformed and moved toward the craton. This produced the isoclinal folds and pervasive foliation. Thrust faulting and transitional blueschist metamorphisn accompanied this deformation. Melange development and deformation probably was initiated during this Late Triassic period. In latest Triassic or early Jurassic time the Guichon Batholith intruded and possibly tilted Nicola volcanics while contributing to hydrothermal alteration of the Nicola

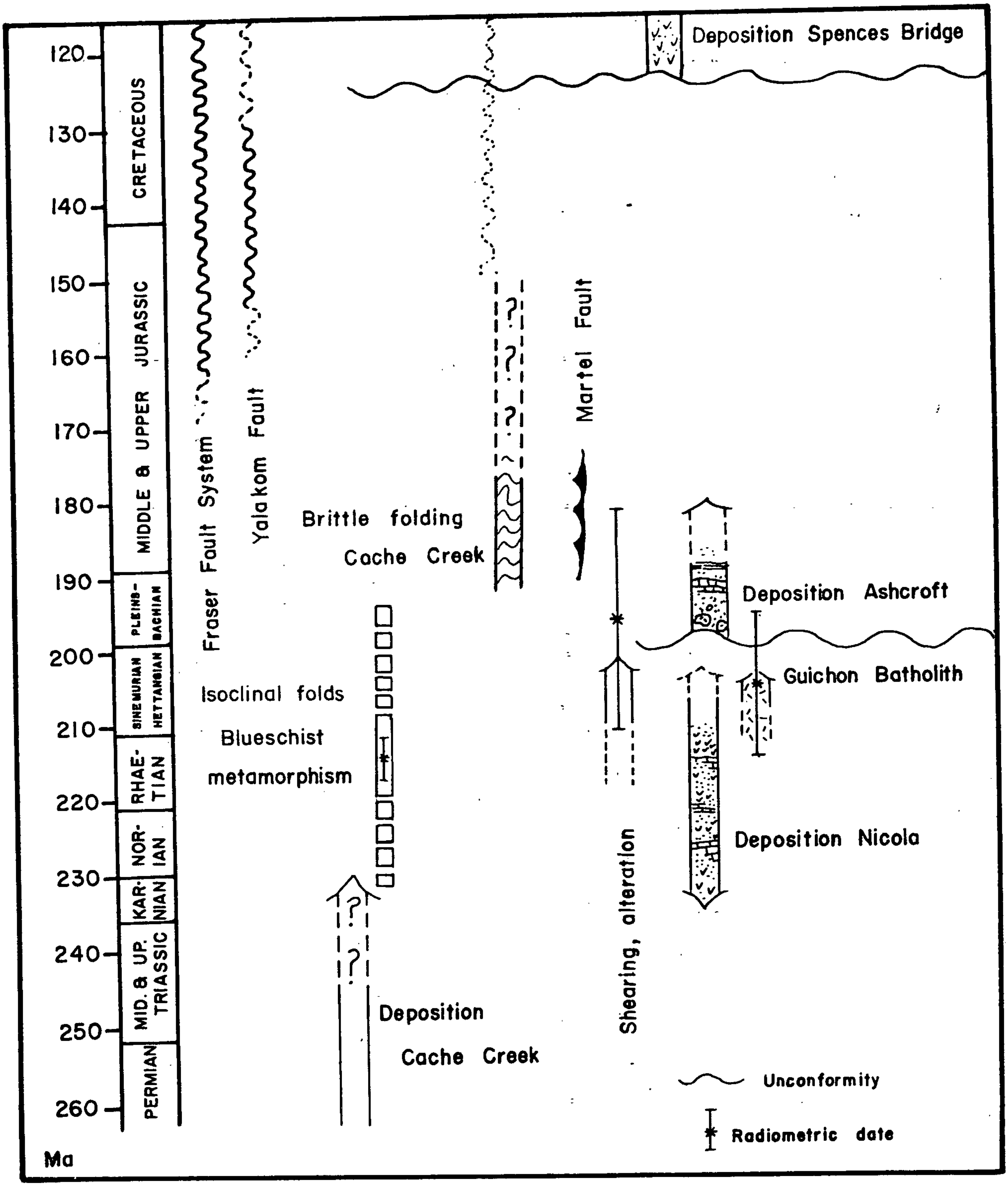


Figure 34. Timing of events in the type area of the Cache Creek. Broken lines indicate possible continuation of events. Data for Fraser Fault System from Eisbacher (1977) and for the Yalakom Fault from Tipper and Richards (1976). Radiometric age for the Guichon Batholith from R.L. Armstrong (pers. comm., 1978); blueschist metamorphic date from Paterson and Harakal (1974); alteration date of Nicola from present study.

Group. The foliation in Nicola rocks, best developed along the Martel Fault, is apparently the same age as hydrothermal alteration. Cache Creek rocks do not appear to have been affected by the hydrothermal event. One would expect Cache Creek rocks to be similarly altered if they were adjacent to the Nicola at the time the batholith was emplaced.

Following intrusion of the Guichon, the next event was the beginning of deposition of the Ashcroft Formation in Lower Jurassic time, likely Sinemurian (H.W. Tipper, pers. comm., 1975). That also marks the time of exposure of the Guichon Batholith and locally, the end of volcanism. Farther north and near the Nicola type area, Nicola volcanism continued into the Jurassic (Campbell and Tipper, 1971; Tipper and Richards, 1976; Preto, 1974).

Timing of events following deposition of the lowermost Ashcroft strata is not easily determined from the present study. There was abundant post Lower Jurassic faulting and further post lower Cretaceous faulting. Later folds in Cache Creek rocks, brittle folds that fold the earlier foliation, are probably related to later fault movement. Volcanism was renewed in early Cretaceous, Aptian time (Duffell and McTaggart, 1952), when Spences Bridge Group andesite, dacite, and rhyolite were deposited umconformably on older rocks.

Some of the faulting in this area may be related to movement along the Fraser and Yalakom Faults. Right lateral movement of several hundred kilometers has been proposed for both (Tipper, 1977; Tipper and Richards, 1976; Eisbacher, 1977).

In conventional plate tectonic models, tectonic melange, which includes thrust sheets and shows areas of high-pressure low temperature metamorphic conditions, is interpreted as developing in subduction zones (Dickinson, 1972). Highest pressure conditions are generally found on the arc side of the melange wedge. In the present study highest pressure assemblages are found in the structurally lowest part of the Cache Creek which now sits on the eastern side of the Cache Creek Group. This may be because the section has been tilted and might not be related to the original configuration. Thus if the Cache Creek melange is related to subduction, facing of the concurrent arc is not clear.

Tectonic models that include Cache Creek rocks of the type area suggest eastward subduction of an oceanic assemblage underneath the Nicola volcanic arc (Monger and others, 1972; Travers, 1978). As in the Pinchi-Stuart Lake Area (Paterson, 1977b), there are spatial problems with this model. Cache Creek melange is now adjacent to the are complex and as close as 3 kilometers to the Guichon Batholith, the root of the Nicola arc. This is much closer than standard models of an arc-trench system. There is considerable speculation as to whether the alkaline Nicola volcanic rocks represent a true arc. Alkaline chemical trends are thought to imply a rifting origin (Preto and others, 1975; Hollister and others, 1975). Yet alkaline rocks can develop in arcs where there is a very low convergence rate, less than 2 cm/yr (Miyashiro, 1973), so these chemical trends do not preclude an arc interpretation for the Nicola volcanics. The space problem noted above can be solved by allowing the Martel thrust fault to have considerable displacement .

SUMMARY AND CONCLUSIONS

In the Venables Valley area, the southernmost exposure of type Cache Creek Group rocks, the Cache Creek is thought to be a tectonic melange. Exotic, isolated blocks sit in a deformed chert-argillite matrix. Some blocks, especially limestone and possibly greenstone, are thought to be emplaced as slide blocks, as there is abundant evidence of debris flows and turbidity current deposits in finer grained clastic sedimentary rocks. Other exotic blocks, notably serpentinite and volcanic rocks showing high pressure metamorphic conditions might be tectonically emplaced; one large mass of greenstone is clearly fault bounded. Metamorphic conditions, though poorly documented, may range from temperatures below 250° C with pressures probably 4 kb or less, to pressures approaching 6 kb and temperatures near 350° C. Rocks of most severe deformation and highest metamorphic grade are found in the eastern, structurally lower part of the Cache Creek Group. Only one fossil age, Late Permian, was obtained for a Cache Creek limestone block.

Nicola rocks can be distinguished from Cache Creek by their lack of a pervasive foliation, by hydrothermal, albite epidote alteration rather than dynamothermal metamorphism, and by the lack of a sheared pelitic matrix and exotic blocks. Rapid facies changes occur, and some lithologies have little lateral extent, but there is no indication of isolated blocks, and there are no ultramafic rocks in the Nicola Group. Volcanic rocks include andesite and dacite rather than basalts seen in the Cache Creek. A Rb/Sr isotopic date of 196 $\pm$ 15 Ma for Nicola greenstones is likely the time of hydrothermal alteration related to intrusion of the Guichon Batholith.

Today the contact between the two groups is a vertical to steeply west dipping fault, named the Martel Fault. The entire Cache Creek through Lower Jurassic section is tilted to the southwest and if this tilting is removed the fault becomes a thrust. Movement is post Lower Jurassic.

Brittle deformation in the Cache Creek is probably related in part to movement along this fault.

Tectonic models in which the Cache Creek is interpreted as a subduction complex related to the Nicola arc are too simplified. Concurrent and later transcurrent faulting and thrust faulting have complicated the original spatial arrangement of the Cache Creek and Nicola Groups. Before the entire tectonic puzzle can be solved additional quantitative data must be obtained for the Cache Creek Group. These include paleotologic dating of radiolarian cherts, isotopic and chemical data for volcanic rocks, especially augite prophyry volcanics, better pressure-temperature information for metamorphic conditions, and isotopic dating of metamorphic events.

REFERENCES CITED

Albee, A.L. and Ray, L., 1970, Correction factors for electron probe micro-analysis of silicates, carbonates, phosphates, and sulfates: Analytical Chem., Vol. 42, p.1408-1414.

Armstrong, J.E., 1949, Fort St.James map-area, Cassiar and Coast districts, British Columbia: Geol. Surv. Can., Mem. 252.

Bence, A.E. and Albee, A.L., 1968, Empirical correction factors for the electron microanalysis of silicates and oxides: J. Geol., Vol. 76, p.382-403.

Black, P.M. and Brothers, R.N., 1978, Blueschist ophiolites in the Melange Zone, Northern New Caledonia: Contrib. Mineral. Petrol., Vol. 65, p.69-78.

Bosellini, A. and Winterer, E.L., 1975, Pelagic limestone and radiolarite of the Tethyan Mesozoic: a genetic model: Geology, Vol. 3, p.279-282.

Brown, E.H., 1977a, Phase equilibria among pumpellyite, lawsonite, epidote and associated minerals in low grade metamorphic rocks: Contrib. Mineral. Petrol., Vol. 64, p.123-136.

Brown, E.H., 1977b, The crossite content of Ca-amphiboles as a guide to pressure of metamorphism: J. Petrol., Vol. 18, p.53-72.

Cameron, B.E.B. and Monger, J.W.H., 1971, Middle Triassic conodonts from the Fergusson Group, northeastern Pemberton map area, British Columbia: Geol. Surv. Can., Pap. 71-1B, p.94-96.

Campbell, R.B. and Tipper, H.W., 1970, Geology and mineral exploration potential of the Quesnel Trough, British Columbia: Can. Inst. Min. Met., Trans., Vol. 73, p.174-179.

__________, 1971, Geology of Bonaparte Lake map-area, British Columbia: Geol. Surv. Can., Mem. 363.

Carr, J.M., 1962, The geology of part of the Thompson River Valley between Ashcroft and Spences Bridge: B.C. Rept. Minister of Mines Petrol. Res., Ann. Rept., p.28-45.

Cockfield, W.E., 1948, Geology and mineral deposits of Nicola map-area, British Columbia: Geol. Surv. Can., Mem. 249.

Coleman, R.G. and Papike, J.J., 1968, Alkalai amphiboles from the blueschists of Cazadero, California: J. Petrol., Vol. 9, p.105-122.

Connelly, W., Hill, M., Hill, B.B., and Moore, J.C., 1976, The Uyak Formation, Kodiak Islands, Alaska: an early Mesozoic subduction zone complex: Geol. Soc. Am., abs., Vol. 8, No. 3, p.364.

Danner, W.R., 1965, Limestones of the western Cordilleran eugeosyncline of southwestern British Columbia, western Washington and northern Oregon, in D.N. Wadia Commemorative Vol., Min. Met. Inst. India, p.113-125.

__________, 1967, Organic, shallow-water origin of bedded chert in the eugeosynclinal environment: Geol. Soc. Am., Prog. 1967 Ann. Mtg., p.42.

__________, 1974, Geology of San Juan Island, Washington: Geol. Soc. Am., Abs., Vol. 6, No. 3., p.160.

__________, 1975, Notes on Cache Creek Group: Prep. Handout for a field trip to the western Intermontane Belt, 4p.

__________, 1976, Limestone Resources of southwestern British Columbia: Mont., Bur. Mines Geol., Spec. Publ., No. 74 (Eleventh industrial minerals forum), p.171-186.

__________, 1977, Paleozoic rocks of northwest Washington and adjacent parts of British Columbia in Paleozoic Paleogeography of the Western United States, Stewart, J.H., Stevens, C.H., Fritsche, A.E. (eds.): Soc. Econ. Palentol. Mineral., Pacific Section, p.481-502.

Dawson, G.M., 1894, Report on the area of the Kamloops map-sheet, British Columbia: Geol. Surv. Can., Repts., Vol. 7, p.18-427B.

Dickinson, W.R., 1972, Evidence for plate-tectonic regimes in the rock record: Am. J. Sci., Vol. 272, p.551-576.

Drysdale, C.W., 1912, Geology of the Thompson River Valley below Kamloops Lake, British Columbia: Geol. Surv. Can., Summary Repts., 1912, p. 115-150.

Duffell, S. and McTaggart, K.C., 1952, Ashcroft map-area, British Columbia: Geol. Surv. Can., Mem. 262.

Eisbacher, G.H., 1977, Mesozoic-Tertiary basin models for the Canadian Cordillera and their geological constraints: Can. J. Earth Sci., Vol. 14, p.2414-2421.

Faure, G. and Powell, J.L., 1972, Strontium Isotope Geology, Springer-Verlag, New York, 188p.

Frebold, H. and Tipper, H.W., 1969, Lower Jurassic rocks and fauna near Ashcroft, British Columbia and their relation to some granitic plutons (92-I): Geol. Surv. Can., Pap. 69-23, 20p.

Hollister, V.F., Allen, J.M., Anzalone, S.A., Seraphim, R.H., 1975, Structural evolution of porphyry mineralization at Highland Valley, British Columbia: Can. J. Earth Sci., Vol. 12, p.807-820.

Hsü, K.J., 1974, Melanges and their distinction from olistostromes in Modern and Ancient Geosynclinal Sedimentation; problems of palinspastic restoration: Soc. Econ. Palentol. Mineral., Spec. Publ., No. 19, p.321-333.

Jones, D.L., Irwin, W.P., Ovenshine, A.T., 1972, Southeastern Alaska - a displaced fragment?: U.S. Geol. Surv., Prof. Pap. 800-B, p.B211-B217.

Ladd, J.H., in press, Mapping southwest of Ashcroft on Red Hill and along the Cache Creek - Nicola contact: B.C. Dept. Mines and Petrol. Res.

McMillan, W.J., 1974, Stratigraphic section from the Jurassic Ashcroft Formation and Triassic Nicola Group contiguous to the Guichon Creek Batholith: Geological Fieldwork, B.C. Dept. of Mines and Petrol. Res.

______________, 1975, Geology and genesis of the Highland Valley ore deposits and the Guichon Creek Batholith <u>in</u> Porphyry Deposits of the Canadian Cordillera: Can, Inst. Min. Met., Spec. Vol. 15, p.85-104.

Miyashiro, A. 1973, Metamorphism and metamorphic belts, John Wiley and Sons, New York, 492p.

Monger, J.W.H., 1969, Stratigraphy and structure of Upper Paleozoic rocks, Northeast Dease Lake map-area, British Columbia (104J): Geol. Surv. Can., Pap. 68-48.

______________, 1972, Oceanic crust in the Canadian Cordillera: <u>in</u> The Ancient Oceanic Lithosphere, Canadian Contrib. No. 4 to Geodynamics Project, p.59-64.

______________, 1975a, Upper Paleozoic rocks of the Atlin Terrane, northwestern British Columbia and south-central Yukon: Geol. Surv. Can., Pap. 74-47, 63p.

______________, 1975b, Correlation of eugeosynclinal tectono-stratigraphic belts in the North American Cordillera; Geosci. Can., Vol. 2(1), p.4-10.

______________, 1977a, Upper Paleozoic rocks of northwestern British Columbia <u>in</u> Report of Activities, Part A: Geol. Surv. Can., Pap. 77-1A, p.255-262.

______________, 1977b, Upper Paleozoic rocks of the western Canadian Cordillera and their bearing on Cordilleran evolution: Can. J. Earth Sci., Vol. 14, p.1832-1859.

Monger, J.W.H. and Paterson, I.A., 1974, Upper Paleozoic and Lower Mesozoic rocks of the omineca mountains: Geol.Surv. Can., Pap. 74-1A, p.19-20.

Monger, J.W.H. and Ross, C.A., 1971, Distribution of fusulinaceans in the western Canadian Cordillera: Can. J. Earth Sci., Vol. 8, p.259.

Monger, J.W.H., Souther, J.G., Gabrielse, H., 1972, Evolution of the Canadian Cordillera; a plate-tectonic model: Am. J. Sci., Vol. 272, p.577-602.

Mosher, L.C., 1968, Triassic conodonts from western North America and Europe and their correlation: J. Paleontol., Vol. 42, p.895-946.

Paterson, I.A., 1973, The geology of the Pindhi Lake area, central British Columbia: unpub. PhD. thesis, Univ. British Columbia, Vancouver, B.C.

Paterson, I.A., 1974, Geology of Cache Creek Group and Mesozoic rocks of the northern end of the Stuart Lake Belt, Central British Columbia: Geol. Surv. Can., Pap. 74-1B, p.31-42.

_____________, 1977a, Possible evidence for transform faulting on the Pinchi system during the Late Triassic: Geol. Assoc. Can., Program 1977 Annual Meeting, p.41.

_____________, 1977b, The geology and evolution of the Pinchi Fault Zone at Pinchi Lake, central British Columbia: Can. J. Earth Sci., Vol. 14, p.1324-1342.

Paterson, I.A. and Harakal, J.E., 1974, Potassium-argon dating of blueschists from Pinchi Lake, central British Columbia: Can. J. Earth Sci., Vol. 11, p.1007-1011.

Pearson, W.N., 1974, Zeolite facies metamorphism of the Spences Bridge Group, Spences Bridge, southern British Columbia: unpub. B.Sc. Thesis, Univ. British Columbia, Vancouver, B.C.

Pessagno, E.A., Jr. and Newport, R.L., 1972, A technique for extracting Radiolaria from radiolarian chert: Micropaleontology, Vol. 18, No. 2, p.231-234.

Preto, V.A.G., 1974, Geology of the Nicola volcanics and related mineralization at Aspen Grove, B.C. (Abs.) in Volcanic geology and mineral deposits of the Canadian Cordillera: Cord. Sect., Geol. Assoc. Can., Abs. Prof., Vol., Volcanoes and mineralization symposium.

Preto, V.A., Lefebure, D.V., Atkinson, S.J., 1975, The Nicola Group: Mesozoic volcanism related to rifting in southern British Columbia: Geol. Soc. Am., Abs. Prog., Vol. 7, No.6, p.841-2.

Schau, M.P., 1968, Geology of the Upper Triassic Nicola Group in south central British Columbia: unpub. PhD thesis, Univ. British Columbia, Vancouver, B.C.

__________, 1970, Stratigraphy and structure of the type area of the Upper Triassic Nicola Group in south central British Columbia: Geol. Assoc. Can., Spec. Pap. 6, p.123-135.

Selwyn, A.R.C., 1872, Journal and Report on British Columbia: Geol. Surv. Can., Report of Progress, 1871-72, p.16-72.

Tipper, H.W., 1977, The Fraser Fault System of southwestern British Columbia: Geol. Assoc. Can., Program 1977 Annual Meeting, Vol. 2, p.53.

Tipper, H.W. and Richards, T.A., 1976, Jurassic stratigraphy and history of north-central British Columbia: Geol. Surv. Can., Bull. 270, 73p.

Travers, W.B., 1978, Overturned Nicola and Ashcroft strata and their relation to the Cache Creek Group, southwestern Intermontane Belt, British Columbia: Can. J. Earth Sci., Vol. 15, p.99-116.

Winkler, H.G.F., 1974, Petrogenesis of Metamorphic Rocks (4th Edition), Springer-Verlag, New York, 334p.

York, D., 1967, The best isochron: Earth Planet. Sci. Lett., Vol. 2, p.479-482.