BRITISH COLUMBIA

Ministry of Energy and Mines
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GEOLOGY AND MINERAL RESOURCES OF THE TAGISH LAKE AREA (NTS 104M/8,9,10E, 15 and 104N/12W) Northwestern British Columbia

By Mitchell G. Mihalynuk, P.Geo

With Contributions by:

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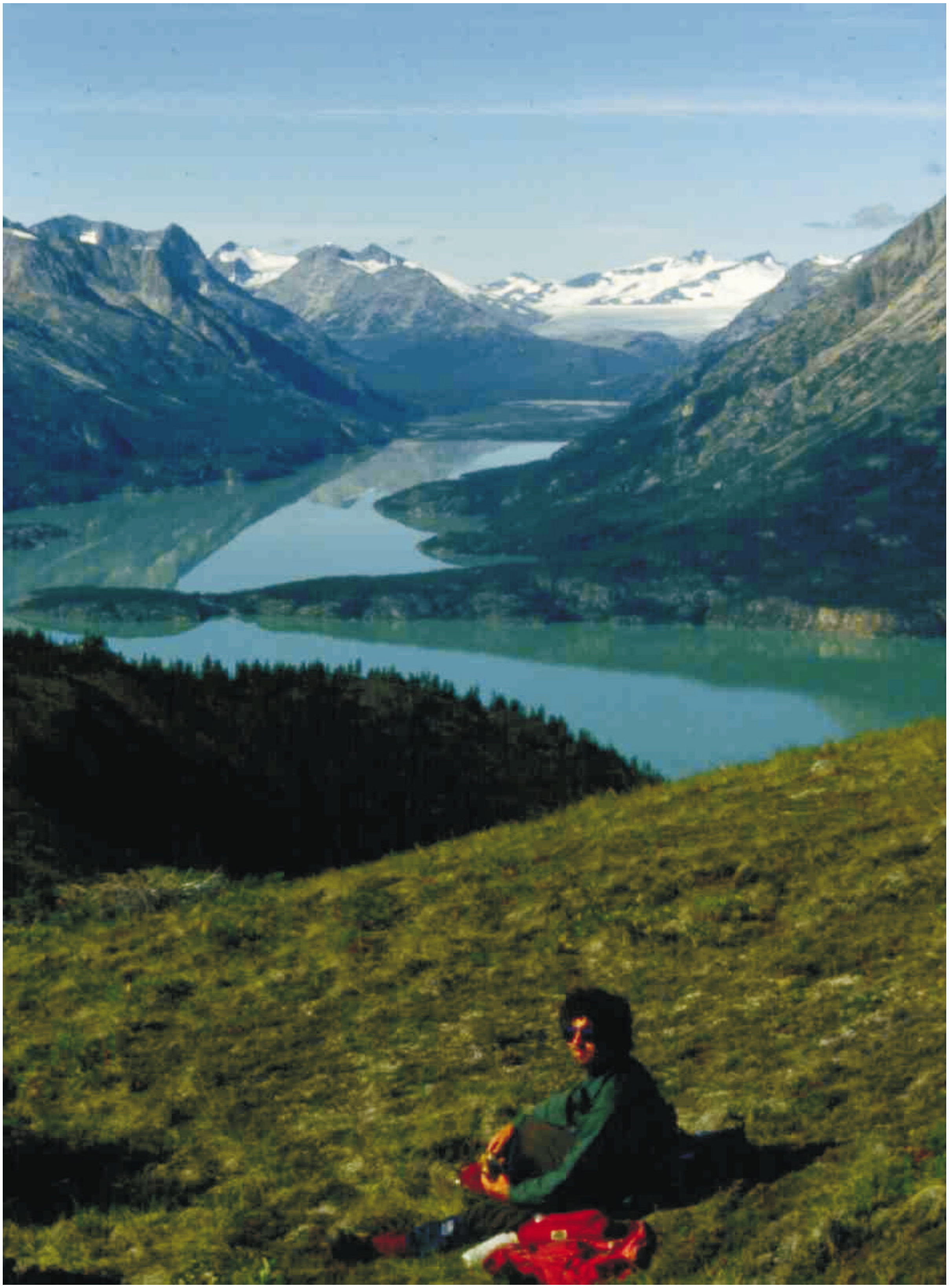

Frontispiece: Craggy Coast Mountains envelop the southern end of beautiful Tagish Lake, viewed from Engineer Mountain looking west. Expansive glaciers of the centre background extend to tidewater in Alaska. Ben-My-Chree, a past producer of silver and gold, is located above the farthest western limit of the north shore. A dock and resort facility at Ben-My-Chree accepted well-heeled guests arriving by paddle wheeler from Carcross, but is now a private seasonal residence.

Summary

The Tagish area is located in the northwest corner of British Columbia. It is bounded by the Yukon border to the north, rugged Coast Mountains to the west, and Atlin Lake, British Columbia's largest natural water reservoir, to the east. It is an area with a colourful mining history that blossomed during the Klondike gold rush and discovery of the Atlin placers in 1898. It is richly endowed with mineral showings and one mine, the Engineer, having produced over 560 000 grams of gold. A belt of anomalously high regional gold-arsenic and antimony geochemistry extends the length of the area, coextensive with the crustal-scale Llewellyn fault.

The geology is dominated by three crustal fragments of strikingly different character that converge in the Tagish area. In the east are weakly metamorphosed, Carboniferous to Triassic oceanic plateau remnants of the northern Cache Creek Terrane, here known as the Atlin complex. In the west are two suites of metamorphic rocks that comprise a polydeformed belt belonging to the Yukon-Tanana Terrane: a pre-Mississippian, quartz-rich clastic succession of pericratonic origin; and a Devonian to Permian, heterolithic suite interpreted to correlate with volcanic arc strata of the Stikine Terrane. Sandwiched in between are Triassic arc, clastic arc apron, and overlying Jurassic basinal strata of the Whitehorse Trough. They are juxtaposed across two crustal-scale faults, the Nahlin to the east and Llewellyn to the west, that brought the crustal fragments together, mainly in Triassic to Middle Jurassic times. Geological interrelationships are complicated by structural intermixing and by voluminous Late Cretaceous and Eocene intrusion of the Coast Plutonic Complex. Pre-Jurassic deformational histories of each crustal fragment are distinctive, but all are affected by early Middle Jurassic, predominantly south and west-verging folds and thrusts that shortened and stacked them. Reactivation of major faults and subsidiary splays is apparent from dextral offsets that affect rocks as young as Eocene.

Quartz-rich clastic rocks of the Yukon-Tanana Terrane are rifted relicts of ancestral North American margin across which the Paleozoic and Mesozoic arc complexes of Stikinia and Quesnellia were linked, similar to the manner in which the Aleutian and Japan arcs are joined across ensialic crust of Kamchatka. Stikinia was rotated counter-clockwise throughout the Early Mesozoic, entrapping relicts of oceanic plateau of the Atlin complex prior to collision with Quesnellia in early Middle Jurassic time. Near orogen-parallel fault displacements modified the terrane distribution into the Early Tertiary.

Yukon-Tanana terrane, Whitehorse Trough and Atlin complex display different styles of mineralization. In the Atlin complex, gold-quartz veins are developed in mafic and ultramafic rocks. Although important placer production has been has been attributed to this source, no significant past gold production has come from lodes. Oceanic mafic rocks are also be prospective for Cyprus-type massive sulphide copper-zinc mineralization, but none is known.

Old Yukon-Tanana Terrane rocks were deposited in part during rifting of the North American continental margin, a setting in which sedimentary exhalative deposits accumulated elsewhere in the Cordillera. Younger Yukon-Tanana terrane rocks were deposited in a volcanic arc environment. The arc package includes felsic submarine volcanics which may have correlatives in the Tulsequah area where such rocks host Kuroko-style volcanogenic massive sulphide accumulations like at the Tulsequah Chief deposit.

Upper Triassic arc rocks of the Whitehorse Trough are lithologically and temporally equivalent to those hosting important copper-molybdenum-gold porphyry deposits in southern B.C. Minor synsedimentary volcanic rocks in the Early Jurassic trough strata may hold potential for shallow subaqueous hot spring deposits rich in gold and silver like those at the Eskay Creek mine.

Cretaceous and younger plutons cross the crustal fragment boundaries. Cretaceous plutons produce copper skarn mineralization where they cut Upper Triassic carbonates in the Whitehorse Copper Belt, and the southern end of the belt may extend into the Tagish area. Tertiary plutons and coeval volcanic rocks are associated with gold skarn mineralization in the northern Tagish area, and epithermal gold mineralization in both the Tagish area and southern Yukon.

Crustal-scale faults, as well as related secondary faults, provide conduits for pluton emplacement and mineralizing hydrothermal systems. Thus, they are important environments for thermal aureole gold deposits. Deep epithermal gold mineralization at the Engineer Mine developed adjacent splays of the Llewellyn fault, probably coeval with a nearby Eocene volcanic centre.

High mineral potential exists in the Tagish area for a number of deposit types. Juxtaposition of three disparate crustal fragments has created mineral exploration opportunities as varied and challenging as the geology.

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Chapter 1 Introduction

British Columbia is renowned for its natural beauty and large tracts of wilderness. It is also a province richly endowed with mineral wealth. Exploitation of this mineral wealth has been an economic mainstay, particularly in northern parts of the province, since early this century. Today, remnants of this mining heritage in the Tagish area are as much a part of the scenery as the huge lakes which stitch together the rugged coastal and interior plateau regions (Frontispiece).

British Columbia is less widely known as a province of incredible geologic diversity and complexity. Such qualities paradoxically enhance the chances of economic accumulations of metals, while at the same time making such accumulations harder to find. Understanding the geological elements of an area and knowing how existing mineral deposits relate to such elements greatly sharpens the focus of exploration for similar deposits. Until recently, widespread geological map coverage in British Columbia was available mainly as Geological Survey of Canada mapping at 1:250 000 scale. However, in many areas this geological database is outdated and cannot provide the benefits derived from application of modern concepts and analytical techniques. In some places, early geological surveys either placed little emphasis on economic geology, or are not detailed enough to meet the demands made by stakeholders of today. For example, land-use evaluation processes rely heavily on an understanding of mineral potential. In regions of complex geology and correspondingly small but distinctive geologic domains, the mineral potential may change dramatically over small areas (tens of square kilometres or less), and thus, high-resolution mapping is of paramount importance to either an accurate mineral potential assessment or a focused mineral exploration program.

It is for these and other reasons that in 1986 the province initiated a 1:50 000 geological mapping program to investigate areas of prime importance to both the province's resource database and the mineral industry. The mapping project reported on here investigated a northwest-trending belt of rocks between Atlin, British Columbia and Skagway, Alaska (Figure 1-1) that was known to be anomalous in arsenic, antimony and gold (Schroeter, 1986). Previously published Geological Survey of Canada mapping of the area was conducted by Christie between the years 1954 and 1957. A 1:250 000 map was published in 1957, but it was not accompanied by a synoptic report.

Geological mapping under this project highlights the details of, and interrelationships between, major lithologic assemblages and their bounding structures (Figure 1-1). Mapping was conducted in concert with a comprehensive regional geochemical sampling program, some results of which are also reported here. In total, four 1:50 000 UTM sheets covering over 3000 square kilometres were covered over the course of the project (see Figure GM97-1 "Reliability Diagram" inset). North and south limits to the area discussed here are the Yukon border and Atlin Provincial Park. Tagish Lake and the rivers that feed it extend over much of the study area.

Survey Methods and Philosophy

Geologic data collected during the project are presented here. A consistent effort has been made to maintain a distinction between objective and subjective information. Where such a distinction may not be intuitive, extrapolations have been labeled as 'interpretive' or 'inferred'. Where solid data are lacking, geological intuition occasionally dictates assignment of outcrops to one unit or formation as opposed to another. Appendices provide the reader with raw data such as fossil identifications and geochemical results.

One of the most persistent problems encountered within the Tagish area is the need to distinguish between stratigraphic and structural contacts. Much of the geology of the area reflects the juxtaposition of four terranes or assemblages and significant crustal shortening. Such shortening occurs wherever it can be accommodated most easily. Consequently, pre-existing discontinuities are commonly the locus of significant contraction. Movement along unconformities, deformation within incompetent lithologies such as argillaceous sediments, and dislocations along other contacts, including pre-existing faults, accommodate most of the shortening. It is a challenge to determine whether the magnitude of offset at such discontinuities is significant, and to clearly represent them in map and cross sections. Wise *et al*. proposed a legal definition for faults: *that entire class of phenomena characterized by relatively tabular or planar discontinuities in which the zone as a whole or any macroscopic part of it contains displacement parallel to the zone greater than 0.5 to 1 cm and displacement at least five to ten times greater than the width of that part regardless of whether the zone is marked by loss of cohesion or extreme ductile deformation.* Clearly, this definition is not appropriate within the map area. Instead, partly arbitrary contact definitions are applied in this

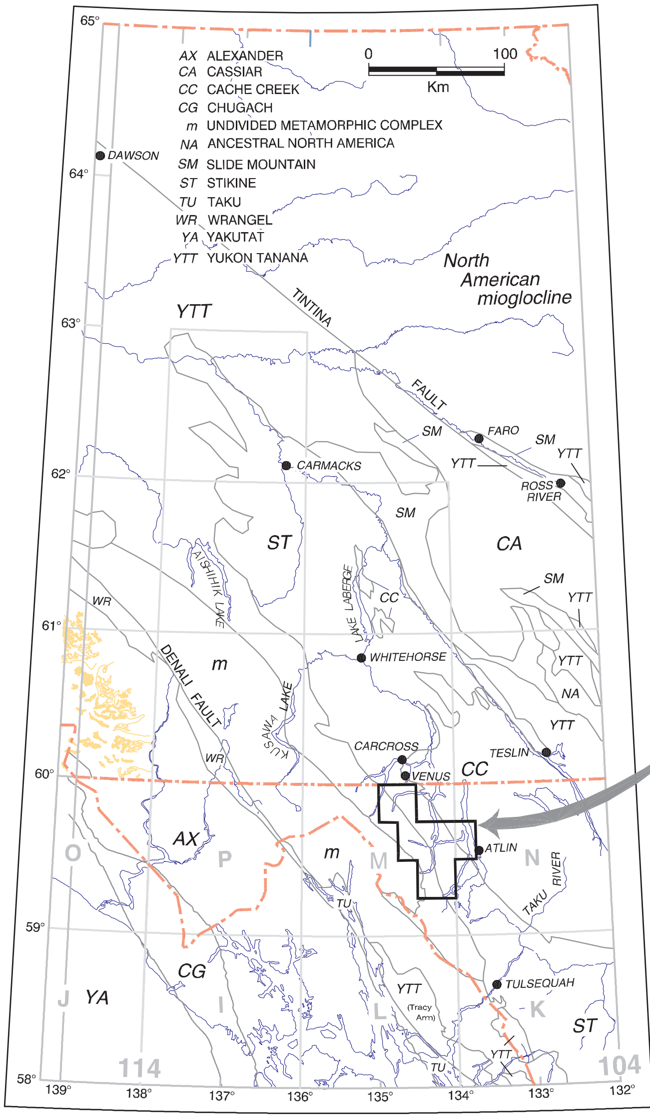
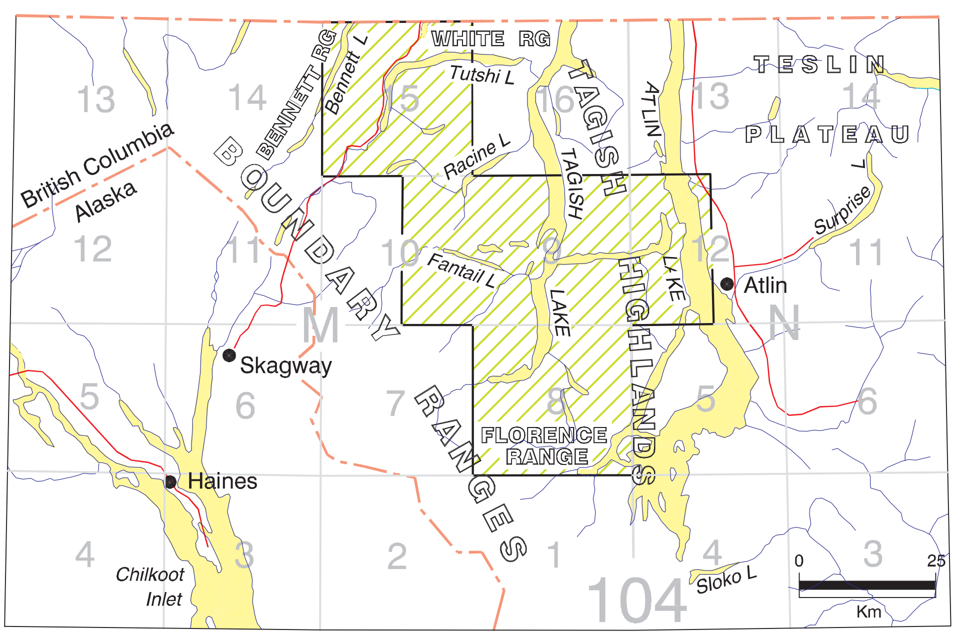


Figure 1-1. (a) Location map of the map area within British Columbia. (b) Regional geography and terranes modified after Wheeler and McFeely (1991). (c) 1:250 000 and 1:50 000 map sheets, place names and physiographic subdivisions referred to in the text.



paper: a contact that was originally stratigraphic is mapped as a fault if more than 10 metres of displacement can be **demonstrated**. If offset can not be proven, then the magnitude of displacement **suspected** must exceed 100 metres before the contact is designated as a fault. On Figure GM97-1, only the most significant faults are shown. These have offsets of 1 km or more.

The scale of mapping and scale of presentation of map data pose problems in representing units that are less than 50 metres thick. Important units can be considerably thinner than 50 metres. If they are, their thickness may be exaggerated on geological maps rather than omit them because they can not be accurately represented at 1:100 000 scale. Where this has been necessary the warning "thickness may be exaggerated" is added in the map legend.

Fieldwork on the Tagish project was completed on a quadrangle by quadrangle basis, beginning in the northwest and ending in the south and east. Geologic complexity appears to decrease southward, thus, mapping is most reliable in the southern sheets due to application of knowledge gained in the more geologically complex setting to the northwest.

Interest in terrane interactions that constrain the tectonic evolution of the Cordillera has spurred field research in northwestern British Columbia and adjacent parts of Yukon and Alaska. These areas are geologically complex as they are comprised of a number of terranes (*cf.* Wheeler *et al.*, 1991), some of which are poorly exposed and remain poorly understood. One byproduct of the proliferation of geologic investigations across terrane boundaries (and across domestic and international borders) is a proliferation of nomenclature. Special effort has been made here to clarify nomenclature and, where appropriate, to cite origins.

Mapping conducted as part of this project is commensurate with 1:50 000 British Columbia Geological Survey Branch mapping standards (BC Geological Survey, 1997).

Location and Access

An extensive network of large glacier-fed lakes provides good boat access into the study region. The Klondike Highway, which connects Skagway with Whitehorse, runs diagonally across the Tutshi Lake map area in the northern part of the region. Built earlier, but for the same purpose, the rehabilitated, narrow gauge White Pass Railway carries tourists up the pass during the summer months. Plans are eventually to extend the trip to take in the eastern shore of Bennett Lake (westernmost Tutshi Lake area).

Besides major land routes, all-terrain-vehicle roads have been pushed to alpine elevations at the headwaters of Graham Creek and the high plateau north of Tutshi Lake. Similar routes ascend nearly to timberline up Hope Creek and up the north side of Pavey Pass.

Several wide trails or wagon roads that terminated at the shore of Tagish Lake have been kept clear through intermittent use as traplines, travel by vehicles barged to their shoreline termini, or constant use by animals. Many kilometres of roads of various vintage were built around the old Engineer mine. A road that at one time followed the old power line from the Wann River hydroelectric dam to the mine is well maintained from the mouth of Wann River to the damsite, the remainder is thoroughly overgrown. A relatively well marked walking trail continues from the damsite to Edgar Lake. A clear trail links southern Windy Arm with Tutshi Lake. A trail along the eastern side of Teepee Creek leads at least 5 kilometres from the creek mouth to the headwater meadows. An old wagon trail, now suitable only for foot or horse travel, can be followed from Tagish Lake up Bighorn Creek to the old minesite. A well maintained horse trail extends at least 3 kilometres south of Racine Lake and apparently continues to Brownlee Lake.

A host of lakes between 1.5 and 8 kilometres long permit float plane access to various otherwise remote parts of the map area. Away from the lakes, access is on foot or by helicopter. Both charter helicopters and float planes are based year-round in Atlin.

Fieldwork planning in the area is guided to a large degree by breakup and changing levels of the major lakes. In general, persistent winter lake ice disappears sometime during the first week of June. Immediately following spring thaw, lake levels are low, shores are easily traveled on foot, and rock exposures are often excellent. By midsummer, lake levels have risen several metres, pushing the shoreline back into the brush and foot travel is impeded. At maximum lake level, the west-flowing Atlin River becomes a fast-flowing, although navigable link between Tagish and Atlin lakes. Early in the season only very shallow draft boats can navigate this river. From the start of the Atlin River, it is only 5 kilometres across Atlin Lake to the town of Atlin.

The winter snowpack provides most of the spring runoff and continually recedes through the summer. Large tracts of alpine terrain are generally clear of snow by early July. By the first week in September, late summer storms begin the cycle again.

Physiography

The study area straddles two geomorphological subdivisions: the rugged Coast Belt underlain by dominantly crystalline rocks, and the more subdued Intermontane Belt, underlain by dominantly volcanic and sedimentary rocks. At the latitude of the study area, these subdivisions are named more specifically the Boundary Ranges of the Coast Mountains and the Teslin Plateau of the Interior

Plateau (Figure 1-1). At the transition between them, the Tagish Highlands include most of the map area. They are an incised upland plateau punctuated by groups of rugged peaks like Teepee Peak and Engineer Mountain. Although mountainous and glaciated, the highlands are generally easily traveled on foot. The amount of glacier cover and the topographic relief decrease to the east toward the Teslin Plateau in the most northeastern part of the map area.

Peaks rise up to 2300 metres elevation in both the Tagish Highlands and the Boundary Ranges. Upland plateaus are thoroughly dissected by erosion and alpine glaciation. In the Tagish Highlands small glaciers flanking the highest peaks are remnants of a once extensive ice sheet. Coastal weather patterns and higher precipitation maintain more extensive glaciers in the Boundary Ranges.

Valley bottoms are commonly occupied by major lakes with water levels around 700 metres. Collectively they are an enormous headwater reservoir for the Yukon River. These lakes form a north-south and east-west interconnected network that probably mimics the path of ancient ice movement, but is oblique to the geologic grain of the area.

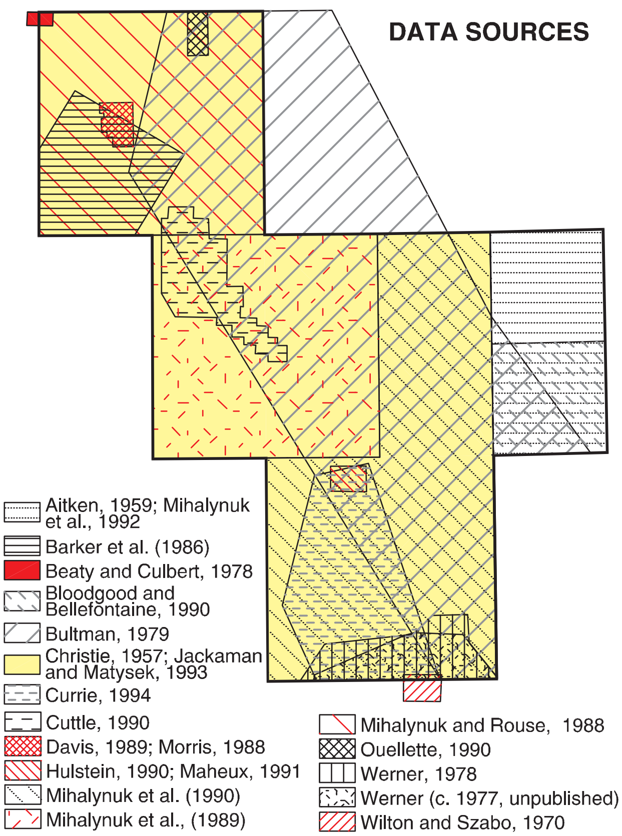


Figure 1-2. Sources of map information used in this Bulletin.

Treeline elevation varies between 1100 and 1400 metres. Lower slopes are timbered by lodgepole pine, spruce, aspen, balsam poplar, black cottonwood and sparse hemlock. Mountain (slide) alder, willows and, on wettest slopes, devil's club and Labrador tea comprise the forest ground cover. Near treeline, subalpine fir, juniper and dwarf birch (buckbrush) take over. In the forested areas, mature pine growth is the most easily traversed. Although vegetation is generally moderate, creek beds and clear avalanche paths provide the easiest routes to reach alpine areas.

Early Exploration and Previous Geological Work

Michael Byrnes carried out the earliest recorded exploration in the Tagish Lake area. He is thought to have reached Tagish lake in 1867 (Dawson, 1889) on behalf of the ill-fated Collins Overland Telegraph scheme[1]. In 1892, N.B. Garveau and party were sent by the Government of British Columbia to conduct a survey of the area between the Tahltan River and the 60th Parallel and return by the Chilkoot and White passes. Due to bad weather, the survey reached only as far as Atlin Lake (Gauvreau, 1893), but the party probably traversed part of the Tagish area on their return.

Discovery of rich goldfields in the Klondike in 1896 caused a great influx of gold-seekers that peaked in 1897 and 1898 (Young and Brock, 1909). Thousands of veteran to neophyte prospectors scoured the Bennett Lake valley en route to the Klondike. In July of 1898 the first claims were staked in the Atlin placer camp, and by the end of the year approximately 3000 people had made their way to Atlin; most of them via waterways of the Tagish area. This great passage of people, about 30 000 a year traveling to the Yukon, spurred the search for a railroad route from tidewater across the Coast Mountains. In 1900, engineers surveying a "southern" route discovered gold-bearing quartz veins on the east shore of southern Tagish Lake; this soon became the Engineer mine. In the years that followed, several gold prospects were developed to a considerable degree, but the Engineer mine, with a recorded yield of over 560 000 grams of gold, remains the only significant producer in the immediate Tagish area. However, in the Yukon, just a few kilometres outside the study area, the Venus mine which has been worked intermittently since the early 1900s, produced from polymetallic veins and still contains almost 140 000 tons of proven and probable reserves grading 13.85 grams

1 *Bilsland (1953) believes it unlikely that Michael Byrnes traveled much farther than Fort Fraser in 1866. Furthermore, Thomas Elwyn was placed in charge of northern exploration in late 1866, just prior to the end of the Collins Overland Telegraph scheme in 1867.*

per tonne gold and 263 grams per tonne silver (Stubens, 1988).

Despite a favourable geologic setting, relatively little mineral exploration activity took place in the area between 1925 and 1987. To date mineralization discovered throughout the region continues to be mainly veins carrying arsenic, antimony and gold, and in some instances, base metal sulphides (and tellurides) as the primary constituents.

Earliest systematic geologic surveys date back to Cairns's (1912, 1913) work for the Geological Survey of Canada. In 1910 he mapped gross lithologic packages adjacent to Tagish Lake south of the 60th Parallel (Figure 1-1). Christie (1957) conducted the first comprehensive quadrangle geological mapping at 1:250 000 scale (Figure 1-2). His map has proved a strong platform for more detailed study. Werner (1977, 1978) mapped the southernmost part of the area, but a completed geological map was never published. A doctoral study by Bultman (1979) included geological mapping at 1:100 000 scale. He also presented an extensive report on the geology and tectonic history of the Whitehorse Trough, which is central to the Tagish area, but neither his map, nor his major findings were ever published. Recent property-scale mapping included in assessment reports by numerous mineral exploration companies contribute details of local lithology and economic mineral distribution.

Our work includes three full and two partial field seasons of 1:25 000-scale geological mapping that is compiled at 1:50 000 (Mihalynuk and Rouse, 1988b; Mihalynuk *et al*. 1989b, 1990, 1992b) and presented here in Figure GM97-1 at 1:100 000-scale, covering four 1:50 000 quadrangles (in pocket). Regional-style stream sediment and moss-mat sampling programs were conducted in conjunction with the mapping. Prior to this study no regional geochemical data were available for the 104M map area.

Geological Hazards: Volcanism and Landslides

Pleistocene and younger basaltic flows and cinder cones occur south and east of the town of Atlin. According to one unsubstantiated rumour, at least one eruption occurred in historic times within sight of the town of Atlin, when near the turn of the century placer miners were said to have worked at night by the glow cast from the eruption. More recent geological investigations have been unable to confirm this report and it seems unlikely that an effusive volcanic eruption would have cast such light. A lack of evidence for such young volcanic deposits within the map area, and the very sparse population of northwestern British Columbia in general, mitigates any significant hazards.

Two landslides debris deposits with aerial extents in excess of 500 m^2 occur on the flanks of mountains within 10km east and north of Edgar Lake. The largest of these covers about 1.5 km^2 and is comprised of blocks of Laberge Group siltstone and wacke. Bedding orientation is nearly orthogonal to the failure surface which is parallel to both the predominant jointing and the orientation of the failed mountain flank. Similar geological conditions exist on the southeast flank of Mt. Racine and west of southern Tutshi Lake where slope failures could result in blockage of the Klondike Highway. A lack of any permanent human habitation in these areas diminishes the hazards posed by such landslides.

Acknowledgments

This work has benefited from the able assistance of many geologists; each having added their individual colour. Ordered by project year, they are: Jonathan Rouse, Duncan Moore and Peter Friz in 1987; Lisel Currie, Keith Mountjoy and Carol Wallace in 1988; Keith Mountjoy, Neil Winder and Derek Lofthouse in 1989; Keith Mountjoy, Bill McMillan, Chris Ash, and Jan Hammack in 1990; and Moira Smith, Jeff Nazarchuk and Rob Dutchak in 1991.

Thanks go to many individuals for their magnanimous exchange of ideas and knowledge. Foremost in this list is Craig Hart (Yukon Geoscience Office), working on the "other side" of the BC-Yukon border, for an unimpeded exchange of intuitions and data. Jay Jackson (Exxon) and Lisel Currie (Carleton University, now GSC) furnished critical discussions on their areas of expertise. David Brew (US Geological Survey) has for many years been a source of inspiration and sage counsel. Colleagues Derek A. Brown, Larry J. Diakow, Filippo Ferri, James M. Logan, JoAnne L. Nelson and Vittorio A. Preto shared their experience in various Paleozoic and Mesozoic arc terranes. Moira T. Smith (Teck Corp.) and Janet Gabites (UBC) attempted to educate me on the nuances of U-Pb isotope systematics. Chris H. Ash, Graham T. Nixon and Nicholas W.D. Massey (all BCGS) helped to direct my plunge into the world of geochemical discrimination, crustal growth and ophiolites, and ultramafic oddities. Howard Tipper, Fabrice Cordey and Mike Orchard (all GSC) provided the timely fossil identifications that are so critical to establishing an age framework for the study area. Many other geoscientists contributed to our understanding of the area including John O. Wheeler, James W.H. Monger (both GSC emeritus) and James K. Mortensen (UBC).

The Tagish Project map area overlaps to a large degree the area studied by Tom Bultman for his doctorate degree. Our work has benefited from excellent, unpublished observations recorded in his thesis, which is constantly referenced in the pages that follow. We acknowledge his impressive contribution to our understanding of the geology of the area.

Cooperation with industry is essential to the success of our field programs. Numerous geologists under the auspices of their employers were courteous hosts who helped us to understand the connection between geology and mineralization within the map area. Most have now changed employers, but these individuals, and their employers at the time were: Hans Smit of Total Energold Corporation, Hugh Copeland of Noranda Exploration Company, Limited, Jim Cuttles of Earth Search Exploration Limited and Chris Marriott of Suntak Minerals Corporation.

Northern hospitality is legendary. In our experiences this legend is alive and well through the kindness of Norm Graham and Haley Holzer, Jim and Marion Brook, Keith Lumsden and a host of Atliners.

This paper has benefited significantly from the comments of Bill (W.) J. McMillan and, in selected sections, Craig J.R. Hart. Careful editorial review by John M. Newell helped to significantly clarify the manuscript. Verna Vilkos spent many hours painstakingly revising multiple versions of the digital figures and was instrumental in bringing the electronic document to life.

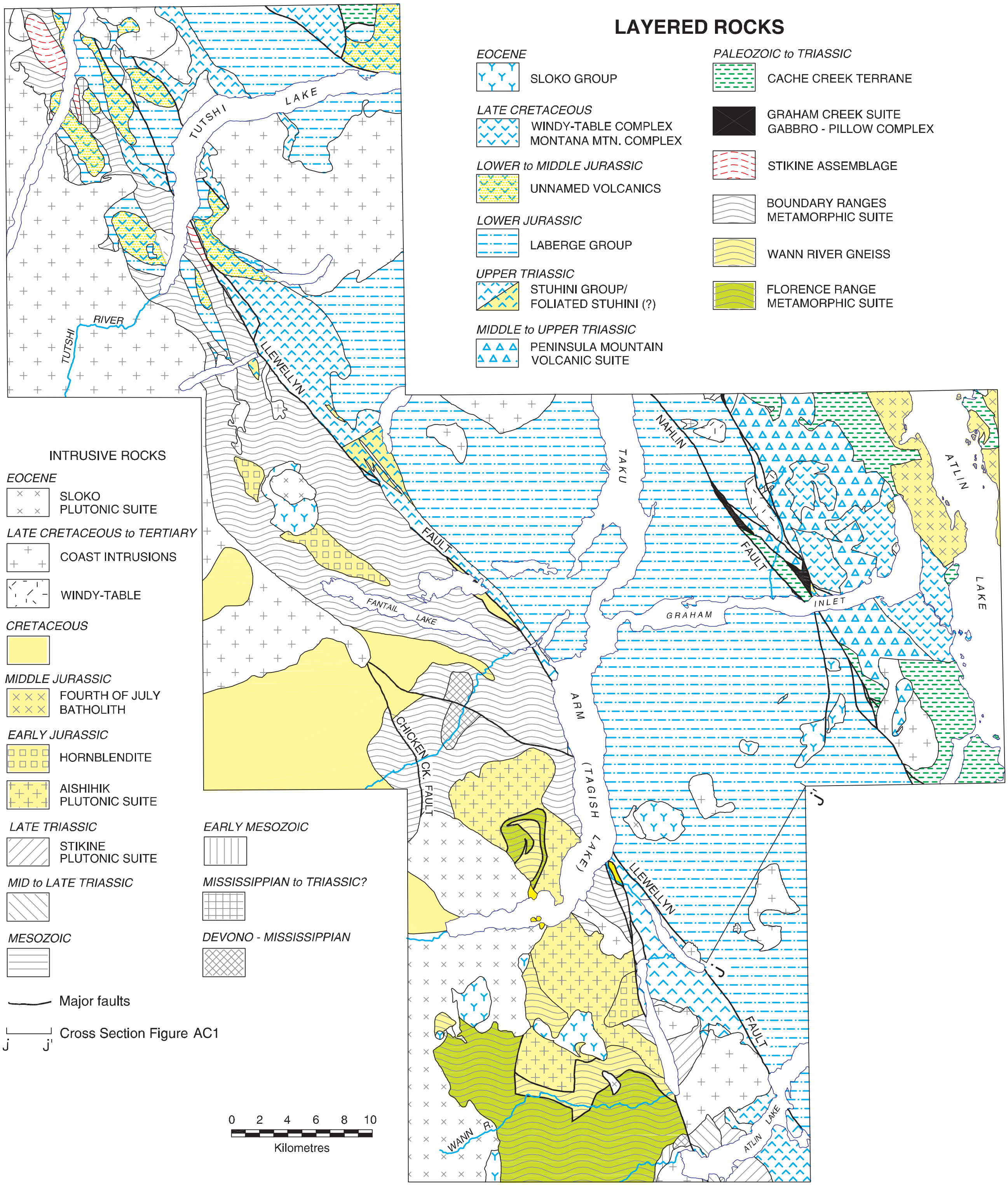


Figure 2-1. Generalized Geology

Along most of British Columbia's length plutonic rocks of the northwest-trending Coast Belt intrude mainly volcanic and sedimentary rocks of the Intermontane Belt (Figure 1-1). First-order geological characteristics of the study area reflect its location at the contact between these two belts. The Coast Belt is the result of mainly Late Cretaceous and Tertiary magmatism, whereas the Intermontane Belt at this latitude is composed of predominantly Mesozoic arc volcanic and arc-derived sedimentary rocks.

Second-order geological characteristics (Figure 2-1) are developed through tectonostratigraphic terrane and assemblage interactions. According to Wheeler *et al*. (1991) the architecture of the area is a product of Late Triassic to Early Jurassic amalgamation of the following terranes (from east to west): mainly Paleozoic and lesser early Mesozoic oceanic crustal and supracrustal rocks of the Cache Creek Terrane; early Mesozoic arc volcanic and related sedimentary rocks of the Stuhini Group, at this latitude representing Stikine Terrane; and possibly (?) Late Proterozoic to Paleozoic metamorphosed epicontinental rocks of the Nisling Terrane. These terranes are overlapped by Lower to Middle Jurassic basinal turbidites of the Laberge Group that form part of the Inklin overlap assemblage. Laberge strata are succeeded by late Mesozoic and Tertiary mainly felsic volcanic strata of the Windy-Table and Montana Mountain complexes and the Sloko Group. Intrusive roots to the several volcanic episodes postdating Laberge deposition include the granitoids of the Whitehorse Trough and Coast Belt.

Geological data presented in this paper indicate a slight departure from the above terrane interpretation for the region. Current data indicate that both the Laberge Group **and** the Stuhini Group strata (which at this latitude represent Stikine Terrane) together constitute an overlap assemblage which is herein termed the Whitehorse Trough overlap assemblage. Furthermore, the nature of the Nisling rocks is in question; it is not certain that they really constitute a separate terrane. Until terrane characteristics are established for the Nisling rocks, it would probably be better to refer to them as the Nisling **assemblage** as in Mihalynuk *et al.* (1989a). However, to maintain consistency with widespread current usage and for other reasons as outlined in the next chapter they are here referred to collectively as the Yukon-Tanana Terrane.

Two major subparallel, north-northwest-trending faults are grossly coincident with the boundaries between the Cache Creek and Whitehorse Trough and between the Whitehorse Trough and the Yukon-Tanana Terrane. The Nahlin fault, which more or less marks the western extent of the Cache Creek Terrane, is a steeply dipping to vertical fault (or series of faults). These have been intermittently active, probably since the Late Triassic into the Tertiary. The major Llewellyn fault trace forms the contact between regionally metamorphosed rocks, including the Nisling assemblage, and Mesozoic strata of the Stuhini Group within the map area. Like the Nahlin fault, several lines of evidence indicate that the Llewellyn fault was sporadically active over the Late Triassic into the Tertiary, with displacements greatest during the earlier episodes (see Chapter 13).

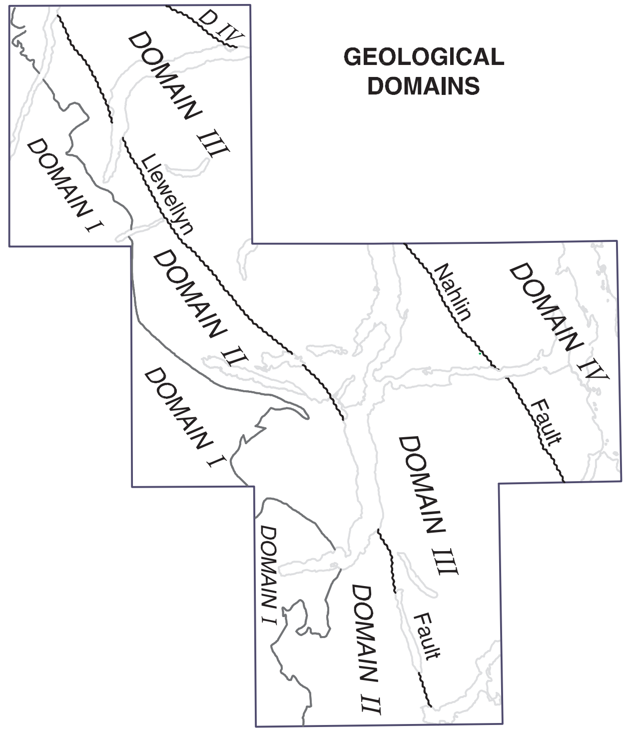


Figure 2-2. Geologic domains

Several geologic environments with high mineral potential occur within the map area. Shear-related gold-bearing quartz veins are hosted by the Llewellyn fault zone or by kinematically linked structures. Listwanitized ultramafic rocks with lode gold potential crop out on the western margin of the Atlin placer gold camp within the Cache Creek Terrane. Volcanogenic massive sulphide deposits are known to be hosted by subalkaline submarine volcanic rocks of the Upper Triassic Stuhini Group outside the map area (*e.g.* the Rock and Roll prospect) and coeval intrusive bodies elsewhere are known hosts to low-grade large-tonnage porphyry copper-gold systems. Sedex potential in metamorphic rocks of probable Yukon-Tanana Terrane is indicated by local massive sulphide occurrences (*e.g.* Jason prospect). Widespread Cretaceous and Tertiary volcanism may have related epithermal-style mineralization, but no significant showings of this type have been discovered to date. Gold-bearing quartz veins related to these volcanic and intrusive systems, such as those at the Engineer mine, display characteristics transitional between epithermal and mesothermal deposit types. Auriferous polymetallic veins, such as at the Crine showing, probably formed in a mesothermal environment. Polymetallic vein occurrences account for over half of the mineral showings in the map area. Potential for other deposit types may become more apparent as new deposit models are developed.

Chapter 3 Layered Metamorphic Rocks

Distribution and General Geology

Thermal metamorphism in the contact aureoles of intrusions is common throughout the study area, but layered, regionally metamorphosed rocks are restricted to a southward-broadening belt 2 to 17 kilometres wide along its western margin(Figure 3-1). Rocks of this belt record a range of metamorphic conditions from lower greenschist facies through middle amphibolite facies (Figure 3-2). Protoliths are variable, from sediments of continental margin affiliation to probable basalts and tuffs. They record a long deformational history. At least four phases of deformation can be recognized locally (see Chapter 13). Granitic through tonalitic intrusions emplaced at various times during the deformational history have been deformed to a lesser degree. In general, the degree of deformation of intrusive rocks is less in younger bodies.

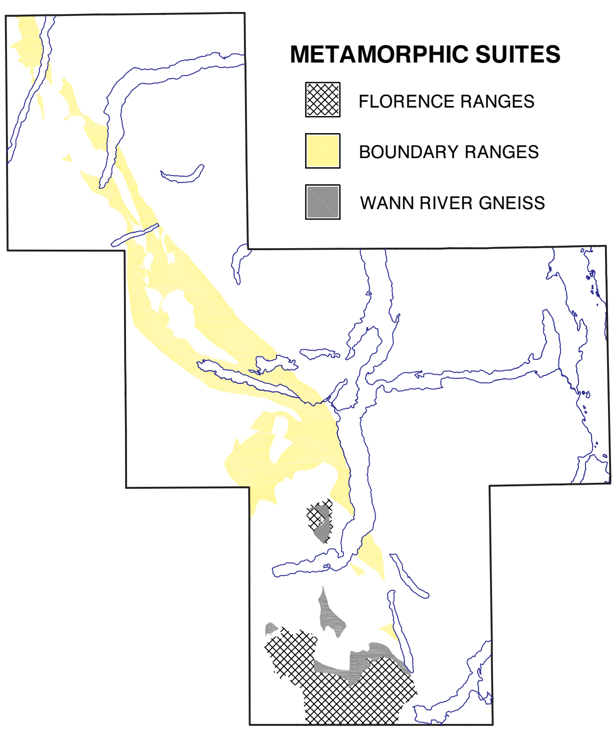


Figure 3-1. Distribution of regionally metamorphosed rocks in the Tagish area.

The belt of metamorphic rocks continues as far south as the Tulsequah area (Souther, 1971; Nelson and Payne, 1984; Mihalynuk *et al.,* 1996).It is extensively ice - covered and intruded by late Mesozoic and Tertiary granitoid bodies (Brew and Morrell, 1983; Brew, 1988) of the Coast Belt. As a result, its extent is poorly known. The distinctive evolved Neodymium isotopic signature of some metapelitic rocks found within the study area (Jackson *et al.*, 1991) is like that recognized west of the Coast Belt in the Prince Rupert area (Samson *et al.*, 1989) suggesting that these rocks are part of a belt that persists across the Coast Belt. Supporting U-Pb isotopic data indicate that the belt may extend the entire length of the western margin of the Canadian Cordillera (Gehrels *et al.,* 1990a,b,c).

In south and western Yukon, related metamorphic rocks are extensive, but less well exposed. They underlie more than a third of the area between the Denali and Tintina faults. Their southwestern limit lies just north of the study area, where they are extensively intruded and surrounded by Mesozoic and Tertiary plutons (Hart and Radloff, 1990). Farther northwest, they underlie much of the Aishihik Lake (Tempelman-Kluit, 1974; Johnston, 1988) and the Snag map areas (Tempelman-Kluit, 1974). Their southeastern extent is near Teslin, where they were mapped as the Big Salmon Complex by Mulligan (1963). To the northwest they extend to the Yukon Plateau in the Dawson area (Green, 1972), and the Tanana Uplands in eastern Alaska (Mertie, 1937). East of the Tintina fault, related metamorphic rocks occur as an allochthonous sheet atop autochthonous North American strata (Tempelman-Kluit, 1976) or perhaps are juxtaposed with North America at a transpressive suture (Mortensen and Jilson, 1985). Most of these metamorphic rocks can be included in the Yukon-Tanana Terrane (Coney *et al.*, 1980) as recommended by Mortensen (1992). Little consensus exists on nomenclature of Yukon-Tanana rocks: a problem that is accentuated by an array of recent studies (*e.g.* Mortensen, 1992; Erdmer, 1990; Currie, 1990, 1991; and others). The view of Yukon-Tanana rocks within the study area is most consistent with that of Mortensen (1992). Except for local naming conventions, his recommended terminology is followed here. Contemporary nomenclature and its derivation are briefly summarized below; a more thorough review is presented by Mortensen.

History of previous work and nomenclature

Cairnes (1913) conducted the earliest comprehensive mapping in the Tagish area which identified the metamorphic rocks. He included them as part of the Mount Stevens Group, first named in the Wheaton district of southern Yukon (Cairnes, 1912). They were thought to correspond to similarly described rocks in Alaska (Brooks, 1906) and in the Dawson district of west-central Yukon (McConnell, 1901). Christie (1957) mapped metamorphic rocks in the Tagish area as the "Yukon Group"; correlative with rocks in the Dezadeash area (Kindle, 1953) and with those along the Yukon River near the Yukon - Alaska border, where the name originated (Cairnes, 1914).

Most of the metamorphic rocks in southern Yukon came to be known as the Yukon Group, irrespective of their known or implied age. In many instances, as Tempelman-Kluit (1976) pointed out in a review of early literature, the useage of "Yukon Group" was clearly inappropriate, and he instead created the name "Yukon crystalline terrane". Recognizing that a large portion of the terrane is mylonitic, Tempelman-Kluit later (1979) refered to it as the Yukon cataclastic complex. In adjacent parts of Alaska, this package of rocks underlies the Yukon-Tanana Uplands and hence is termed the "Yukon-Tanana Terrane" (YTT, Coney *et al.,* 1980). A southwestern prong of metamorphic rocks of unknown age not included in the Yukon-Tanana Terrane was called the Tracy Arm Terrane by Coney *et al*. (1980).

Researchers in the 1980s built upon the ideas of Tempelman-Kluit (1976, 1979) and Coney *et al.* (1980) and subdivided the Yukon-Tanana Terrane into several pericratonic terranes. The most substantial works in this regard are those of Wheeler and McFeeley (1991) and Wheeler *et al.* (1991); they defined the Nisling, Nisutlin (a subterrane of the Kootenay), and Pelly Gneiss terranes and discontinued use of Yukon-Tanana Terrane. Southern Nisling Terrane included much of what was previously considered the Tracy Arm Terrane and most of northern Nisling was previously considered Yukon-Tanana Terrane within the Yukon.

Hansen (1990) attempted yet another subdivision of the Yukon-Tanana rocks, dividing them into the Nisling and Teslin-Taylor Mountain terranes. Under this scheme the Nisling Terrane comprises mainly Devonian to Mississippian Pelly orthogneisses, but also includes Nisling Terrane rocks of Wheeler *et al.* (1991). The Teslin-Taylor Mountain Terrane is almost spatially co-extensive with the Nisutlin Terrane of Wheeler and others. This subdivision is based primarily upon cooling ages and poorly constrained apparent structural positions, however, neither of these criteria are terrane specific. Thus, Hansen's subdivisions are not adopted here. Instead, lithology and protolith age are utilized, which form the basis of the nomenclature of Wheeler *et al.* (1991).

Mortensen (1992) recognizes the pre-Devonian Nisling Terrane, which is potentially basement to the Yukon-Tanana Terrane, as a subset of that outlined by Wheeler *et al.*, (1991); it is essentially equivalent to the former Tracy Arm Terrane (Coney *et al.*, 1980). Under Mortensen's scheme, most of the other metamorphic rocks of Tempelman Kluit's cataclastic complex are part of the Yukon-Tanana Terrane: their similarities outweigh their differences. Fragments of the oceanic Slide Mountain[1] terrane are admixed with the Yukon-Tanana rocks (Mortensen and Jilson, 1985; Hansen, 1990) and might also be considered part of the composite terrane, but this point of view has not been widely adopted.

In the Tagish area, rocks included within the Nisling Terrane by both Wheeler and McFeely and Mortensen comprise several distinct lithologic packages (*e.g.* Currie, 1990) and collectively may be more correctly thought of as a metamorphic "assemblage". For this reason Mihalynuk *et al.* (1989a) and Mihalynuk and Mountjoy (1990) used Nisling "assemblage" to collectively refer to the two major metamorphic suites in the Tagish area (Boundary Ranges and Florence Ranges metamorphic suites). However, Hart and Radloff (1990) also use the

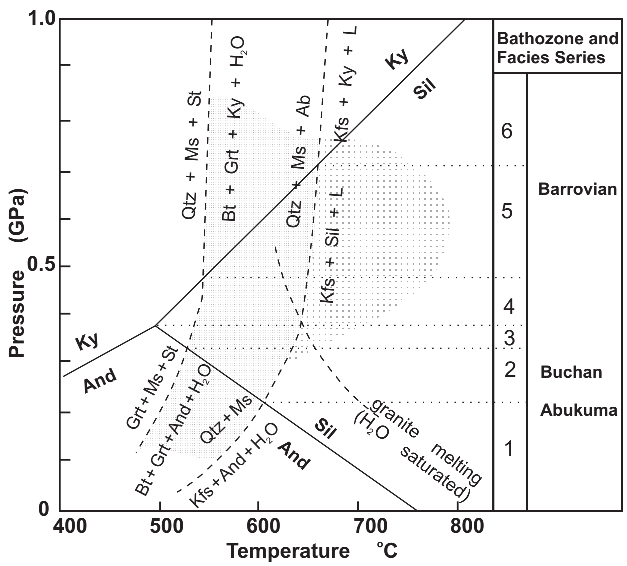


Figure 3-2. Pressure-temperature plot showing key prograde metamorphic reactions in pelites and bathozones of Carmichael (1978), and the facies series of Miyashiro (1973). Shown in the light and dark shaded patterns are the broad peak PT range experienced by much of the Boundary Range and Florence Range metamorphic suites respectively as determined from petrographic analyses.

1 *Originally considered a highly allochthonous terrane (e.g. Harms, 1986), the Slide Mountain Terrane is now recognized to have loose stratigraphic linkages to North America (Ferri, 1997).*

name "Nisling assemblage" to refer to a specific component of the "Nisling Terrane" which they correlate with the "biotite schist" of Tempelman-Kluit (1976) who loosely correlated it with the Windermere Supergroup.[2] The "biotite schist" unit also correlates with the "lower unit" of the Yukon-Tanana Terrane of Mortensen (1992). Thus, use of the term Nisling assemblage in the context of Hart and Radloff (1990) is more regionally applicable and is adopted here. As used here, Nisling assemblage would include the Florence Range suite, a named used by Currie (1990) for quartz-rich metaclastic rocks of the Tagish area. The term Boundary Ranges metamorphic suite was used by Mihalynuk and Rouse (1988a) to refer to greenschist to amphibolite facies, arc-related metamorphic rocks in the Tagish lake area. Yukon-Tanana Terrane provides a means to collectively refer to all regionally metamorphosed rocks within the Tagish area. Implications of this terrane assignment on relative age and correlations will be discussed below; a selection, but not an exhaustive list of age constraints and correlations is given in Table 3-1.

Recent Geological Studies

In the southern third of the project area, Yukon-Tanana metamorphic rocks have been mapped in detail by Currie (1990, 1991) as a continuation of mapping begun in 1988 under the auspices of this project (Mihalynuk *et al.*, 1989b; Figure GM97-1 inset). Currie (1991) extended mapping south of the Tagish project area to include parts of the Swanson River (NTS 104M/7) and Hoboe Creek (NTS 104M/1) map sheets, previously mapped in part by Werner (1977, 1978 and unpublished). Yukon-Tanana rocks in these southern areas are amphibolite grade, in contrast to mainly greenschist grade (Figure 3-2) rocks to the north. Low grade rocks to the north are known as the Boundary Ranges Metamorphic Suite (DTB; Mihalynuk and Rouse, 1988a). This metamorphic suite can be subdivided into several lithologic packages, but the distribution of separate lithologies is erratic and unpredictable. Part of this erratic distribution arises from multiple phases of deformation, particularly non-coaxial folding (see under "Structure, Chapter 13"); and part can be attributed to vertical tectonics related to the nearby Llewellyn fault. Still further complications arise from overprinting of different, but indistinct, low grade metamorphic events. In contrast, amphibolite grade rocks contain distinct, mappable units including: metasediments of the Florence Range Metamorphic Suite (Currie, 1990, 1991), Mount Lawson Metamorphic Suite (Currie, 1991), and probable metavolcanics of the Mount Lawson gneiss, Chicken Creek gneiss (both named by Currie, 1991) and Wann River gneiss (Currie, 1990). Metaintrusives in the southern region include the Bighorn Creek orthogneiss (Currie, 1991), Hale Mountain intrusive (Mihalynuk *et al.*, 1989a,b; 1990b) and Mount Caplice granite.

Map extents of the Mount Lawson Metamorphic Suite, Mount Lawson gneiss and Chicken Creek gneiss shown by Currie (1991) disagree with field observations recorded in 1989 (Mihalynuk *et al.*, 1990), and only the Mount Lawson gneiss is retained by Currie (1994) who calls it the "Mount Lawson orthogneiss" (she also renamed the Mount Lawson gneiss (Currie, 1991) as "orthogneiss"). As a result, none of these map units and contact relations are included in Figure GM97-1. With more work, map differences will be resolved and these units may prove to be important. Thus, they are described below.

Mount Lawson Metamorphic Suite

In southeastern Fantail Lake area (104M/9W), the Mount Lawson Metamorphic Suite comprises the structurally lowest rocks mapped by Currie (*in* Mihalynuk *et al.,* 1989a,b; Currie, 1990, 1991). Minor marble and a minimum of 300 metres of muscovite, biotite and garnet-biotite schists comprise the metasedimentary portion of the suite. At least two phases of deformation can be recognized in the field and they exhibit a gently plunging top-to-the-south sense of shear.

Structurally above the schist is a unit called the Mount Lawson gneiss by Currie (1991). It is a fine-grained muscovite-quartz-feldspar gneiss forming a band at least 400 metres thick. Currie suggested that its protoliths are felsic tuffs or flows.

Currie's (1991) lithologic descriptions of the Mount Lawson Metamorphic Suite are almost indistinguishable from those of the biotite schist unit of the Boundary Ranges suite (unit DTBb; Mihalynuk *et al.,* 1989a,b). The only difference is that the latter locally contains minor chlorite-actinolite interlayers. Unit DTBb forms a continuous belt along the western margin of the Boundary Ranges suite that extends to the northeast for some 20 kilometres. It is interlayered, particularly in the south, with muscovite-rich schists. This association brings into question the uniqueness of the Mount Lawson Metamorphic Suite, and whether it is actually part of the Boundary Ranges Metamorphic Suite, or whether there exists a gradational contact between the two. Recognizing this, Currie (1994) reassigned the Mount Lawson Metamorphic Suite to the "undivided Boundary Ranges suite". On

2 *Many of the recent isotopic studies in northern British Columbia, Yukon and eastern Alaska have focused on testing Tempelman-Kluit's (1976) correlation between the biotite schist unit of the YTT (his Yukon Crystalline Terrane) and continental terrace sediments of the Windermere Supergroup. Because pre-Cambrian rift-related stratigraphy hosts several world-class sedex deposits, most notably the Sullivan deposit (mid-Proterozoic), this correlation is highly significant from a mineral exploration perspective.*

Table 3-1. Correlations and contact relationships of metamorphic rocks in northwestern British Columbia and adjacent areas

AUTHOR (Locality)	PREVIOUSLY OBSERVED CONTACT RELATIONSHIPS	AGE	CORRELATIONS
Christie, 1957 (Bennett, 104M)	contacts with other layered rocks not seen	pre-Permian, in part Mesozoic? and Precambrian	Yukon Group (in part Mesozoic volcanics?)
Aitken, 1959 (Atlin, 104N)	clasts deposited in overlying 'Pen ± Perm' conglomerate (later found to be Upper Triassic) contact not seen	pre-Permian based on stratigraphic evidence	Yukon Group (lithologic similarity with Whitehorse and Bennett areas)
Wheeler, 1961 (Whitehorse, 105D)	deformed orthogneiss E Jurassic or older.	possibly Precambrian in part, contains late Paleozoic	Yukon Group
Wasserburg *et al.*, 1963, (Birch Ck. schist, E Alaska)		1170 Ma Rb-Sr model age	
Souther, 1971 (Tulsequah,104K)	contact not seen; elsewhere may be gradational? with 'Triassic and older' strata	Permo-Carboniferous? appears to grade into these sediments	Yukon Group (in part), and ?Permo-Carboniferous chert-carbonate succession
Green, 1972 (Dawson, 106A, 116A, B, C)		Paleozoic based on macrofossils	
Gilbert & Redman, 1977 (E Alaska)		Middle to Late Devonian macrofossils	Nasina assemblage garnet-muscovite-graphite schists and graphitic quartzite
Werner 1977, 1978 and unpublished (mainly 104M/1)	??	Approx. 1150Ma model age from Rb-Sr isochron = protolith age	
Bultman, 1979 (Bennett and Atlin, 104M and 104N)	metamorphic clasts in Upper Triassic conglomerate; contact not seen, assumed a faulted unconformity	Older than cross-cutting 215±5Ma porphyritic granodiorite (K-Ar Hb) and Stuhini dikes	
Aleinikoff *et al.,* 1981 (E Alaska??)		Mississippian U-Pb, Sm-Nd intrusive - metamorphic age, Proterozoic contamination	
Watson *et. al.,* 1981 (Primrose Lk, 105D)		Whole rock Rb-Sr isochron yielding 1200 Ma model age	
Armstrong *et al*. 1986, (NWBC to WAK compilation)		Late Proterozoic, less than 770 Ma	
Aleinikoff *et al*. 1987, (E Alaska: Yukon-Tanana Upland)		U-Pb &Sm-Nd data indicate Early Proterozoic age	
Doherty & Hart, 1988 (S Yukon, 105D)		Deformed in Paleozoic or pre-Upper Triassic time	Yukon crystalline terrane, "biotite schist" division of Tempelman-Kluit 1976
Hart & Radloff, 1990 (S Yukon, 105D)	Nisling and Nasina assemblages cut by early Mesozoic and younger intrusives	pre-Late Triassic (220 Ma cross-cutting intrusive) In part Paleozoic based on crinoid calyx from marbles	Nisling assemblage equivalent to "lower biotite schist" division of Tempelman-Kluit, 1976

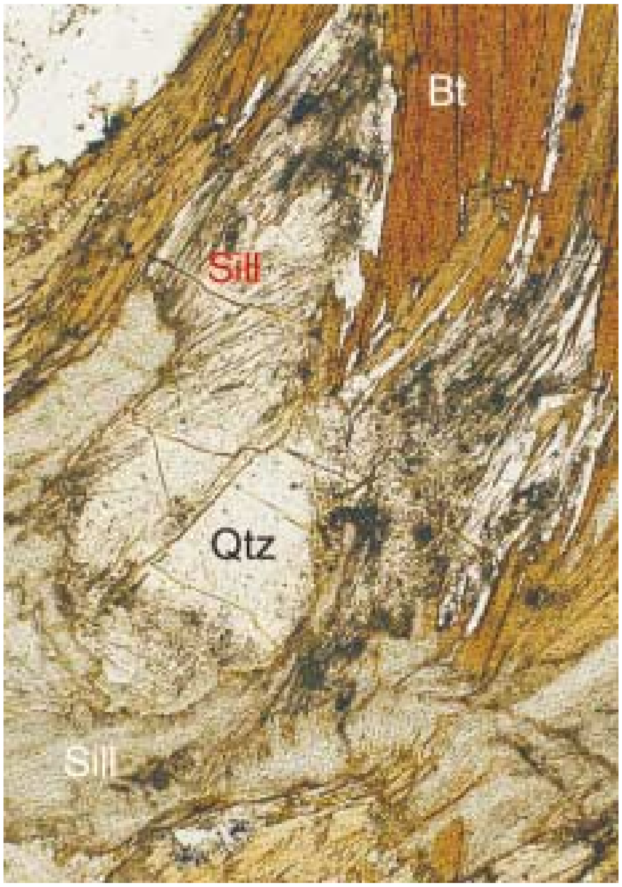


Photo 3-1. Photomicrograph of metapelite near Willison Creek shows quartz (Qtz) and biotite (Bt) replaced by abundant fibrolite (Sil). Long dimension of photograph represents 1.8 millimetres.

Figure GM97-1, Currie's Mount Lawson suite is shown as chlorite-actinolite, chlorite-biotite and undivided schists and gneisses of the Boundary Ranges suite.

Chicken Creek Gneiss

An area of a few square kilometres on the west side of Chicken Creek in the southeastern Warm Creek and northwestern Edgar Lake map sheets was mapped by Mihalynuk *et al.* (1989b, 1990) as impure metaquartzite and biotite schist. This area was mapped in more detail by Currie (1991) who used the term Chicken Creek gneiss to describe fine-grained muscovite-quartz-feldspar gneiss of this package. It shares many similarities with the Mount Lawson gneiss except that, unlike the Mount Lawson gneiss, it is juxtaposed against much different lithologies, including hornblende-plagioclase gneisses that are probably correlative with the Wann River gneiss.

The Chicken Creek gneiss unit was abandoned by Currie (1994) who includes it with undivided Boundary Ranges suite. It is likewise designated on Figure GM97-1.

Boundary Ranges Metamorphic Suite (DTB)

Mihalynuk and Rouse (1988a) termed low grade metamorphic rocks in the Tutshi Lake area, which were previously assigned to the wide ranging Yukon Group (Christie, 1957), the "Boundary Ranges metamorphic suite" because they mainly underlie the Boundary Ranges. Wheeler and McFeely (1991) include these rocks in the Nisling Terrane. The name "Boundary Ranges Metamorphic Suite" is retained here. It is considered part of the Yukon-Tanana Terrane in the sense of Mortensen (1992; see "History of Previous Work and Nomenclature" preceding).

Boundary Ranges metamorphic rocks form a belt of polydeformed rocks (Domain II, Figure 2-2) bounded on the east by the Llewellyn fault and on the west by mainly intrusive rocks of the Coast Belt. Locally preserved relict textures display a wide range of protoliths from quartzose to pelitic or carbonaceous and calcareous sediments through volcanic tuffs or flows to small lenses to large bodies up to several kilometres across of gabbroic, dioritic, granodioritic and granitic intrusives and ultramafite. This lithologic diversity is similar to that described by Wheeler (1961) in the Whitehorse map area, suggesting a correlation with the metamorphic rocks there. Original thicknesses are exceedingly difficult to estimate due to the high degree of deformation, and particularly, non-coaxial folding and interstratal slip. These same factors make it very difficult to trace specific layers more than a few hundred metres in outcrop.

Doherty and Hart (1988) mapped quartz mica schists just north of the British Columbia - Yukon border which they correlated with the biotite schist unit of Tempelman-Kluit (1976). The only significant difference between metamorphic rocks north and south of the border seems to be an increase in metavolcanics to the south, although these do not appear to persist as far south as the Edgar Lake map area (104M/8; Werner, 1977, 1978). In the Edgar Lake area metamorphic rocks again display characteristics identical to those described for the biotite schist unit. These are the metapelitic rocks of the Florence Range Metamorphic Suite (see below).

Age limits for the Boundary Ranges metamorphic suite in the Tagish area are constrained primarily by data from Currie (1994) who determined U-Pb ages for metamorphosed volcanics of the Wann River Gneiss and the deformed Bighorn Creek granite. Both are components of the Boundary Ranges suite and their reported ages are 270 ±5Ma and 366 ±9 Ma respectively. Similar magmatic ages are known from the Stikine Assemblage of the Stikine Terrane lending support to speculations by Mortensen (1992) about correlations between yukon-Tanana Terrane arc rocks and those of the Stikine Assemblage. If Boundary Ranges metamorphic suite rocks are correlative with Stikine Assemblage, then protolith ages can be expected to range from Devonian to Triassic.

Biotite-Plagioclase-Quartz Schist (DTBb)

Biotite schists form a belt along the western edge of the metamorphic belt. Although biotite is commonly the most conspicuous mineral in outcrop, the proportion of minerals is normally quartz > plagioclase > biotite, but nearly pure biotite layers up to 10 centimetres thick are common. Locally these schists contain sparse garnet porphyroblasts, most are 1 to 3 millimetres in diameter, but rare crystals are up to several centimetres. Muscovite and actinolite are normally subordinate phases, but both can be found in amounts subequal to biotite in isolated layers. Biotite schists generally display a strong foliation which is disrupted by minor folds. They form compact, low outcrops that weather rusty, dark grey.

Impure Metaquartzite (included in DTBb)

These rocks are similar in many respects to the biotite schists. However, they typically contain less than 10% biotite and less than 20% feldspars. These compositional differences are mappable in the field.

Marble (DTBm)

Resistant, yellow, orange and tan-weathering, medium-grained marble layers up to 200 metres thick are the best marker units within the metamorphic package. Locally the marble is well banded with grey graphite-bearing, green chlorite-bearing or orange iron oxide stained septa. Spectacular tight chevron parasitic folds are outlined by the banding.

Unfortunately, like all other rocks within this polydeformed metamorphic domain, these units are discontinuous on a scale of kilometres or even hundreds of metres. Carbonate units are the most useful lithologies for outlining structures (see Figures GM97-1and 15-1) because their colour and weathering contrasts well with adjacent lithologies.

Graphite muscovite schist (DTBc)

Finely crystalline graphite and muscovite(?) impart a silver-grey sheen to these rocks which generally form rubbly to blocky outcrops depending on the degree of induration. They may grade into actinolite-chlorite schists and commonly contain calcareous interlayers. Quartz, chlorite and feldspar contents vary, but black, graphitic folia are diagnostic (Photo 3-2). Protoliths probably included fetid, silty argillite with calcareous layers.

In the Warm Creek map area these rocks are of particular interest; they host base metal-gold-arsenopyrite veins and tectonic breccia zones at the Crine property. These rocks may have direct equivalents in the Mount Caplice and Tulsequah Glacier map areas (Figure 1-1; unpublished data, Mihalynuk 1991; Smith and Mihalynuk, 1992). Graphitic schists and black, graphitic quartzites within the Florence Range suite are possible facies equivalents. Such rocks are also very similar to the Nasina quartzite in the Yukon (*cf*. Mortensen, 1992), known as the Nasina assemblage just north of the border (Hart and Radloff, 1990).

Muscovite-rich schist (included inDTBc)

Muscovite schists are generally closely associated with the graphite muscovite phyllite unit, but lack carbonaceous partings and rarely enclose carbonate bands. Pure muscovite-quartz-plagioclase schists of significant thickness occur only locally. Generally they contain local interlayers of biotite ± chlorite ± actinolite schist.

Where best developed, the muscovite is coarse and wraps around garnets that are up to 0.75 centimetres in diameter. In isolated occurrences garnet comprises as much as 30% of the schist. Generally it is severely retrograded.

Photo 3-2. Photomicrograph of blackgraphite folia in phyllite of unit DTB_c. Long dimension of photograph represents 4.6 millimetres.

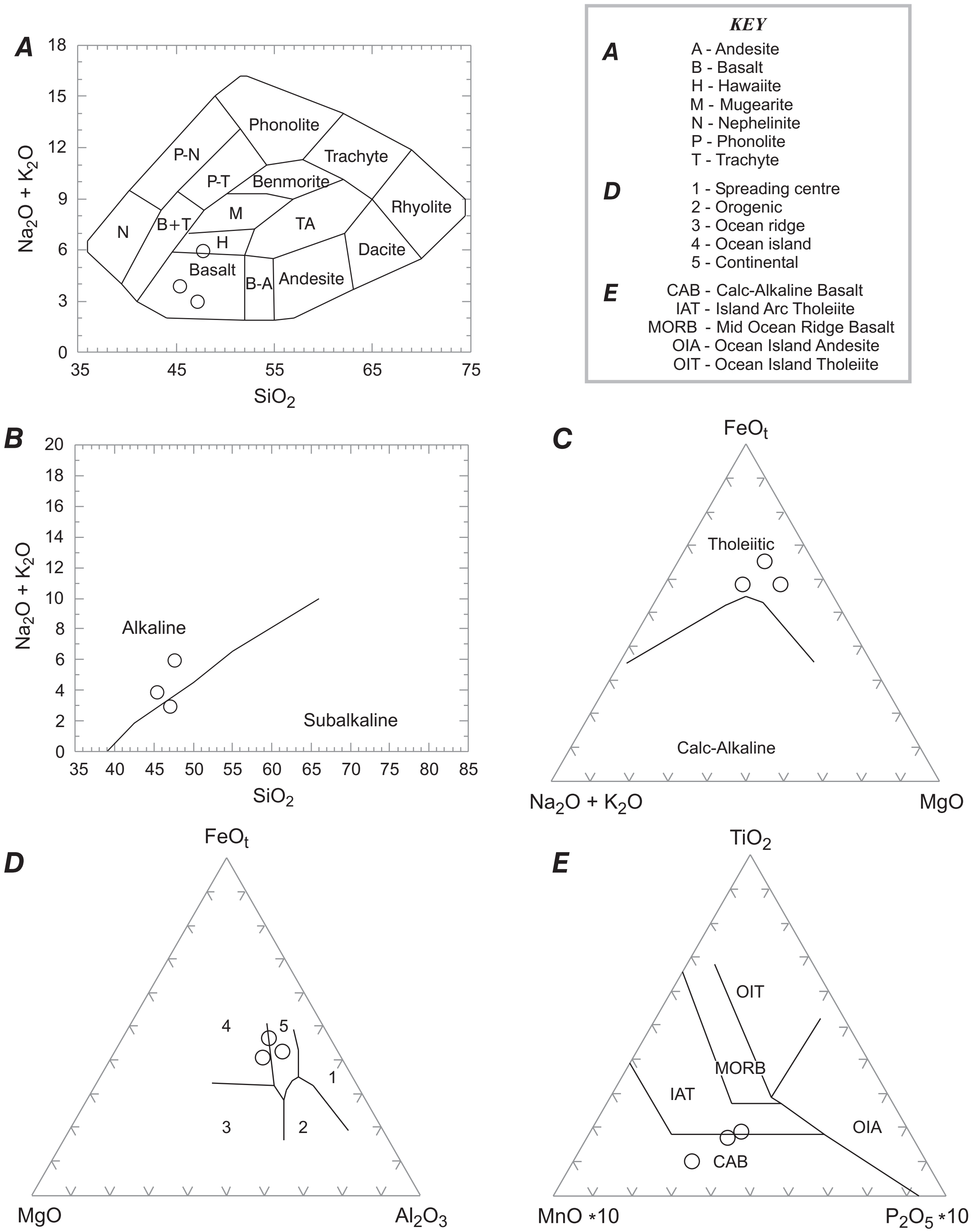


Figure 3-3. Geochemistry of Boundary ranges metamorphic suite mafic schists: (a) alkalis versus silica classification diagram shows that the samples fall within the basalt to hawaiite compositional fields of Cox *et al*. (1979); (b) alkalis-silica diagram shows that two of three samples are alkalic and (c) AFM diagrams of Irvine and Barager (1971) for comparison; (d) the tectonic discrimination plot of MgO-Al_2O_3-FeOt (Pearce *et al*., 1977) shows that the samples fall within either the ocean island or continental basalt fields, inconsistent with (e) MnO*10-P_2O_5*10-TiO_2 plot (Mullen, 1983) that shows the samples to be primarily of calc-alkaline arc affinity.

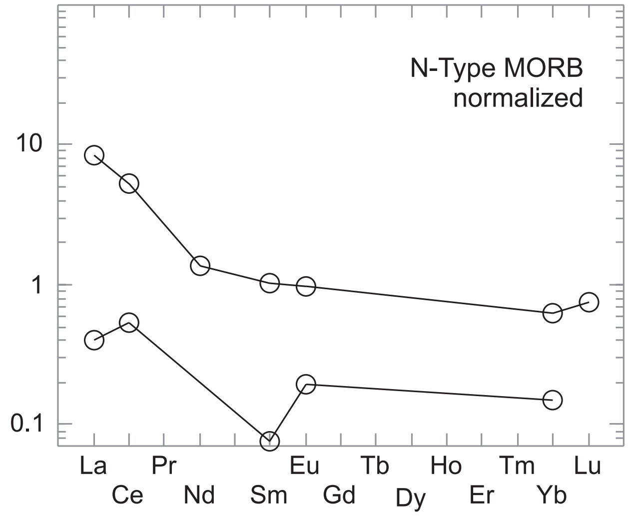


Figure 3-4. Normal MORB-normalized rare earth element plots of Boundary Ranges metamorphic suite mafic schists of strongly differing character. The upper, enriched curve is like that of arc basalt. The lower curve is enigmatic, perhaps illustrating a significant sedimentary component.

Such rocks commonly host an irregular second fabric or crenulation.

Chlorite schist (± actinolite-garnet; DTBa)

Chlorite actinolite schists are the most abundant rocks of the metamorphic suite. Plagioclase and quartz may comprise up to 50% or more of the rock, which results in mineral segregation so that the outcrop displays gneissic green and white banding. Biotite and rare garnet may be present as accessory phases; the abundance of biotite layers increases towards the contact with unit DTBb. Chlorite may be coarse, but is generally fine grained and oriented within a well developed schistosity. Actinolite is easily identified as dark green, acicular crystals ranging in size from 1 to 30 millimetres on cleavage surfaces. It is almost always subordinate to chlorite in abundance. It may outline a distinct lineation at one side of an outcrop but be randomly oriented within a foliation plane only a few centimetres away.

Pure chlorite schist is not extensive but does underlie a significant area north of Fantail Lake. Chlorite porphyroblasts are well developed and up to 2 centimetres diameter in places, but fine-grained schists are much more common. Chlorite schists may display well developed crenulations, or several generations of crenulations with widely varying orientations. They are generally more highly strained than other rock types as indicated by the common occurrence of sheath folds.

Geochemical analysis of mafic schists from unit of southern Tutshi Lake and Bighorn Creek and unit DTBa from Hoboe Creek show that they are of basaltic composition (Figure 3-3). However, major oxide discrimination diagrams are inconsistent, perhaps due to variable element mobility or variable protoliths. REE patterns from Hoboe Creek samples are inconsistent (Figure 3-4). The sample with elevated REEs is similar to volcanic arc basalt, but the depleted sample collected from nearby outcrops is strikingly different, probably due to a significant sedimentary component.

Pyroxene-plagioclase-chlorite schist (DTBp)

Pyroxene plagioclase schists with lesser chlorite and actinolite form conspicuous units several hundreds of metres thick north of Fantail Lake. They also occur as volumetrically minor layers within chlorite actinolite schist. Pyroxene crystals are typically 0.5 to 1 centimetre in diameter within a matrix of chlorite, actinolite and plagioclase. The latter minerals tend to wrap around the more competent pyroxene crystals. Proportions of pyroxene in a given sample vary from a few to about 50%. Basic tuffs or gabbroic intrusives are the most likely protoliths for these rocks. In the Tutshi Lake area similar schists grade into a weakly foliated gabbroic body.

Wann River gneiss (Pw)

Wann River gneiss (Currie, 1990) is a widespread and distinctive unit cropping out in elongate zones from Hale Mountain to south of Mount Caplice. The most extensive portions of this unit are many square kilometres in areal extent, but there are also slivers too small to be mapped at 1: 50 000 scale. In such instances they are interpreted to be structurally interleaved with the Florence Range Metamorphic Suite. One of the most distinctive characteristics of the Wann River gneiss is its millimetre to decimetre-scale compositional layering which varies in a gradational fashion from hornblende diorite to gabbro (<20 to >50% hornblende); both display subordinate biotite and late epidote. Fabrics and compositions of this type may result from the deformation of mafic to intermediate volcanic strata and comagmatic intrusive rocks.

Relatively felsic portions of the Wann River gneiss can be mistaken for rocks of the Early Jurassic Hale Mountain intrusion, but several features permit their distinction. Wann River gneiss is consistently intensely foliated and does not contain the plagioclase porphyroblasts which are so characteristic of the Hale Mountain granodiorite. Wann River gneiss is commonly, but not always, crisscrossed by plagioclase-rich pegmatites (pegmatitic layers are not uncommon within the Hale Mountain granodiorite, but the oldest pegmatites are synkinematic and concordant with foliation). Contacts with adjacent lithologies are generally strongly foliated and abrupt. In at least one case, however, the contact is a pegmatite-flooded zone some 200 metres across that separates it from the Hale Mountain granodiorite. At a locality near Nelson Lake Currie (1990) observed lenses of meta-

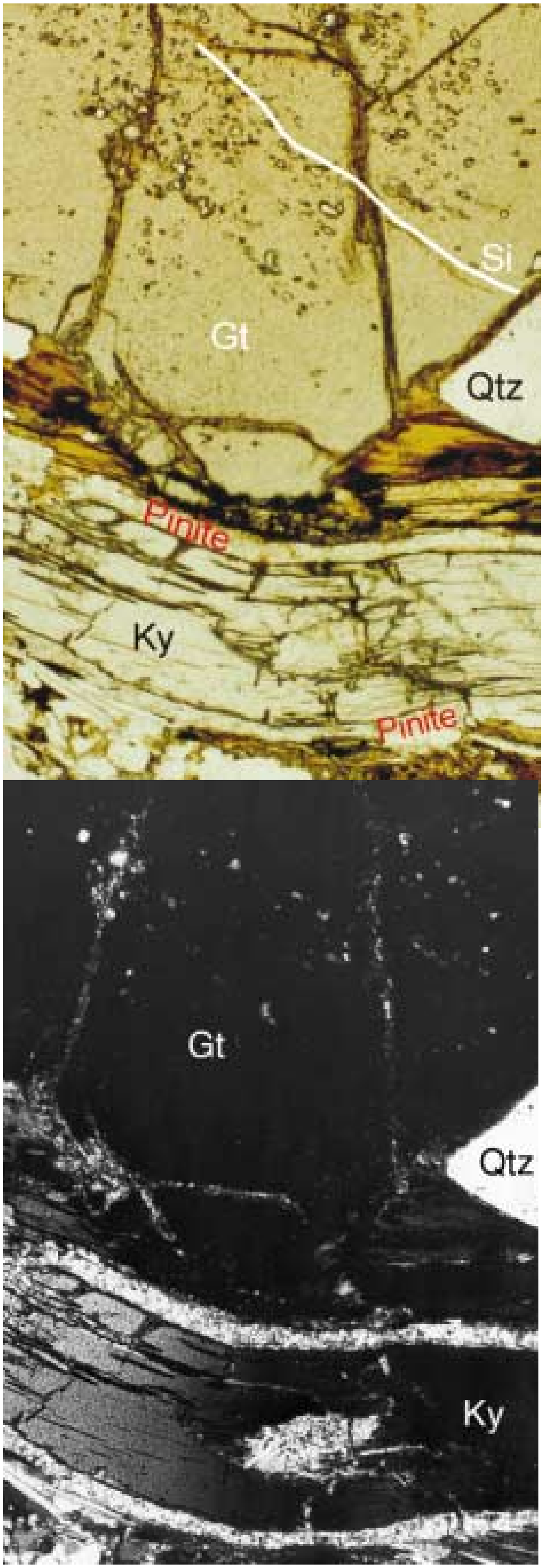


Photo 3-3. Photomicrograph of kyanite porphyroblast mantled by pinite? in pelitic schists of the Florence Range Metamorphic Suite. Note that the kyanite has been strained and not annealed. (a) plane polarized light (b) cross polarized light. Long dimension of photograph represents 4.6 millimetres.

sedimentary rocks 20 metres thick at the sheared contact between these two units.

Florence Range Metamorphic Suite (PDs)

The Florence Range Metamorphic Suite (Currie, 1990) extends from Hale Mountain to beyond the southern extent of the study area. Within the study area, it is best developed in the Florence Range where it is dominated by upper amphibolite grade metapelite, with lesser, but conspicuous carbonate, amphibole gneiss and quartzite layers. Protoliths are most likely clastic strata of cratonic derivation and platformal carbonate deposited in a continental margin setting. Amphibole gneisses may represent basalt flows, tuffs, sills or dikes. Within the study area, continental derivation is indicated not only by protolith compositions, but also by evolved neodynium and strontium isotopic values (Jackson *et al.*, 1991).

Rocks of the same grade and compositional range also crop out to the north in the Aishihik Lake map area in southern Yukon (Tempelman-Kluit, 1974; Johnston, 1988). Of any metamorphic rocks within the map area, Florence Range rocks correlate best with the Nisling assemblage or the lower unit of Mortensen (1992).

Rb-Sr isotopic model age determinations were made on correlative rocks to the north and south. Results are: 1170 Ma (Wasserburg *et al.*, 1963); Late Proterozoic (less than 770 Ma; Armstrong *et al.*, 1986); 1200 Ma (Watson *et al.*, 1981), and a similar age (1150 Ma) for equivalent rocks immediately south of the map area in 104M/8 (L.J. Werner, unpublished data; R.L. Armstrong, personal communication, 1988). Aleinikoff *et al.* (1981) interpret an Early Proterozoic age based on U-Pb and Sm-Nd isotopic data for similar rocks in the Yukon-Tanana Upland in eastern Alaska.

Metapelite to metaquartzite (unit PDsq*)*

Metapelites dominate the Florence Range suite. They are mainly muscovite -biotite- quartz - plagioclase - garnet schists with or without sillimanite (Photo 3-1) and graphite. Rare remnant kyanite (Photo 3-3), and late-forming andalusite (Photo 3-4) have also been identified . These rocks are well layered on a scale of decimetres to tens of metres.

Quartzite occurs as layers up to 3 metres thick (Currie, 1990). It is generally impure having micaceous partings. Massive quartzite is resistant and pink weathering.

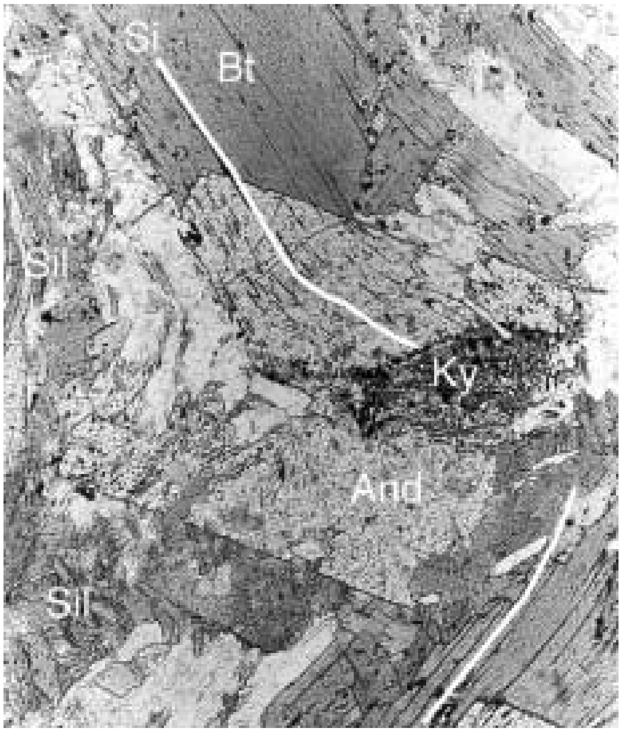


Photo 3-4. Photomicrograph of idioblastic andalusite which has passively overgrown biotite and matrix quartz. Opaque mineral grains that outline biotite cleavage traces continue undisrupted into the andalusite. Long dimension of photograph represents 4.6 millimetres.

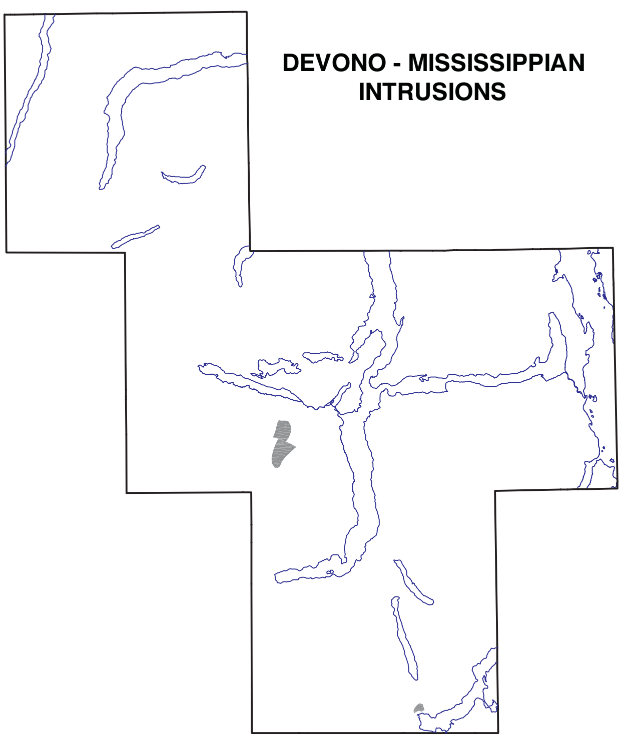


Figure 3-5. Distribution of Devono-Mississippian Bighorn orthogneiss and related orthogneiss in the Tagish area.

Compositional gradations from pelite to quartzite are common, but the units are too deformed to permit determination of stratigraphic tops.

Carbonate and associated calcsilicates

Carbonate and associated calcsilicate gneiss become increasingly important in the southern part of the study area, generally comprising 10 to 15% of the Florence Range suite (locally over 50% of some mountainsides). Carbonate forms bands up to 200 metres thick which may have been thickened due to folding or other structural complications. They are generally white and weather to pale hues of yellow and orange.

Calcsilicate units typically form discrete layers less than 1 metre thick. They are composed primarily of calcite with at least one of: tremolite, diopside, actinolite, grossularite, anorthite and possibly scapolite. Where these minerals form very coarse intergrowths they can commonly be identified without petrographic analysis.

Amphibole gneiss

Amphibole gneiss layers up to several tens of metres thick consist primarily of hornblende with lesser plagioclase and garnet. They are spatially associated with carbonates, and probably represent metamorphosed basaltic sills or flows. Currie (1990) suggests that such layers may also represent tuffs and reworked tuffs; presumably this interpretation is based upon the common co-occurrence of amphibole gneiss with micaceous partings of pelitic origin.

Meta-intrusive Rocks

Investigating the age of meta-intrusives that are infolded with the metasediments to various degrees is the most direct way to determine a minimum age for host protoliths. Currie (1994) contributed significantly to the geological understanding of the Tagish area with age dates on the Bighorn Creek orthogneiss, and Hale Mountain granite as well as other meta-intrusive bodies.

Bighorn Creek orthogneiss

The Bighorn Creek orthogneiss (Mihalynuk *et al.*, 1989a, b; Currie, 1991) crops out over an area of about 8 square kilometres in southwest Fantail Lake area (Figure 3-5). It is a well foliated, medium-grained, leucocratic body containing 50% quartz, and 40% feldspar with 6 to 7% combined muscovite, biotite, hornblende, chlorite and accessory pyrite. In the Bighorn Creek valley it typically weathers as isolated, rounded, low-relief white to pink outcrops. A fabric is well developed, but not everywhere to the same extent (Photo 3-5). A dominant schistosity is locally accompanied, where phyllosilicate content is sufficiently high, by an oblique second cataclastic fabric. Fabrics dip shallowly to the southwest and west.

U-Pb zircon age data (Currie, 1994) show this unit to be 366 ±9Ma (Late Devonian). Orthogneiss of this age is common within the Yukon-Tanana Terrane.

Hale Mountain Granodiorite

Hale Mountain granodiorite occurs as discontinuous tabular bodies between Hale Mountain and Nelson Lake. It is structurally interlayered with Nisling assemblage metasedimentary strata with the same structural fabric. In the Aishihik Lake area, Yukon, granodiorite of nearly identical age and lithology intrudes the Nisling Assemblage (Johnston, 1993). These meta-intrusions were considered part of the Klotassin suite (Wheeler and McFeely, 1991), but are herein named the Aishihik intrusive suite (*see* Chapter 12 for discussion and description). An Early Jurassic date (Currie, 1992) places a maximum age on the

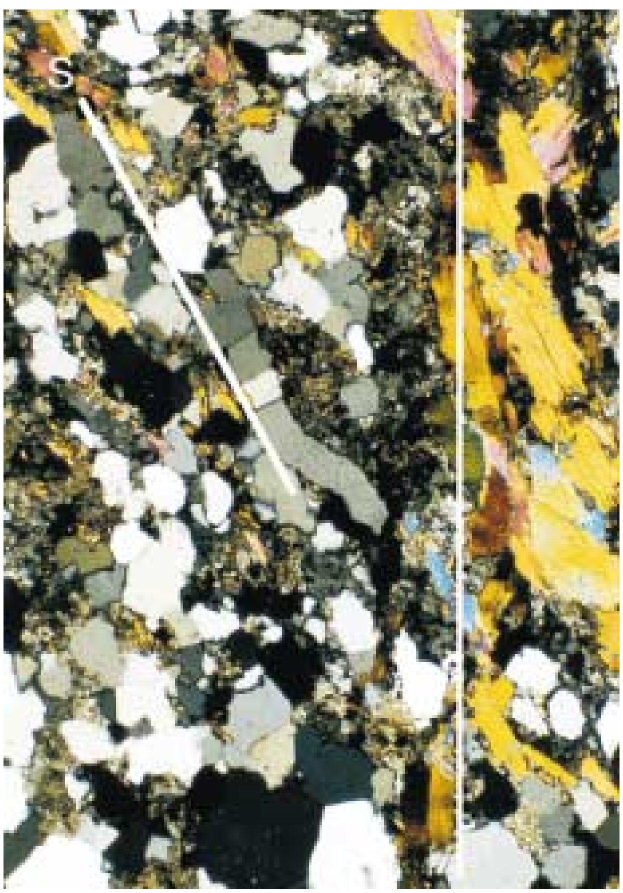


Photo 3-6. Photomicrograph of the Bighorn Creek orthogneiss. Sparse secondary epidote and chlorite (after hornblende) occur in a matrix of strained quartz and feldspar. An early schistosity (S) is overprinted by a protomylonite fabric outlined by micas. Long dimension of photograph represents 4.6 millimetres.

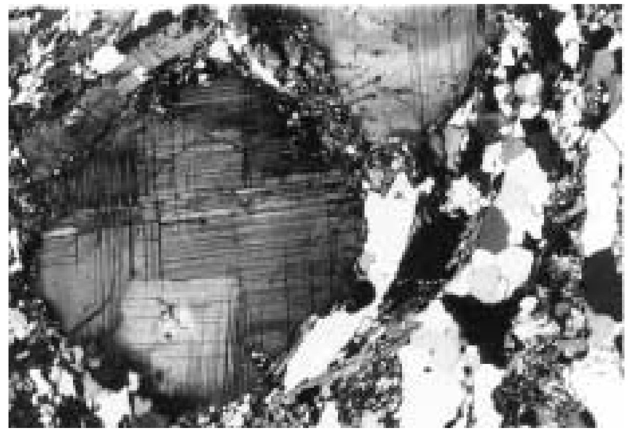


Photo 3-5. Photomicrograph of Hale Mountain granodiorite showing patchwork plagioclase augen, well aligned hornblende, and equant epidote (high relief).

latest ductile deformation (Photo3-6) affecting Domain II.

Mount Caplice & other Meta-intrusives

Glomeroporphyritic hornblende biotite tonalite at the southern end of Willison Bay is thought to be correlative with rocks south of the Tagish area mapped by Currie (1991) as belonging to the Mount Caplice meta-intrusive body. It is well foliated, white to dark grey weathering, and medium to coarse grained (but grain size does not exceed 1 centimetre). Biotite occurs as clots of plates comprising 10% of the rock. Quartz (20%) is xenomorphic and displays dynamically recrystallized tails; less commonly it is medium grained. Plagioclase and minor orthoclase? comprise 50% of the rock. Abundant fine to medium-grained dikelets are randomly oriented with respect to the steeply west-dipping foliation. Chlorite commonly, but not always coats joint surfaces. Epidote occurs as a minor alteration product within the rock groundmass.

Other meta-intrusive rocks have been mapped near the Mount Caplice tonalite by Currie (1990), but have not been investigated as part of this study.

Metamorphics south of the map area

Reconnaissance mapping of metamorphic rocks south of the map area was conducted in 1991 in order to determine the following:

- The southern continuation of the Llewellyn fault and its role in the distribution of metamorphic rocks in the region.
- The relationship between low grade metamorphic rocks assigned to the Boundary Ranges suite (unit DTBb) and higher grade and apparently less struc-

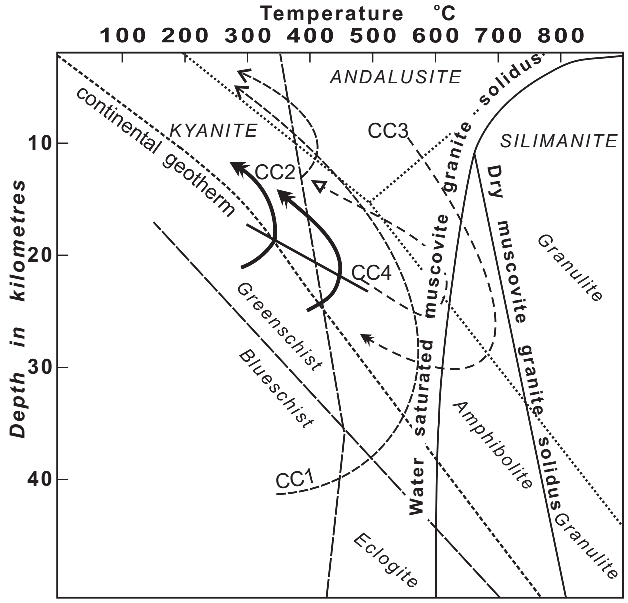


Figure 3-6. Pressure-temperature plot showing some pressure-temperature-time (PTt) paths for well-studied Barrovian metamorphic terrains (heavy double-headed arrows). Shown for reference are the aluminosilicate stability fields of Holdaway (1971), the dry and H_2O saturated granite solidus of Huang and Wyllie (1973) and the steady-state continental geotherm (short dashes; after Philpotts, 1990). PT paths from continental collision zones are shown for comparison. CC1 and CC2 from the lowest and highest strata within the Tauern Window (eastern Alps) are a byproduct of the African - European plate collision. CC3 and CC4 are a product of the Acadian orogeny. Clockwise CC3 resulted from protracted formation of the Merrimack synclinorium (PTt curves from Philpotts, 1990 and sources therein).

turally complicated rocks of the Florence Range suite (unit PDs).

- The relationship between the above metamorphic suites and rocks thought to belong to the Paleozoic Stikine assemblage.

Preliminary conclusions point to the following:

The Llewellyn fault gently sweeps to the east as it continues south and is obscured by the overlying Sloko Group volcanics. It appears to emerge from beneath the Sloko Group to the south in the Tulsequah River area on the northwest side of Shaza Creek (Figure 1-1). There it separates weakly to nonfoliated intermediate to mafic volcaniclastic rocks and bedded to massive carbonate and intercalated mafic flows from foliated rocks that in the field display one to two phases of deformation, but are derived from the same general type of protolith.

In the Tulsequah Glacier and Tulsequah River areas the contact between units DTBb and PDs may be more

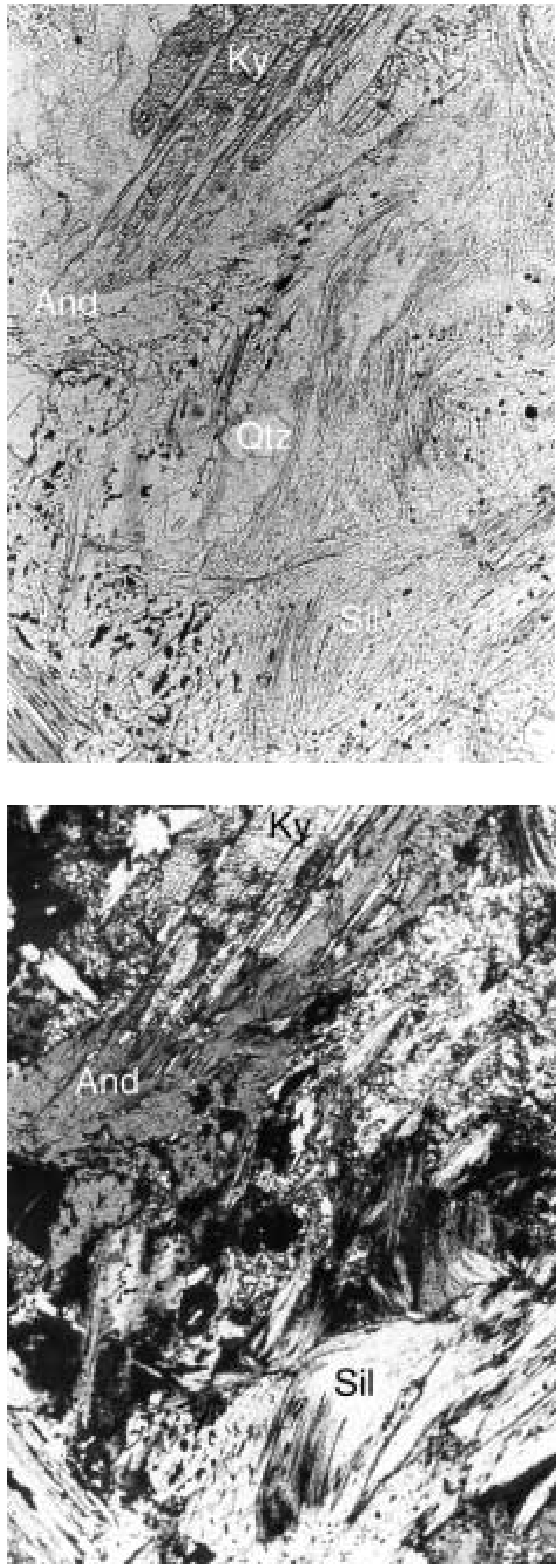


Photo 3-. Photomicrograph showing three coexisting aluminosilicates: kyanite (Ky) mantled by andalusite (And) which is in turn overgrown by swirling fibrolite (Sil). (a) cross polarized light (b) plane polarized light. Long dimension of photograph represents 1.8 millimetres.

gradational than it is to the north. This observation is in general agreement with those made by Souther (1971). As in the north, the Llewellyn fault marks the contact between foliated and metamorphosed rocks that probably belong to unit DTBb and those that are weakly to undeformed. Whereas the oldest undeformed rocks in the north are the Stuhini Group volcanic and sedimentary rocks, in the south they belong to the Paleozoic (in part Mississippian) Stikine assemblage.

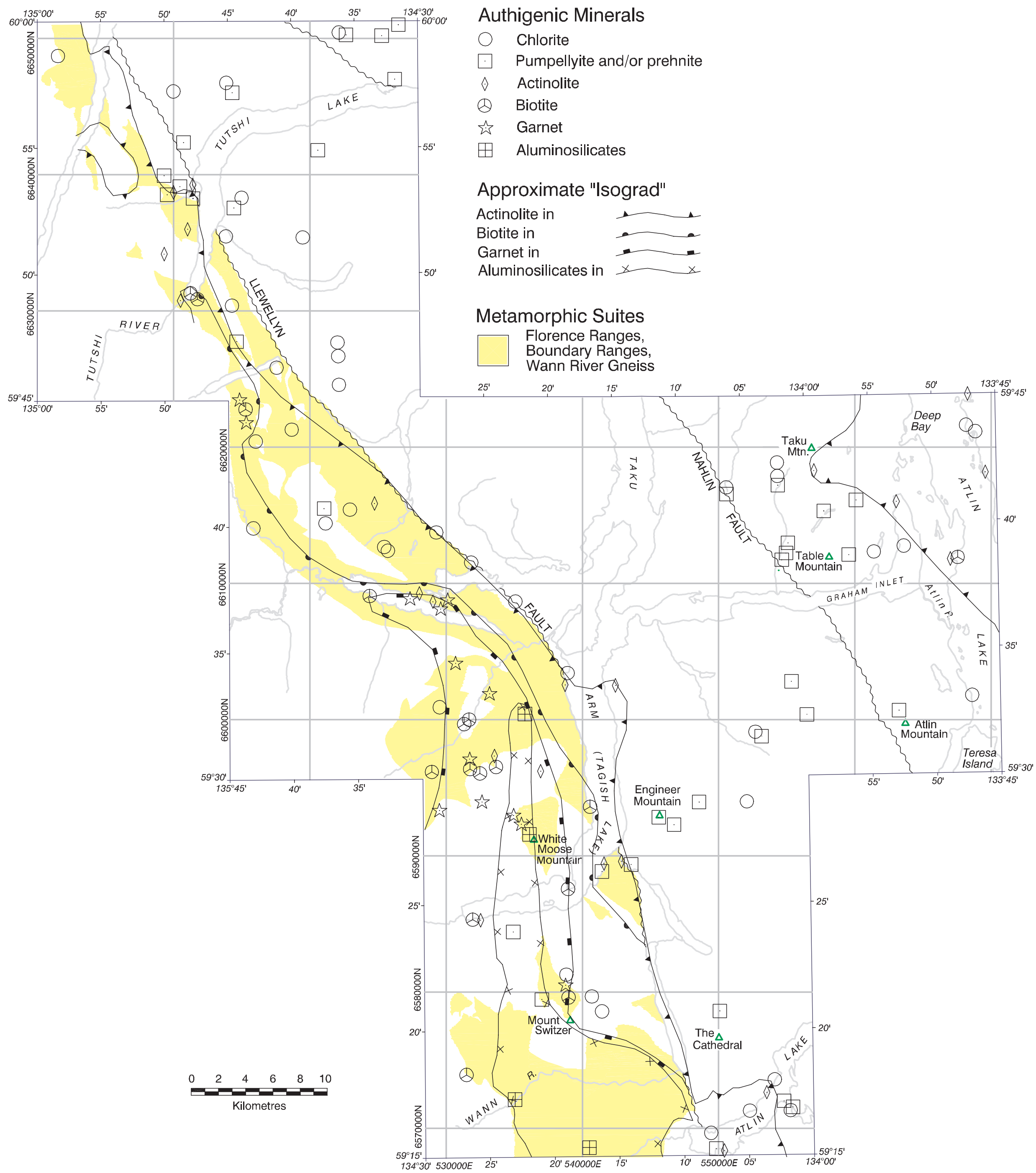


Figure 3-7. Approximate isograds within the map area, based upon a retrospective study of thin sections and hand samples. Metamorphic suites are highlighted.

Pressure - Temperature Estimates

Temperature, and to a lesser extent pressure of formation of metamorphic rocks in the Tagish Lake area can be estimated crudely from high-variance mineral assemblages, and more precisely from low-variance mineral assemblages. Temperatures can be estimated quite accurately (±50°C) from the application of geothermometers that are well calibrated under conditions matching those of the samples analyzed. Textural evidence for the instability of modal minerals provides hints as to the trend of the pressure-temperature (PT) path at the time that the metamorphic mineral assemblage was imprinted on its protolith.

Metamorphic rocks in the Tagish area can be subdivided into a mainly middle amphibolite grade suite (Florence Range suite) and a greenschist to transitional greenschist-amphibolite suite (Boundary Ranges suite). Meta-intrusive rocks generally fall somewhere in between these two end members, as they were intruded at various stages during the metamorphic history.

P-T estimates, Florence Range suite

Metapelites of the Florence Range Metamorphic Suite typically contain biotite, muscovite and garnet in textural equilibrium in addition to quartz, plagioclase, potassium-feldspar and, less commonly, sillimanite ± kyanite ± andalusite. Sillimanite tends to be a late-forming phase which occurs as fibrolite. As a first approximation the Florence Range suite as a whole has experienced peak metamorphic conditions that fall within the sillimanite stability field and locally extend to the high temperature side of the muscovite breakdown curve (Figures 3-2, 3-6) as leucosome development is reported by Currie (1994).

There are insufficient data to allow accurate characterization of isogradic surfaces in the Florence Range suite, but in light of the structural complications it is unlikely that they are horizontal. This is particularly evident where metamorphic index minerals such as kyanite record strain, indicating syn- to post-metamorphic deformation (Photo 3-2). Poorly constrained isograds are shown in Figure 3-7.

Andalusite occurs as both euhedral porphyroblasts (Photo 3-4) and anhedral masses (Photo 3-7); the chiastolite variety has yet to be reported despite a local abundance of graphite-rich protoliths ideal for its formation. In some cases andalusite occurs as an overgrowth on kyanite and biotite. Where it has grown at the expense of biotite, it has locally incorporated opaque mineral trails that extend into adjacent biotite crystals where they outline folded cleavages (Photo 3-4). This, together with the lack of any strain within the andalusite crystals, indicates that they grew under lithostatic conditions, apparently post-kinematic, but probably during a tectonic lull following emplacement of the Hale Mountain granodiorite.

Sillimanite occurs as swirling mats of fibrolite that commonly form at the expense of biotite. More rarely, evidence of polymorphic transformations between andalusite or kyanite and sillimanite is preserved (Photo 3-7). Fibrolite generally grows over metamorphic fabrics, but is locally aligned with the fabric, indicating a late to post-kinematic formation. Most fibrolite probably formed in response to a sharp thermal pulse such as would accompany a major intrusive event, probably in Late Cretaceous to Early Tertiary time as recorded in the Aishihik Lake area by Johnston (1993).

Staurolite has not been reported from the study area, although a single locality is known in a fault-bounded block of schist within the Willison Creek Fault zone just south of the map area (*cf*. Currie, 1994 p. 174). Common retrograde alteration of garnet and biotite is an indication of post peak-metamorphic mineral instability. Retrograde mineralogy includes chlorite after biotite and garnet (Photo 3-8), and, in more calcic lithologies, epidote may form. Kyanite is locally altered to a fine-grained phyllosilicate mat. Generally, retrograde metamorphism of the Florence Range suite is not extreme, in contrast to that of the Boundary Ranges suite.

P-T estimates, Boundary Ranges suite

Rocks of the Boundary Ranges suite tend to be of lower metamorphic grade and represent a more variable protolith suite than do those of the Florence Ranges. In the Boundary Ranges suite metabasites are more common, quartzites are relatively rare, and sedimentary protoliths were probably more calcic overall, perhaps indicating a tuffaceous or epiclastic component. As a consequence, metamorphic mineralogy tends to be more diverse and iron-rich calcium-bearing minerals are common. Few index metamorphic minerals are in evidence, but aluminosilicates do occur rarely (*cf*. Currie, 1994, p. 167). At many localities within the Boundary Ranges biotite, and less commonly, garnet are stable. Chloritic knots within altered biotite-muscovite schists can be seen in thin section to host remnants of altered garnet, indicating that garnet was much more widespread prior to retrograde alteration.

One of the most widespread mineral assemblages is actinolite-chlorite-epidote. It may occur with or without biotite, garnet and rare andalusite. The maximum number of variables (ν) imposed on the system that can be changed given (c) components: Al_2O_3, CaO, FeO, MgO (SiO_2 and H_2O are excluded components as they occur as pure phases) without altering the number of phases (ϕ) is given by application of Gibb's phase rule (ν=c-ϕ+2). Thus a maximum of five phases from the above assemblage can coexist in any one sample. The overall variance of such a system is then, only one. Hence, given some in-

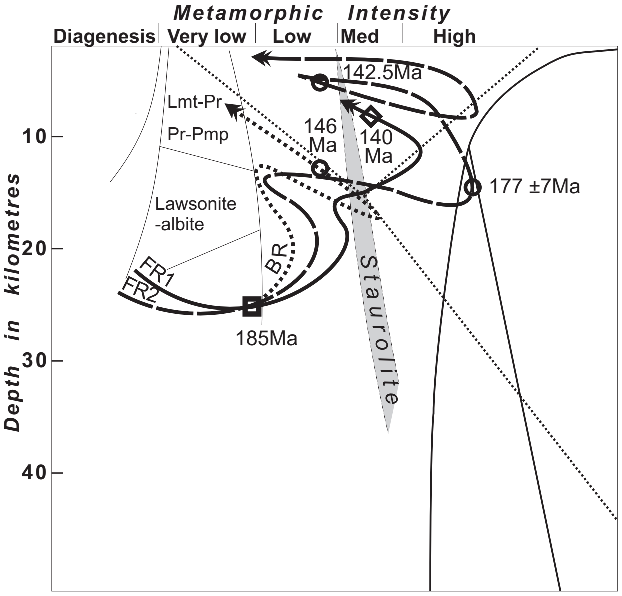


Figure 3-8. Hypothetical PT trajectories for high grade schists of the Florence (FR1 and FR2 paths, heavy solid and long dash) and Boundary Ranges metamorphic suites (BR, heavy dotted path). Data points are: crystallization age and geobarometry from the Hale Mountain granodiorite (square; Currie, 1994). Titanite and rutile cooling ages (circles; Currie, 1994). Geothermobarometry of Johnston (1993) is shown by the diamond and low P loop of FR2.

dependent determination of either the temperature or pressure, the other intensive variable can be determined. Unfortunately, several problems thwart this application of Gibb's rule. First, chlorite is one of the five phases that comprise this low variance assemblage, yet it is unclear whether chlorite is a stable member of the prograde metamorphic assemblage. It certainly comprises a significant part of the retrograde mineral assemblage. Second, the metabasite petrogenetic grid is poorly constrained and may be sensitive to oxygen fugacities. In particular, the stability limits of actinolite are not well known, nor are the compositional limits of actinolite, epidote and chlorite determined for the samples of interest. Finally, it appears that this mineral assemblage is the result of two thermal events. That is, rather than representing a prograde reaction, a lower grade chlorite - actinolite - epidote assemblage persists at the expense of a pre-existing higher grade garnet - biotite ± actinolite assemblage. Existing data point to a lower amphibolite grade event overprinted by an upper greenschist event.[3] This interpretation is supported by available geothermometric data.

Geothermometric analyses were conducted on a selection of samples from the Boundary Ranges Metamorphic Suite in order to determine their temperature of formation. Microprobe analyses of garnet-biotite mineral pairs permitted the use of Fe-Mg exchange geothermometers. The utility of geothermometric results in this case is somewhat diminished due to retrograde and compositional problems as explained by Mihalynuk and Mountjoy (1990). Nevertheless, calculated temperatures for the least altered samples (500° to 600°C) are shown in Table 3-2. Compositional corrections by the method of Ganguley and Saxena (1984) yield temperatures that are 20° to 70°C higher than those calculated by the calibration of Thompson (1976). Exchange temperatures calculated from the Thompson (1976) and Ferry and Spear (1978) calibrations indicate core to rim temperature increases for three of the four samples reported in Table 3-2. Such temperatures tend to be consistent with lower amphibolite grade conditions whereas the mineral assemblage in these rocks points to transitional greenschist- amphibolite facies. However, in consideration of the probable ±50°C error limits on the geothermometric determinations (±75°C for Ganguley and Saxena), the lower limits of these temperature determinations fall within the epidote amphibolite facies of Miyashiro (1973), particularly if pressures of formation were in excess of 0.2 GPa (Liou *et al.*, 1983) at low oxygen fugacities (Liou *et al.*, 1985).

Table 3-2. Geothermometric results of microprobe analyses on biotite-garnet pairs from selected schist samples of the Boundary Ranges Metamorphic suite.

SAMPLE	LC11-1A			MM11-1		MM14-2B			MM27-6	
Number of Analyses	6	8	4	4	5	2	8	4	4	4
Location on grain	middle	rim	core	middle	rim	middle	rim	core	middle	rim
$\ln K_D$	-1.87	-1.71	-1.79	-1.74	-1.77	-1.74	-1.66	-1.67	-1.70	-1.78
Thompson*	526	566	546	557	551	558	578	576	568	547
Ferry and Spear	530	582	548	570	562	572	599	592	585	557

A number of analyses were used to obtain an average composition for each sample location. Note that sample MM27-6 displays a consistent core to rim decrease in temperature (592 to 557°C).
*A pressure correction of 4Kb is used for the Thompson calibration.

3 *It is possible that the perceived "second" event could result from a protracted low-grade portion of the PTt path experienced by these rocks. This possibility is discussed further in Chapter 13.*

Relative PTt trajectories and strain history

Pressure-temperature paths can be temporally constrained at points where their topology is the product of geologic events of known age. In the study area the relative ages of several such events are known or surmised, and work by Currie (1994) and Johnston (1993) provide some isotopic age data which permit absolute timing of these key metamorphic episodes. Nevertheless, PT trajectories shown in Figure 3-8 are tentative.

PTt path topology is constrained by several data sets and assumptions. First, the Florence Range and Boundary Range suites were intruded by the Hale Mountain granodiorite (Aishihik plutonic suite) analogous to the Aishihik pluton in the Aishihik Lake map area (Johnston, 1993). Thus, the PTt paths of parts of each suite intersect at 185 Ma (age constraints for this intrusive episode are presented in Chapter 17, Geologic History). Second, rapid exhumation immediately followed emplacement of the mid-crustal Aishihik plutonic rocks as seen by the cospatial and essentially coeval emplacement of upper crustal pink quartz monzonite in the Yukon (Johnston, 1993) and Tulsequah (Childe and Mihalynuk, 1995) areas. Third, despite relatively flat fabrics, not all parts of the Florence Range suite were subjected to temperatures exceeding the water saturated muscovite granite solidus (Figures 3-2, 3-6). Generation of leucosome at 177Ma (Currie, 1994) is controlled in part by proximity to the Hale Mountain granodiorite as reflected by the diverging PTt paths. FR2 represents Florence Range rocks that are more influenced by the thermal input from Hale Mountain granodiorite. Fourth, a low P loop on FR2 resulted from heating by Late Cretaceous to Tertiary intrusions and static late growth of fibrolite like that seen in the Aishihik Lake area where this thermal event has been dated (Johnston, 1993). Fifth, path BR is controlled by the rare occurrence of kyanite and absence of sillimanite in the Boundary Ranges suite. Lack of sillimanite and andalusite is an accurate reflection of PT conditions during prograde metamorphism and not due to later obliteration by retrograde metamorphism. Sixth, the old segments of FR1 and FR2 represent the changing P conditions during crystallization of the Hale Mountain granodiorite as reported by core to rim hornblende geobarometric determinations Currie (1994).

Petrographic observations from the Florence Range rocks indicate that the PT paths pass through the kyanite stability field and into the sillimanite stability field at peak metamorphism (path FR1, Figure 3-8). In some samples andalusite and sillimanite are present (path FR2, Figure 3-8). In one sample (LCU88-48-2) all three aluminosilicates are present, although they are not in textural equilibrium (Photo 3-7). In most samples textural evidence points to changing PT conditions such that aluminosilicates are stable in the order: kyanite, andalusite, sillimanite.

Kyanite is present as remnant patches and as strained, tabular, oriented porphyroblasts. In examples where kyanite retains strain (Photo 3-7), it is apparent that not only was thermal overstepping insufficient to drive the polymorphic transformation reaction (Ky $\Leftrightarrow$ Sil) to completion, but it also lacked enough persistence to anneal strained kyanite. Deformation of kyanite following the growth of higher temperature polymorphs is not likely as the later phases show little evidence of deformation. To account for the stability of strained kyanite it is suggested that the prograde PT path did not extend far into the andalusite and sillimanite stability fields, and the thermal pulse that was responsible for the formation of sillimanite was relatively short lived (low P loop on FR2, Figure 3-8). Textural evidence points to the growth of both sillimanite and andalusite under lithostatic conditions (Photos 3-3, 3-7), consistent with their formation in response to a transient steepening of the geothermal gradient as a result of intrusive activity.

Protoliths for the Boundary Ranges Metamorphic Suite appear to be somewhat more variable and generally more calcareous than those of the Florence Range suite, perhaps indicating a greater tuffaceous component. Metamorphic grade, as determined from petrographic analyses also appears more variable, ranging from lower greenschist to transitional greenschist-amphibolite facies (or epidote-amphibolite facies) while exchange geothermometry and the presence of rare aluminosilicates indicate amphibolite facies. This being the case, it has been suggested that lower amphibolite grade conditions may have been prevalent in the Boundary Ranges suite and are now obscured due to a widespread regional retrograde overprint (Mihalynuk and Mountjoy, 1990). Alternatively, uncertainty in the upper temperature limits of the epidote-amphibolite facies, particularly with unusual bulk rock compositions, may permit the assemblage garnet-biotite-actinolite and rare andalusite to occur at temperatures normally considered indicative of the lower amphibolite facies (500° - 600° C). Also, given uncertainties in the exchange geothermometry of ± 50° to 75°C, it is possible to place most of the analyzed samples within the lower temperature limits of the lower amphibolite facies field. Thus, in areas where there is no petrographic evidence of retrograde overprinting, the widespread epidote-actinolite facies mineralogy may have formed during prograde metamorphism that peaked at lower amphibolite facies. A pervasive retrograde metamorphic event as envisaged by Mihalynuk and Mountjoy (1990) may have occurred, but it is not required. Boundary Ranges suite rocks may have been affected by a low P loop similar to the one that affects Florence Range rocks after 142.5 Ma, but because they were at higher crustal levels, only a relatively narrow thermal aureole was developed. However, Boundary Ranges suite rocks invariably display significant post peak metamorphic deformation, commonly accompanied by a retrograde mineral assemblage (generally chlorite after biotite and garnet, Photo 3-8). In many samples the retrograde minerals are strongly deformed, consistent with a protracted cooling history as indicated by K-Ar cooling ages (Table AA3) for rocks within and adjacent to the Boundary Ranges suite. Hornblende ages range from 170 Ma of the Hale Mountain granodiorite, to 155Ma of the hornblendite near the Yukon border. Granodiorite at the bend of Taku Arm and adjacent to the Hale Mountain granodiorite returned K-Ar cooling ages of 145Ma (hornblende) and 123Ma (biotite), consistent with a sericite K-Ar cooling age of 132Ma from the nearby Llewellyn Fault zone, and with closure temperatures in hornblende that are higher than those in the micas.

Both the Florence Range and Boundary Ranges suites display PTt paths with an early loop (Figure 3-8) that is shaped like those of a typical Barrovian metamorphic terrain (compare with Figure 3-6). A high temperature loop experienced by both suites at around 177M; the Florence Range loop in particular is similar to the continental collision loop CC4 on Figure 3-6, albeit at lower pressures. The implications of these observations are discussed under "Structure" and "Geologic History" (Chapters 13 & 15).

Problems and Directions for Further Study

Despite formidable contributions by Currie (1994), tectonic affiliation of the Florence Range Metamorphic Suite within the study area has not yet been firmly established. Borrowing on stratigraphic relationships seen outside of the Tagish area (*i.e.* Tulsequah River and Tracy Arm), it is most likely that the Boundary Ranges suite is deformed Stikine assemblage (Paleozoic Stikinia; *cf.* Mortensen, 1992) and that it rests upon the Florence Range suite. However, contacts between the two have been obscured by deformation that postdates juxtaposition of the Florence and Boundary Ranges suites. Could the contact be a terrane boundary? Metamorphic grade and structural style of Florence and Boundary Ranges suites are at first glance quite different, but this is partly related to variation in stratigraphic/structural depth and proximity of the syntectonic Hale Mountain granodiorite. The sequence of structural events as seen petrographically is strikingly similar. Why is this? Critical reevaluation of well-exposed contact relations, as well as structural and metamorphic characteristics of the rocks between Willison Creek and Fantail Lake is needed. For example, an exotic origin of Florence Range suite and its juxtaposition with respect to Stikinia is difficult to reconcile with the northwest-directed emplacement fabrics reported by Currie (1994, p. 307). More effort needs to be directed towards establishing the timing of old deformational events within both the Florence and Boundary Ranges suites. Isotopic age and trace element characterization of magmatic rocks of the Florence Range suite in particular is needed. For example, the age of easily accessible orthogneiss bodies near the mouth of Willison Creek and their contact relationships with Florence Range rocks need to be established. Much more remote, ice-scoured nunataks along the British Columbia -Alaska border both west and south of the map area (*e.g.* Brew *et al.*, 1994) deserve more detailed mapping as they may hold clear evidence of hitherto equivocal geological relationships.

Mineral Potential

From an economic standpoint, the Boundary Ranges rocks hold promise to host undiscovered volcanogenic massive sulphide and gold vein deposits. Two lines of reasoning support a high potential for volcanogenic massive sulphide deposits. First, correlatives both to the north and south host substantial volcanogenic massive sulphide accumulations. To the south, in the Tulsequah mapsheet the Stikine assemblage contains the past-producing Kuroko-style Chief and Big Bull deposits. In the Finlayson Lake district of the Yukon, the recently discovered Devono - Mississippian Fyre Lake, Kudz Ze Kayah and Wolverine volcanogenic massive sulphide deposits are part of the Yukon-Tanana Terrane that may correlate with the Stikine assemblage (Mortensen, 1992). Second, and more importantly, there are two massive sulphide occurrences within the Boundary Ranges rocks that may be volcanogenic. The Nasty Cirque (Big Thing) showing is located 4 kilometres east-northeast of southern Tutshi Lake (MINFILE 104M071 on Figure GM97-1, see also Chapter 14). Structurally (and stratigraphically?) concordant argeniferous galena and sphalerite occur as brown matrix material in a 3 by 3 metre silicified carbonate breccia zone (Mihalynuk and Rouse, 1988a). Grab samples returned assays of 78g/t gold and 617g/t silver. Associated lithologies include metamorphosed fine-grained felsic volcanic rocks and sedimentary strata. The Anyox-Rodeo occurrence (MINFILE 17 on Figure GM97-1) is located along the lower Wann River. Mineralization comprises a 2 metre-wide sulphide pocket where pentlandite and pyrrhotite form a matrix to pegmatitic actinolite in chlorite-actinolite schists. A grab sample collected in 1989 returned 0.6% nickel, 0.15% copper and 0.12% cobalt (Mihalynuk and Mountjoy, 1990). Platinum and palladium are also reported to be anomalous. Potential for future discovery of massive sulphide deposits in the Boundary Ranges metamorphic suite is good, but intense structural disruption of these rocks poses severe challenges for establishing minable tonnage, as demonstrated by the two known occurrences.

Stikine assemblage rocks also host mesothermal gold-arsenic-antimony veins at the Polaris-Taku mine located along the Tulsequah River. Veins may be localized in second or third order faults related to the Llewellyn fault zone. Analogous veins are not known in the Tagish area, but potential for such veins does exist.

Quartz-base metal sulphide veins containing gold are relatively common within Boundary Ranges rocks. Some are associated with Eocene volcanic or related hypabyssal intrusives (*e.g.* Crine, Rupert), others show no intrusive association (*e.g.* Lawson, Tonya). Visible gold occurs with cobaltite in skarns at Teepee Peak (MINFILE occurrences 45 and 49 on Figure GM97-1). Due to the long deformational history displayed by metamorphic assemblages within the Tagish area and their epi-continental to arc character, potential also exists for metamorphosed disseminated Au-Ag deposits (see Chapter 14).

Regional geochemical surveys show that Boundary Ranges suite rocks exhibit a clear anomalous gold signature (Mihalynuk *et al.*, 1989a). Due to the abundance of gold occurrences, the anomalous geochemical response, and the relative lack of exploration within the Boundary Ranges suite rocks, future exploration efforts aimed at gold-bearing vein systems will be well founded.

Chapter 4 Strongly Foliated Rocks

Foliated rocks of unknown age are grouped with either the Boundary Ranges Metamorphic suite or the Stuhini Group in Figure GM97-1 (as had been done previously by Mihalynuk and Rouse, 1988b). However, they are important because they locally preserve good protolith textures and, particulary in the case of the Boundary Ranges metamorphic suite, may hold key clues about genesis of the suite. Future advances in understanding these rocks may rely heavily upon such clues, so these uncommon rocks are highlighted here.

Subdivision of these foliated rocks into packages with similar lithologic character, structural position and preservation of similar relict textures produces several units. Relict textures occur mainly in volcanic facies, but at some localities sedimentary protoliths are dominant (*e.g.* Tutshi Lake). Metamorphic grade is dominantly greenschist, although amphibolite grade is attained where the rocks are hornfelsed.

These units occur sporadically along the eastern margin of the Boundary Ranges Suite. All are within 2 kilometres west of the Llewellyn fault, and occur sporadically from Fantail Lake to at least the British Columbia - Yukon border (Figure 4-1). They crop out at Bennett Lake, Tutshi Lake, Racine Lake and perhaps at Skelly Lake. Just south of the map area, at the head of Hoboe Glacier, a package of phyllites and poorly developed schists with preserved protolith textures has well displayed contact relationships with pillow basalt that probably belongs to the Stuhini Group. Foliated rocks at these localities are described and possible correlations and age relationships are discussed below.

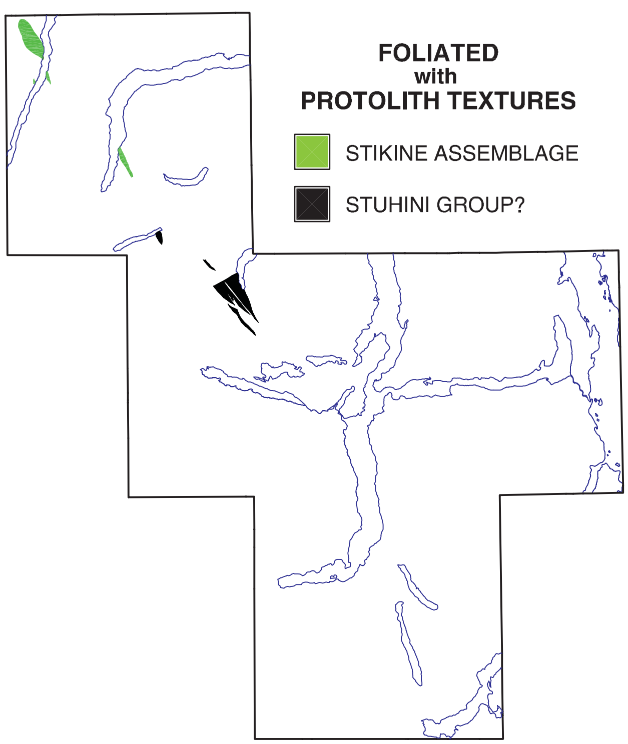


Figure 4-1. Distribution of strongly foliated, but weakly metamorphosed strata in the Tagish Lake area.

Bennett Lake

Foliated rocks of unknown affiliation occur on both sides of Bennett Lake. On the western shore, across from Guard Rail Point, is a poorly mapped area that is underlain by what appears to be moderately foliated, bleached and silicified intermediate lapilli tuffs and epiclastic strata. Rocks on the opposite shore, at Guard Rail Point, are similarly difficult to identify, although traced along strike, they can be linked with units lJL, muJv or DTB. Peak metamorphic grade at these localities can probably be attributed to the close proximity of Cretaceous and Tertiary intrusions of the Coast Belt.

On the ridges west of Bennett Lake and just north of the British Columbia - Yukon border is a package of chlorite-epidote-actinolite-altered pyroxene porphyries originally believed to be part of the Stuhini Group. However, new age data (Hart, 1995 and personal communication, 1993) indicate that a Permian age is more likely. Medium to coarse-grained pyroxene leucogabbro at the border is deformed by quasi-ductile fabrics to locally produce chlorite schist. Isolated parts of this intrusive unit display banding of probable magmatic origin. Identical rocks are reported from within the Tally Ho shear zone of Doherty and Hart (1988).

Tutshi Lake Southeast

Some of the best relict textures within foliated rocks are displayed east of Tutshi Lake and south of Moon Creek. At this locality, two southward converging prongs of metamorphic rocks form the limbs of a late syncline that is cored by younger, unfoliated sediments mapped as Laberge Group (Figure GM97-1). The younger strata contain abundant clasts derived from the underlying metamorphic terrain as well as fossil belemnites, coralites and carbonized plant debris. Deformation and metamorphic grade within both prongs appear to decrease toward the fold hinge where a discontinuous carbonate band marks the contact with younger, probable Laberge strata.

Less deformed parts of both 'prongs', but especially the northern one (shown on Figure 4-1) can be identified as foliated siltstone, wacke, tuffaceous sediment, finely bedded micrite and a fine-grained, cherty, white and black laminated unit. Cherty strata are continuous and dip 45° to 65° degrees east for more than 1.5 kilometres along strike. Graded bedding can be distinguished locally. The units generally have an early foliation which is contorted into disharmonic, although generally coaxial folds.

A weakly foliated, pyrrhotitic and silicified sharpstone conglomerate crops out along the contact between rocks with protolith textures and rocks in which such textures have been obliterated by a foliation. This unit may not be a true conglomerate, but could instead represent a milled fault breccia, perhaps at a detachment surface. Distinction between these two possibilities is of pivotal importance in unraveling the early tectonic history of the area.

Photo 4-1. Strained rhyolite fragments in a chlorite schist matrix. View to the west of southeast-striking fabric. Asymmetry of clasts suggests sinistral motion.

Photo 4-2. Incipiently foliated pillows in probable Stuhini Group near the Llewellyn fault.

Racine Lake Southwest

Between the southern bend of Racine Creek and Brownlee Lake is a relatively continuous belt of foliated volcanic and sedimentary strata. Unique to this belt of rocks are rhyolitic lapilli tuffs which serve to distinguish them from the Stuhini Group. These light green weathering tuffs contain up to 80% angular, white rhyolite lapilli in a reddish or green, chloritic matrix. Rhyolite fragments are poorly to strongly strained within a foliated matrix (Photo 4-1). They are intercalated with strongly foliated chlorite schist containing rare feldspar fragments and 4-millimetre chlorite patches which may be altered mafic minerals. A thin but continuous carbonate unit is moderately to strongly foliated and generally less than 5 metres thick. Little-strained portions were sampled for microfossils, but no samples were productive.

Hoboe Glacier Southeast

Contact relationships between pillow basalt of probable Stuhini Group and schistose carbonate and phyllite are well displayed in an uninterrupted section just south of the map area at the head of Hoboe Glacier. At this locality, well developed pillows of pyroxene-phyric basalt are exposed on the western side of a steeply dipping, continuous section of Stuhini Group tuffs, flows and sediments. The pillows become increasingly more strained (Photo 4-2) to the west until they are reduced to a chloritic schist adjacent a thin, foliated carbonate band. On the western side of the carbonate is a thick package of weakly schistose, fine-grained sediments in which no primary structures have been preserved.

Foliated sediments west of the Stuhini pillow basalt are believed to be part of the Stuhini stratigraphy. Pervasive foliation and disharmonic mesoscopic folding reflect proximity to the Llewellyn fault zone. Strain is concentrated in incompetent horizons such as the fine-grained sediment. However, highly strained zones are common within the main panel of Stuhini rocks as mapped by Mihalynuk *et al.* (unpublished data, 1991) and Werner (unpublished UBC map, 1978) where they may affect both volcanic and sedimentary strata.

Skelly Lake

South of the eastern end of Skelly Lake a half a square kilometre or more is underlain by pyritic rhyolite tuff and clastic strata. Rhyolite appears to grade from massive, indurated breccia and flows to chlorite - quartz - feldspar semischist. Protoliths for the schist appears to be medium to coarse-grained clastic strata derived from the rhyolite tuff. Unfortunately, contact relationships are obscured by thermal metamorphism related to the emplacement of abundant felsic dikes and nearby granodiorite bodies of the Coast Belt.

Regional Correlations, Age & Tectonic Significance

Inclusion of foliated rocks with recognizable protolith textures with either the Stuhini Group (as unit uTSf on Figure GM97-1) or with the Boundary Ranges suite may mask important relationships. Foliated rock packages along strike both north and south of the map area that were originally thought to be Stuhini Group, are now known to be of Permian age in southern Yukon (C.J.R. Hart personal communication, 1993) or of Pennsylvanian age in the Tulsequah area (Mihalynuk *et al.*, 1995). These rocks may be structurally juxtaposed with unfoliated Stuhini Group strata perhaps through protracted shuffling along the Llewellyn fault. Alternatively, differences in fabric may be due to a deformational event that predates Stuhini Group deposition.

Occurrence of a crustal sliver of ammonite-bearing Lower Jurassic sediment that is enclosed by foliated volcanic strata clearly shows that tectonic admixing along the Llewellyn Fault does occur. This is further emphasized by an isotopically dated 58.5Ma rhyolite from within variably foliated volcanic strata near Skelly Lake (Tables AA1, AA2, albeit the sample may have been collected from a late dike). On the other hand, foliation of presumed Stuhini Group at Hoboe Glacier apparently predates intrusion of the Willison Bay pluton at *circa* 217 Ma (see Chapter 12). Because of this, Mihalynuk *et al*. (1996) included the foliated basalts in a unit of Carboniferous to Triassic age. The rocks with very well preserved relict protolith textures at Tutshi Lake, including a probable banded chert unit, could be included in this same unit. Both are believed to be correlative with the Paleozoic Stikine assemblage (as, it is suspected, is the Boundary Ranges Metamorphic suite, see Chapter 3). Foliated rocks west of Bennett Lake extend into the Yukon where they have yielded a Permian age and, on this basis, are also believed correlative with the Stikine assemblage. Foliated rhyolite tuffs south of Racine Lake and southwest of Skelly Lake are more enigmatic.

Photo 4-3. Foliated carbonate layer southwest of Racine Lake, is included with the Stuhini Group.

Rhyolite tuffs at Racine Lake

Rhyolite tuffs within foliated, mainly volcanic strata south of Racine Lake are unlike any unit found within Stuhini Group elsewhere in the map area. However, close association with lithologies typical of the Stuhini Group, such as thin carbonate layers (Photo 4-3), turbiditic wacke and coarse pyroxene-phyric basaltic breccia, suggest a correlation between the two. An unfoliated rhyolite lens 2 kilometres south of Racine Lake may be coeval with the foliated rhyolite tuff. In general these foliated rocks display a single foliation which does not appear to be overprinted by later fabrics. In contrast, two or three fabrics are commonly displayed by rocks of the Boundary Ranges Metamorphic Suite. Thus, they are probably younger than the Boundary Ranges protoliths.

A minimum age limit is difficult to interpret, particularly as variably foliated rhyolitic tuffs above the southwest shore of Skelly Lake, originally thought to belong to this package, could be of Early Tertiary age based upon a preliminary isotopic date (see discussion in preceding section). Lack of age data and similarities of lithology permit correlation with an array of different lithologic packages. Also, as these rocks crop out within the zone disrupted by the long-lived Llewellyn fault, they could be tectonic slivers with no ties to immediately adjacent units. These uncertainties aside, two correlatives appear most probable: Devono-Mississippian Stikine assemblage, in which felsic volcanic strata are common, or a felsic facies of the Stuhini Group, such as is seen in the Iskut area (Logan, 1997). Rhyolites have been mapped in foliated rocks of the Tulsequah map area by Souther (1971) and Mihalynuk *et al.* (unpublished data). However, there are also ambiguities in the Tulsequah area. Rhyolite originally mapped as Upper Triassic Stuhini Group is now known to be Early Mississippian (Sherlock *et al.*, 1994). Doherty and Hart (1988) also point out similarities between foliated rhyolitic rocks in the Yukon, and either the western facies of the Stuhini Group in the Iskut area or felsic volcanic strata in the Permian Stikine assemblage. The age and correlation of these rocks is still open to speculation.

Tutshi Lake foliated sedimentary and volcanic strata

Contacts of foliated strata with adjacent units at Tutshi Lake are generally poorly exposed and virtually no independent age data exist. One possible age constraint is imposed where chlorite - actinolite - quartz ± biotite schist of this unit is cut by a plagioclase and pyroxene - phyric dike. The dike margins have been modified by a younger deformation, but the interior remains unfoliated. Compositionally, this dike is most similar to volcanic units within the Stuhini Group, and it may be a feeder. If this is true then the foliated rocks are older than Late Triassic (Carnian) Stuhini feldspar-pyroxene porphyries. Analogous lithologies and contact relationships occur in areas of good exposure southwest of Sloko Lake (BCGS, unpublished field data) and are described by Bultman (1979) on southern Llewellyn Inlet.

Mineral Potential

Foliated rocks of Stikinia affinity occur primarily within and immediately adjacent to the Llewellyn fault zone. As a result, they are a potential hosts for shear related gold deposits. Several gold showings occur along the Llewellyn fault with some of the most significant prospects being within these foliated rocks. Examples include the Gridiron (MINFILE 104M 001) and the Nasty Cirque (Mihalynuk and Rouse, 1988a; near Moon Lake). Assays from the Gridiron showing returned 3.2 grams gold per tonne and 315 grams silver per tonne, and the Nasty Cirque (Big Thing, 104M071) returned 27 grams gold per tonne and 48 grams silver per tonne (Table DD). However, both of these showings are small, reflecting the discontinuous nature of structural and lithologic units within this foliated package. Yet some units within this foliated unit display significant continuity along-strike; such as the carbonate unit (Photo 4-3) which can be traced for 6 kilometres south of Racine Lake, and the banded silicic sediments east of Tutshi Lake probably extend for more than 1.5 km. Thus, mineralized zones with along-strike persistence might also exist.

Correlation of felsic volcanic units is particularly important. If an early Mississippian age can be demonstrated, then they may correlate with the felsic volcanic facies at the Tulsequah Chief and Big Bull Deposits in the Tulsequah map area, making these felsic units an exploration target for volcanogenic massive sulphide deposits.

Chapter 5 Cache Creek Terrane

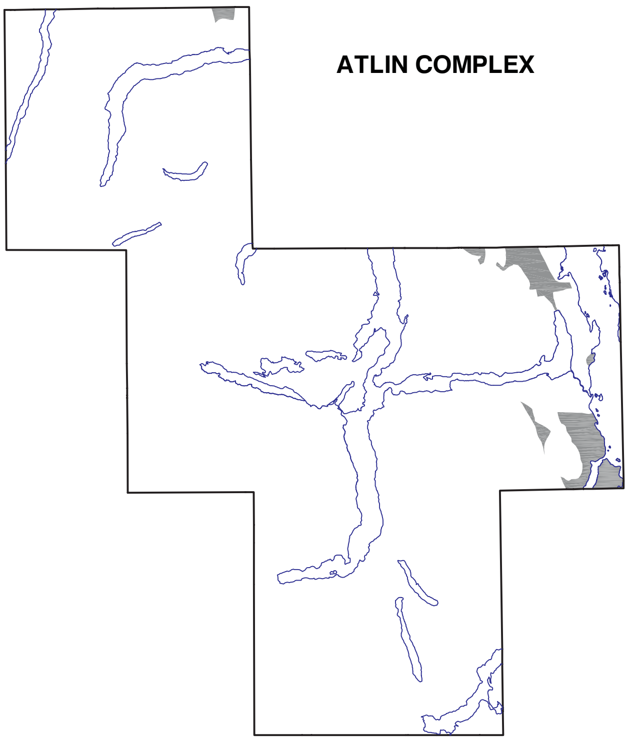


Figure 5-1. Distribution of Atlin complex rocks in the Tagish area.

Oceanic rocks of the Cache Creek Terrane occur along the eastern margin of the map area from northern Teresa Island in the south to Mount Patterson in the north (Figure 5-1). Western extents of the terrane within the map area generally coincide with the Nahlin fault which juxtaposes it with deformed strata of the Lower Jurassic Laberge Group (Figure GM97-1). An exception may occur near Graham Inlet, where volcanic strata of the Peninsula Mountain suite (Chapter 7) apparently separate most of the Cache Creek from the Nahlin fault. At this locality, however, ultramafic and basaltic rocks of the Graham Creek suite (see Chapter 6) occur along the fault. If Graham Creek rocks are equivalent to Cache Creek strata then the Nahlin fault consistently marks the western contact of the Cache Creek Terrane.

Rocks of the Cache Creek Terrane are dominated by basic volcanics and carbonate, but include slivers of ultramafite, chert and argillite of ophiolitic origin (Monger, 1975; Ash and Arksey, 1990b) and coarse clastic rocks of arc affinity. Monger (1975) included these rocks as part of the "southwestern facies belt" later renamed the "Nakina Subterrane" (Monger *et al.,* 1991; Figure 5-2).

Strata and structures in the Cache Creek Terrane have been studied immediately north of the map area by Wheeler (1959, 1961) and Hart and Radloff (1990); to the east by Bloodgood *et al.*, (1989) and Bloodgood and Bellefontaine (1990), and more regionally by Monger (1975, 1977a). Significant paleontological contributions include those of Monger and Ross (1971), Monger (1975, 1977a; fusulinids), Orchard (*in* Bloodgood *et al*., 1989, 1990; conodonts) and Cordey (1990; radiolarians). It has long been recognized that Paleozoic and early Mesozoic fossils from the Cache Creek Terrane are of exotic Tethyan origin. This Tethyan affinity was first established from fusulinids faunas collected in the Atlin area and identified by M.L. Thompson (*in* Harker, 1953). Ultramafic rocks have been the focus of studies by Terry (1977) and Ash and Arksey (1990b); both studies concluded that Cache Creek ultramafic rocks are of oceanic crustal origin.

Parts of the western margin of the Cache Creek Terrane exposed in the map area are highly disrupted. Most units are bounded by faults. Depositional contacts are rare along the margins, but may be more common towards the centre of the terrane (Monger, 1975; Hart and Pelletier, 1989a). Mixtures of various lithologies can occur as structurally interleaved panels or lenses that form spectacular tectonic mélanges, or as polymictic breccias. Formerly these lithologies were assembled as formations (*e.g.* Monger, 1975, 1977a; Hart and Radloff, 1990). Some of the difficulties of applying a nomenclature to

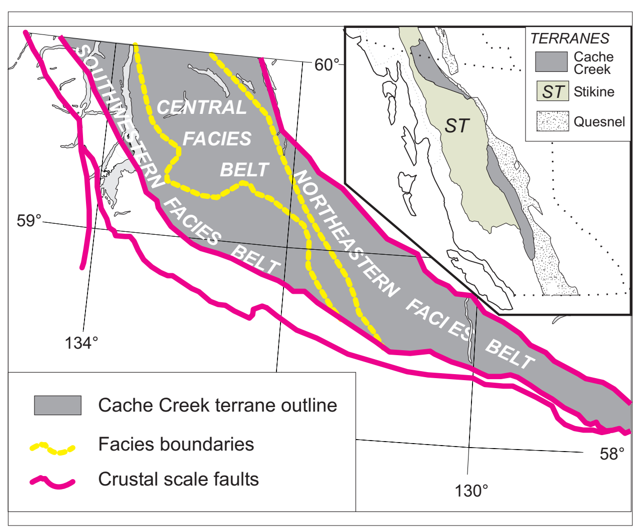


Figure 5-2. Facies belt distribution of Monger (1975) within the Atlin Complex. Inset shows the distribution of Cache Creek Terrane in British Columbia.

units comprising the northern Cache Creek Terrane are discussed by Monger (1975, p.2) who attempted to apply uniform terminology over the entire Atlin area while striving as much as possible to conform to original usage. The formation names of Monger are useful for layered rocks within the bounds of their stated limitations, even though the application of the "formation" designation may locally be inappropriate (*cf*. North American Commission on Stratigraphic Nomenclature, 1983). However, Monger's "Group" designation has not been adopted, rather these rocks are here collectively referred to as the "Cache Creek Terrane" or, in the region around Atlin, the "Atlin Complex" in keeping with recommendations of the North American Commission on Stratigraphic Nomenclature.

Nahlin ultramafic suite (CPu)

Ultramafic rocks within the Atlin complex were named the "Atlin Intrusions" by Aitken (1959), and in the Tulsequah mapsheet, Souther (1971) termed the main ultramafic mass the "Nahlin ultramafic body". Souther recognized that it was emplaced as a solid or near solid intrusion as adjacent rocks are not thermally metamorphosed. Although his interpretations differed, his observations were consistent with the ophiolitic origin later proposed by Terry (1977) who compared the Nahlin ultramafic rocks with the Pindos ophiolites of Greece. Terry included these rocks with the "Nakina Ophiolite Suite". The nomenclature of Souther is preferred here as it is not restricted to a genetic interpretation. However, the Nahlin is composed of a variety of lithologies, so the term "suite" is preferred over "body". Rocks of the Nahlin ultramafic suite range in composition from harzburgite to dunite and serpentinized equivalents (isolated plagiogranite is reported from near Hardluck Peaks, well outside the map area, 104J/13; Terry, 1977; C.H. Ash, personal communication, 1990).

Within the map area, ultramafic rocks occur as elongate lenses that are metres to kilometres in length. South of Graham Inlet they outline the westernmost strand of the Nahlin fault. This relationship also holds to the north of Graham Inlet if ultramafic lenses of the Graham Creek suite are truly correlative with the Atlin complex. Here ultramafic rocks are sandwiched between Peninsula Mountain and Laberge Group strata. Ultramafic lenses and sheets are abundant within the western Atlin Complex. They occur more sporadically in the interior of the terrane where they are dominated by harzburgites in which an early tectonite fabric may be preserved. Such fabrics are common near Atlin (Ash and Arksey, 1990b).

In a typical large lens, medium to coarse, unfoliated harzburgite forms kernels within a sheared, fine-grained groundmass of recrystallized harzburgite and serpentinite. Margins, and to a lesser extent, interiors of such lenses may be extensively altered to quartz, carbonate and mariposite or serpentinized, and display a late, steep fabric (Photo 5-1).

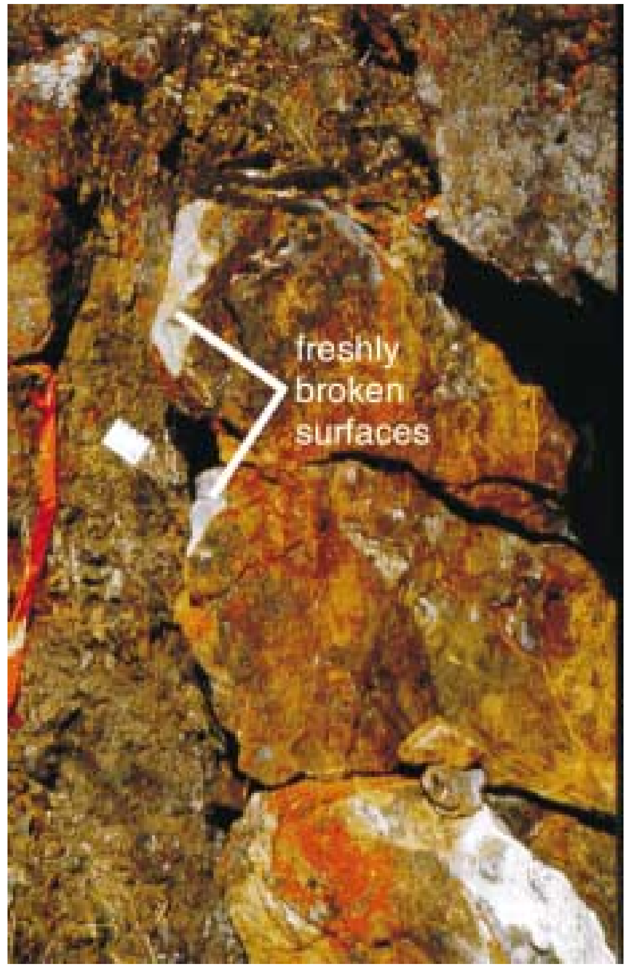


Photo 5-1. Altered ultramafic outcrops along the shores of Atlin Lake are commonly listwanitized and display a late, steep, northwest-trending fabric.

Harzburgites are bright orange or dark red weathering and dark purple-brown to black on fresh surfaces. Altered varieties commonly have a hackley surface due to many generations of crosscutting, resistant quartz veins. Fresh surfaces of quartz-carbonate-altered varieties are white to yellow and flecked with green mariposite (chrome mica) and black magnetite. Serpentinite is probably largely derived from hydrated harzburgite, some of which has survived as relict pods. Serpentinites are bright green to black or blue on both weathered and fresh surfaces. Fabrics within serpentinite are commonly randomly oriented and dominated by slickensided surfaces. Such surfaces are light to medium green, polished, and contain fibrous aggregates.

Ultramafite within the Atlin Complex displays lithologic, mineralogical (Monger, 1975), textural (Terry, 1977), structural, rare earth element and mineral geochemical (Ash and Arksey, 1990b) liknesses to upper mantle components of known ophiolites that occur in alpine ultramafic belts around the world. Earlier thoughts along these same lines were presented by Aitken (1953) and Mulligan (1963). Thus, even though these rocks have not been dated directly, they potentially represent some of the oldest lithologies within the complex.

Serpentinized harzburgite or dunite may be remobilized as diapiric or dike-like intrusions, as has been well-documented in the Franciscan formation of California (Lockwood, 1972). They may, therefore, cut across younger strata (as suggested by Monger, 1975). Subaqueous serpentinite extrusions may be common in forearc environments. They have been well documented at Conical Seamount in the Mariana forearc. Conical Seamount is a kind of "mud volcano" built up by successive serpentine extrusions. Fryer *et al.* (1995) describe active serpentinite seamounts, including Conical Seamount, and propose that they form as a result of two end-member processes: serpentine mud volcanoes and horst blocks. In both cases, the mechanism driving serpentinite emplacement at the ocean floor is hydration of ultramafic source rocks. Hydration is enhanced above subduction zones due to dewatering of the down going slab and may be especially vigorous during the first few million years following initiation of a subduction zone. This hydration expansion or "protrusion mechanism" forces serpentine to the surface as flows and/or by elevating ultramafic horst blocks. Fluid venting on the resultant seamounts produces carbonate and silicate chimneys.

At Sunday Peak, serpentinite intercalated with sediment may have been expelled onto the Mesozoic basin floor, and vacuous siliceous carbonate horizons within the serpentinite may be the relicts of fallen chimneys produced during fluid venting. Many isolated, irregular serpentinite bodies in the northern Whitehorse Trough are surrounded by Laberge Group strata that show no sign of contact metamorphism (Wheeler, 1961). Perhaps the best modern analogues are serpentinite protrusions in the outer portions of active, youthful forearcs like the Izu-Bonin and Mariana, which supports a forearc setting for the site of Laberge deposition (implications of this are discussed in Chapter 15).

Nakina Formation Basalt (CPn)

Basalt of probable Mississippian to Pennsylvanian age that form parts of the western and northern Atlin Complex are dominant constituents of the Nakina Formation (Monger, 1975). As mapped within the Tagish area, the Nakina Formation probably occurs at more than one stratigraphic interval. Thus strict "formation" status may be inappropriate, but is retained for the reasons outlined by Monger (1975, Appendix B).

Distinctive Nakina Formation rocks crop out on Mount Patterson and Sunday Peak. Gabbro and pillow basalt at Graham Creek may be part of this unit, but are discussed separately because they are separated from the main mass of the Atlin complex.

Nakina lithologies include fine-grained, massive black basaltic flows and tuff, mint green basaltic tuff and tuffaceous sediments, and possible flows. Rare primary textures are preserved: these show the local brecciated, pillowed, or amygdaloidal nature of the formation. Peculiar gabbroic patches, which may represent the interiors of flows or large pillows, and widespread networks of feldspar veinlets (Photo 5-2), are more characteristic. Pervasive, randomly oriented black shears and sheared layers containing cataclasts 0.1 to 1 centimetre in size are also distinctive, and may be in part a primary slump or autoclastic feature (as is commonly recognized in core recovered from the Ocean Drilling Program). Weathered outcrops are generally massive, black, green to grey-green and heavily lichen covered. Feldspar and pyroxene phenocrysts are uncommon, but can comprise up to a few percent of the outcrop.

Within the map area, Nakina rocks have been metamorphosed to prehnite-pumpellyite grade (Photo 5-3); although, in the Yukon they apparently attain amphibolite grade (metamorphic hornblende is noted by Monger, 1975, p. 31).

Major oxide geochemistry from this unit confirms their basaltic composition (Figure 5-3a) and tholeiitic association (Figure 5-3b, c). Tectonic discrimination plots based upon major oxide data yield contrasting indications of ocean island tholeiite (Figure 5-3d) and tholeiitic arc basalt (Figure 5-3e). Rare earth elements do not provide a means to discriminate since light REE enrichment can occurs as a result of sub-lithospheric contributions in both within plate (ocean island basalt), and subduction zone (island arc) settings (*e.g.* Pearce, 1983). Ash (1994) concluded that basalts in the Atlin area are of mid-ocean ridge parentage based upon a more complete elemental suite from analysis of 17 samples, of which 5 were analyzed for REEs. Further geochemical investigation is re-

Photo 5-2. Nakina Formation basaltic tuffs. Zones of reticulate quartz - feldspar veinlets, as shown in the lower part of the photo, are common.

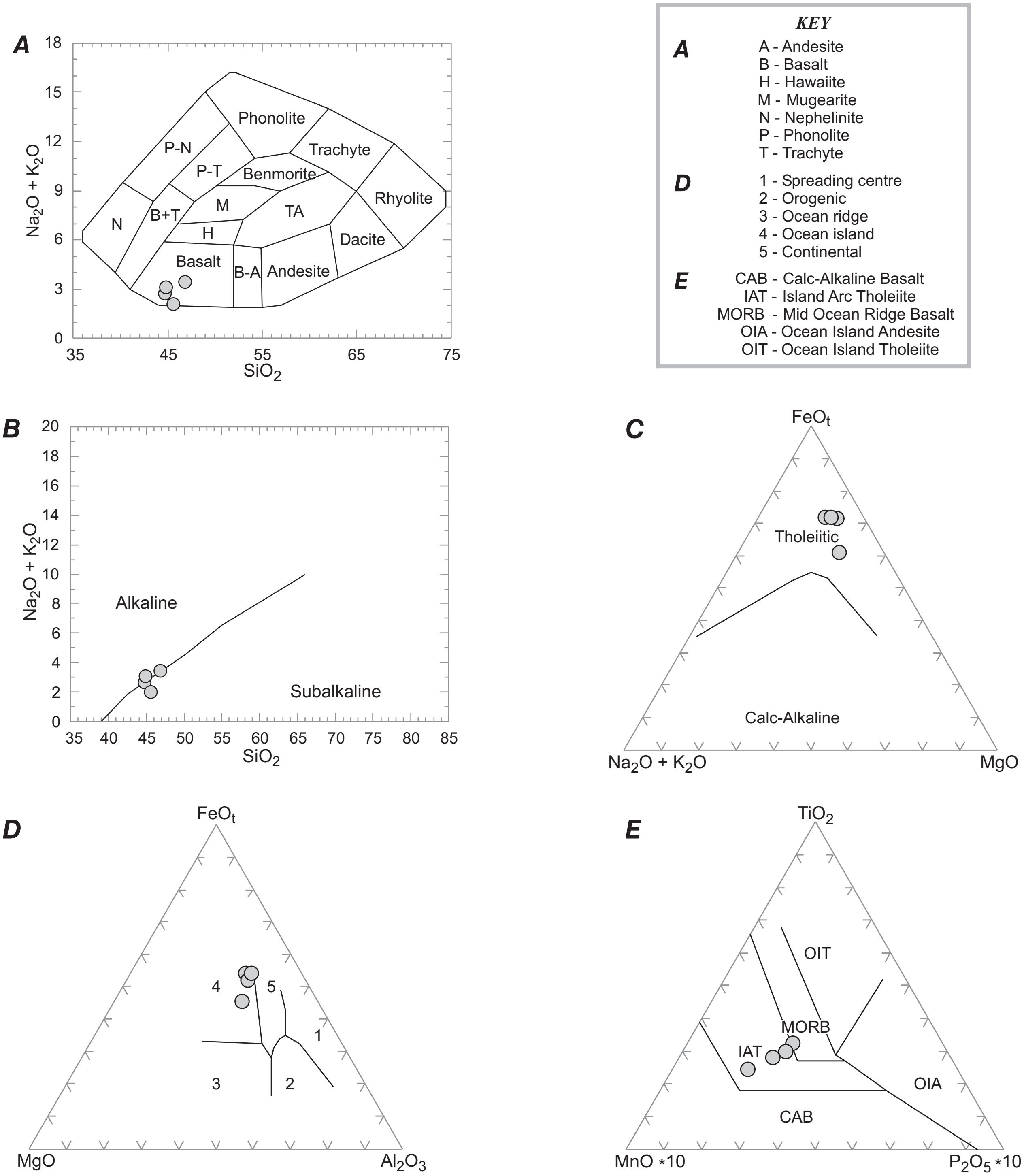


Figure 5-3. Geochemistry of Nakina Formation basalt: (a) alkalis versus silica classification diagram shows basaltic composition (method of Cox *et al.*, 1979); (b) alkalis-silica and (c) AFM diagrams of Irvine and Barager (1971) show a clear tholeiitic trend; tectonic discrimination plots showing (d) MgO-Al_2O_3-$FeOt$ (Pearce *et al.*, 1977) and (e) MnO*10-P_2O_5*10-TiO_2 (Mullen, 1983) are inconsistent in their indication of Ocean Island and Island Arc parentage.

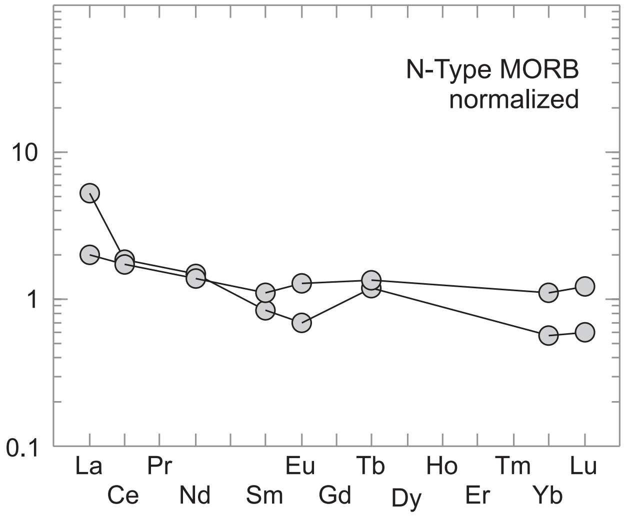


Figure 5-4. REE plot shows that unit CPn is light-REE enriched with respect to normal MORB.

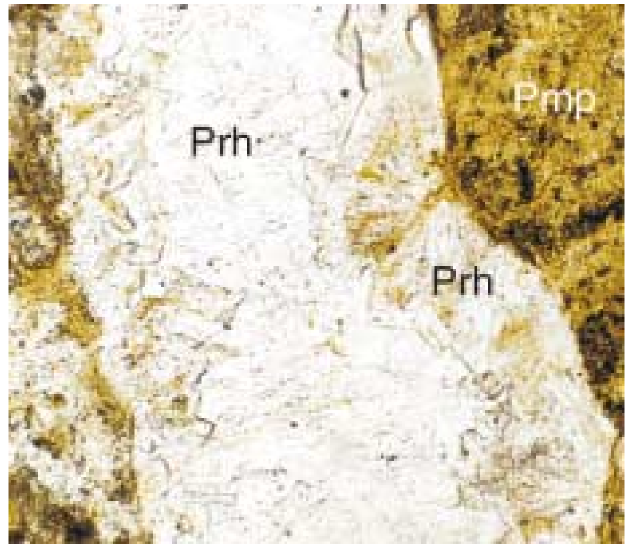


Photo 5-3. Photomicrograph showing authigenic mineralogy in the Nakina Formation. The assemblage includes prehnite (Prh) and pumpellyite (Pmp), indicating that these rocks have been subjected to only very low grade metamorphism. Width of the photo represents 1mm.

quired to fully characterize the paleotectonic eruptive setting of the Nakina basalts.

It has been suggested that the Nakina Formation rocks form the base of the Cache Creek stratigraphic succession (Monger, 1975). They are intercalated with sediments that contain the oldest fossils obtained from Cache Creek rocks at this latitude (early Mississippian; *ibid*.). In the Yukon, apparent structural position and relatively high metamorphic grade also support assignment of the Nakina rocks to the base of the Cache Creek stratigraphy (Hart and Pelletier, 1989a, pp. 9-11). These rocks are directly correlative with the Conrad Member of Hart and Pelletier (1989a). In the Tagish area, a consistent stratigraphic position is not apparent.

Kedahda Formation Chert & Clastics (CPk)

Chert of the northern Cache Creek Terrane crops out at several localities within 104N/12W and probably underlies a significant portion of covered areas. Chert is highly variable in character, occurring as tan, black and less commonly white, red or green varieties, and forms strongly fractured, angular outcrops. Fractures in light coloured varieties are enveloped by black discoloration. Massive and brecciated varieties dominate, but well bedded sections are fairly common. Semi-massive sections typically contain zones with vague contorted bedding or may be folded into tight chevron folds. Ribbon cherts are bedded on a scale of 2 to 10 centimetres with 0.5 to 4-centimetre argillite, or less commonly, medium-grained wacke interbeds. The unusual association with interlayered wackes, which occur both as planar beds and as discontinuous ribbons or boudins, is also reported by Gordey (1991) in the Teslin area. There, chert fragments are a constituent of wacke interlayers.

Massive to brecciated, tan to white and lesser black chert forms the bulk of eastern Ear Mountain. Just to the southeast, near Taku Mountain, massive black chert and chert breccia predominate. Well bedded red chert with argillite interbeds crops out at Telegraph Bay where it is strongly recrystallized in the thermal aureole of the Fourth of July batholith. Ribbon chert is also exposed on northern Teresa Island and on southern Atlin Mountain. Chert south of Atlin River is interlayered with wacke.

Radiolarians are visible in outcrops of chert, but are commonly recrystallized. Where they have survived, they indicate Permian through Late Triassic ages (Cordey, 1990). However, most cherts from the Atlin area are of Middle to Late Triassic age as is the case for ribbon chert in eastern Fantail Lake area (Cordey, 1990).

Angular chert clasts comprise a large portion of the lithic fragments in the wackes. Such wackes may grade into argillite and are commonly interbedded with chert. This relationship implies that lithified chert is eroded and redeposited in the basin in which it is forming. Processes that may explain this nearly contemporaneous deposition and recycling of chert include: sediment cannibalism during fore-arc horst and graben formation, oceanic sediment offscraping and construction of an emergent accretionary prism, or incipient orogenesis during the early stages of collision between the Cache Creek Terrane and North America.

Argillite (CPk, CPac)

Argillite is a common but poorly exposed and, therefore, poorly represented constituent of the Atlin Complex, as it typically weathers recessively to form vegetated areas. It is brown, black or rusty red in colour and commonly well laminated, fissile and incompetent. It may be well bedded, but beds are commonly discontinuous. In many places it grades into chert or contains chert interlayers. Cherty argillite is at least as common as calcareous and fissile varieties. Locally the argillite contains thin interlayers of medium-grained wacke. (Outside the map area to the east, argillite interbedded with medium to coarse wacke is common). Bedding is normally steep. A moderate to strong, spaced fracture is ubiquitous and so close in places that it can be difficult to obtain a fist-sized sample. It is generally not possible to trace layers or packages more than a few hundred metres, and most argillite successions probably occur as fault-bounded lenses. In rare instances where the contacts of the argillite units are exposed, they tend to be strongly sheared. Near intrusions, the argillite becomes well indurated, blocky weathering, purple-brown hornfels. Where argillite occurs over a broad areas of more than a square kilometres in extent, it is included in the Kedahda Formation, CPk (Figure GM97-1). If argillite lenses are tectonically admixed with a variety of other lithologies (serpentinite, carbonate), it is included in the accretionary complex unit, CPac.

Macrofossils are not common in argillites of the Cache Creek Terrane. This may be partly a function of poor preservation potential as a result of the high degree of strain and fracturing within the argillites. However, in eastern Cache Creek Terrane, argillite appears to be a good host for radiolarians (*e.g.* Jackson, 1992).

In western Atlin Complex, fault-bounded lenses of cherty argillite are the dominant facies. Here a steep fabric dominates. The fabric may be emplacement-related or an overprint related to younger, translational deformation along the western margin of the northern Atlin complex. Just to the east of the map area, Ash and Arksey (1990) mapped gently dipping ultramafic sheets that sit structurally above a sedimentary unit composed mainly of argillites displaying steep fabrics. They interpreted the contrasting structural styles as a product of argillite offscraping to produce the accretionary complex (unit CPac) which was overthrust by a dismembered ophiolite (unit CPu). This possibility is further addressed within the context of the overall geologic history of the study area (Chapter 15).

Horsefeed Formation Carbonate (CPh)

Bluffs of massive, pale grey to tan or locally orange coloured carbonate are the most distinctive feature of the

Photo 5-4. Distinctive carbonate of the Horsefeed Formation form resistant but low weathering, poorly vegetated mountainsides like those of Charlie Peak in the Tagish area. The view is to the east along Tutshi Lake.

Cache Creek Terrane (Photo 5-4). They are grey to black on fresh surfaces, and form rounded, poorly vegetated outcrops outlining lensoid bodies hundreds of metres thick. Bedding is rarely seen in outcrop, but can commonly be discerned from a distance. Locally, bedding may roughly coincide with trails of dissolution pockets or irregular bands of hackley, tan to grey chert. In most outcrops, macrofossils are conspicuously absent. Weathered surfaces may develop siliceous spicules or wispy black veinlets of coarsely crystalline calcite that form anastomosing swarms. Brecciated zones or sets of tension gashes may be infilled with coarse, white calcite.

According to Monger (1975) the carbonates host one of the most complete Tethyan fusulinid faunas in North America, and probably accumulated in well oxygenated banks and shoals in shallow waters. Diagnostic fossils from this lithology range from Early Pennsylvanian to Late Permian age.

Horsefeed Formation occurrences within the map area include an extensive mass of carbonate at the north end of eastern Graham Inlet that stretches north, beyond 104N/12W, and an along-strike continuation to the south that forms a band spanning the north end of Torres Channel. Carbonate at the latter locality contains conodonts of Late Carboniferous-Early Permian (Sakmarian) age (Table B2; identifications by M.J. Orchard). Where best exposed, on the north end of Teresa Island, this limestone is in fault contact with adjacent units.

Relatively thin carbonate lenses less than 1 kilometre long crop out on the southeast side of Atlin Mountain and are recrystallized to a coarse marble where thermally metamorphosed by the Atlin Mountain intrusion. Similar carbonates are commonly interbedded with chert, argillite and lesser wacke of the Kedahda Formation (Monger, 1975).

Accretionary Complex (CPac)

Over half of the accretionary complex unit exposed in the map area is a mélange. It includes a tectonic mixture of all lithologies present in the Atlin Complex. One mappable unit, interpreted as broken formation, is characteristic. It is composed of highly strained, fine to medium-grained, medium to dark grey-green volcanic wacke, chert, cherty mudstone, and basalt (Photo 5-5). It is olive-green to brown weathering, and crops out on the north shore of northern Torres Channel. It displays few lithologically distinctive features and is defined primarily as a structural rather than a lithologic entity.

Widespread, small, rootless folds and dismembered compositional layers on millimetre to centimetre scale point to original soft-sediment deformation. Subsequent deformation formed a penetrative brittle shear fabric on an outcrop to mountainside scale. Anastomosing shears bound angular to elongate ellipsoidal domains generally less than 2 centimetres in diameter. Shear surfaces are lined with chlorite and/or calcite and display randomly oriented slickensides. Shears are variably oriented, although on an outcrop or mountainside scale, a high-angle, northwest-striking trend is evident. Zones of cataclasite with black matrix , and lenses of dioritic to ultramafic intrusive rock are also locally present.

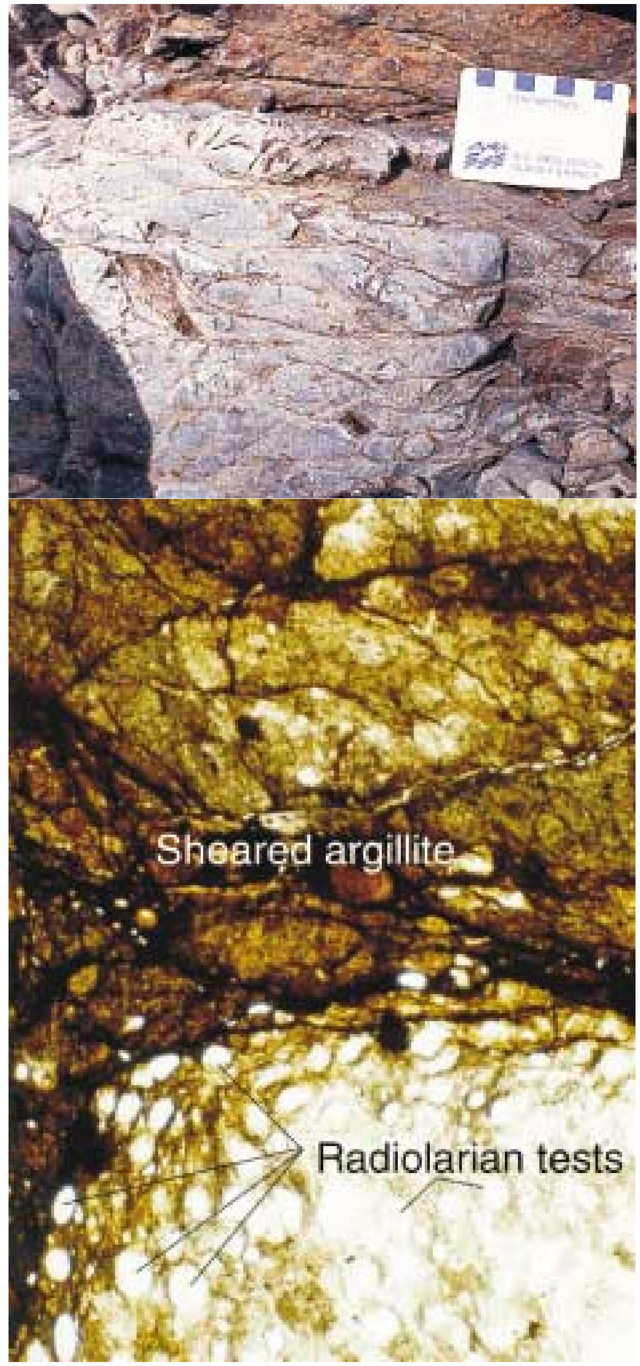


Photo 5-5. Broken formation (top) outcrop of disrupted chert layers in an argillite matrix, and (bottom) photomicrograph of radiolarian chert structurally juxtaposed against argillite (long dimension represents 2.5mm).

Wacke (PJs)

Wackes from the Atlin Complex can be divided into two lithologic packages on the basis of apparent provenance: those dominantly derived from volcanic rocks, and those derived from sedimentary and felsic plutonic sources. They may contain conglomeratic interlayers which aid identification of clast types at the outcrop. They are generally massive in character, but where bedded, commonly display evidence of internal, synsedimentary disruption.

Wackes dominantly derived from sedimentary and felsic plutonic rocks are rare. They are grey to green weathering, dark grey on fresh surfaces, and medium to coarse grained. In one locality a lense of conglomerate is preserved within the wacke. Clast types include angular chert, quartz and those of felsic plutonic origin. A spectacular example is the first set of outcrops south of the point where the Atlin River enters Atlin Lake (below the high water line, Photo 5-6).

Wackes of volcanic provenance occur with light grey chert in the Graham Creek valley where they are in fault contact to the southwest with argillite of the Laberge Group. At the contact, argillite is silicified and extensively cut by irregular, tan to brown dolomite veins up to 30 centimetres thick. Chert and cherty wacke above this contact weather tan, grey or black, with a rubbly surface produced by a myriad of fractures. Outcrops break into popcorn-sized angular fragments making them difficult to sample. In more competent zones, an indistinct bedding locally outlined by wavy argillaceous partings occurs rarely. Beds dip moderately steeply to the southwest, but stratigraphic tops are uncertain.

Photo 5-6. Conglomerate lens containing felsic intrusive clasts, aphanitic to feldspar-phyric volcanic clasts, carbonate cobbles and quartz granules within blue-grey argillaceous wacke matrix.

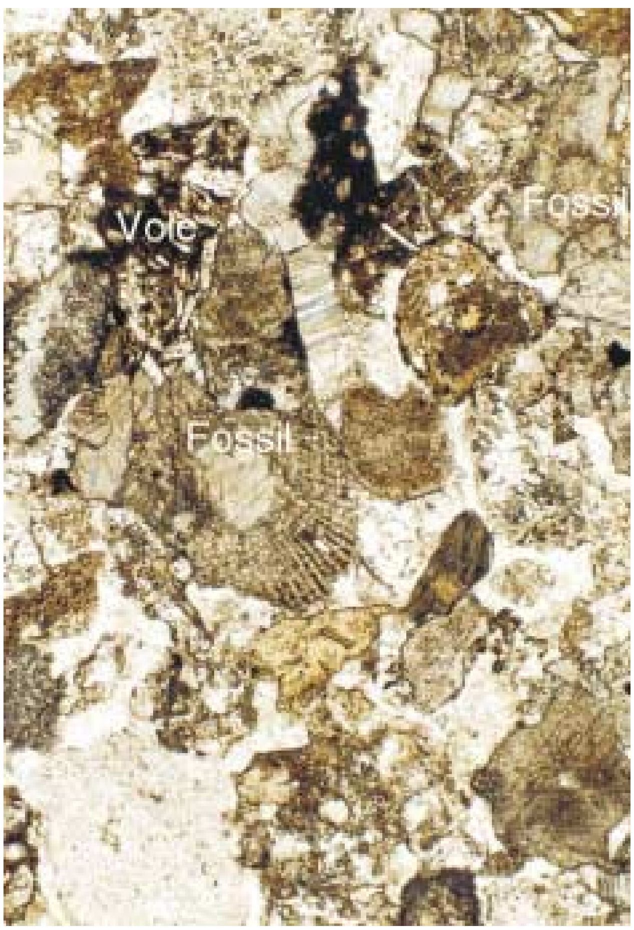


Photo 5-7. Photomicrograph of wacke from unit PJs. Long dimension of photo represents 2.5mm.

Wackes of volcanic provenance are fine to locally coarse grained, and medium to dark grey-green or olive-green weathering. Petrographic analysis of siliceous grain-supported wacke (Photo 5-7) shows that the rock is composed mainly of sericitized feldspar (45%), altered lithic grains (25%, mainly volcanic), quartz with undulatory extinction (15%), twinned carbonate grains (2%),and chloritized mafic minerals (2%). Some coarse clastic grains that can be identified in the field are trachytic basalt, plagioclase and sparse quartz. Petrographic analysis of this unit shows that some of the carbonate grains are derived from fossils (Photo 5-7). Volcanic wacke of this unit is locally very disrupted and may locally be included in the accretionary complex unit (CPac, see above).

Age and Interpretation

The oldest rocks of the Atlin Complex are lower Mississippian based on fusulinid fossils (Monger, 1975). Youngest rocks range up to Lower Jurassic age as determined from fossil radiolarians (Cordey *et al*., 1991). Age distribution appears to vary somewhat systematically according to the facies distribution of Monger (1975, 1977a; Figure 5-2). Data currently available indicate that rocks of the southwestern facies belt are of early Mississippian to Late Triassic age; whereas, the dominantly younger northwestern facies belt is Permian to Middle Jurassic. The possible significance of this distribution of rocks is discussed briefly under the heading of Geological History (Chapter 15). Fossil data from the map area indicate that the rocks span a range of ages from perhaps late Carboniferous (Table B2) to Middle or Upper Triassic (Mihalynuk *et al.*, 1991) if a correlation with the Graham Creek suite is correct (see Chapter 15 for discussion).

Many of the sedimentological aspects of Atlin Complex genesis have been addressed previoiusly (Monger, 1975). Observations that have not previously been emphasized include the presence of quartz-rich wacke, presumably from an evolved arc or continental source, interbedded with chert. Also, chert sharpstone conglomerate units are relatively common and may indicate cannibalistic recycling of emergent or upthrust abyssal components of the Atlin Complex.

Mineral Potential

Ultramafic rocks of the Cache Creek Terrane have historically been called the “Gold series” in order to underscore their persistent association with placer gold camps. In the prolific Atlin placer camp no lode deposits have yet been discovered that could explain the spectacular placer gold recovery from surrounding streams. Despite the historical lack of success of lode gold exploration, the Atlin area still holds significant promise. Two metallogenic environments warrant particular attention. These are: quartz-carbonate-mariposite altered mafic and ultramafic units, and altered zones surrounding secondary intrusive bodies with particular focus on lamprophyres.

Quartz-carbonate-mariposite alteration of ultramafic units is common in the Atlin Complex. In the study area, virtually every major occurrence of ultramafite is locally altered to some degree - particularly adjacent to significant fault zones (Ash, 1994). Elsewhere in British Columbia and the world, major structures spatially associated with carbonatized alpine ultramafic rocks host Mother-lode gold deposits. Although no significant gold production has come from lodes in the Atlin camp, a large amount of coarse placer gold has been recovered (Debicki, 1984). Is a rich lode gold source still to be discovered or have the rich lodes all been eroded, leaving as a sign of their passage the Atlin placers?

Examples of ultramafic lode gold associations within the map area include the Beavis extension at Safety Cove and the Graham Creek property (Mihalynuk and Mountjoy, 1990). Where sampled, however, only spotty anomalously high gold values have been recovered.

Graham Creek is the only stream within the map area that contains significant placer gold. Like the placer streams in the Atlin camp, the Graham Creek watershed is underlain in part by ultramafic rocks (see Graham Creek Suite), underscoring the importance of the ultramafic - gold association. For a more detailed account of the ultramafic - lode gold association in the Atlin camp the reader is referred to Ash (1994).

Intrusive - lode gold associations in accreted oceanic terranes have been recently reviewed by Kerrich (1993). Ash *et al.* (in preparation) discuss this association with special reference to British Columbia examples. The potential for intrusive-lode gold associations adjacent to the Atlin camp remains largely untested. Part of the problem stems from a lack of gold analyses in the existing published regional geochemical survey results (MEMPR, 1977). However, samples archived from the original survey have been reanalyzed and the new geochemical data set, including gold values, is scheduled for release in the near future.

Chapter 6 Graham Creek Suite

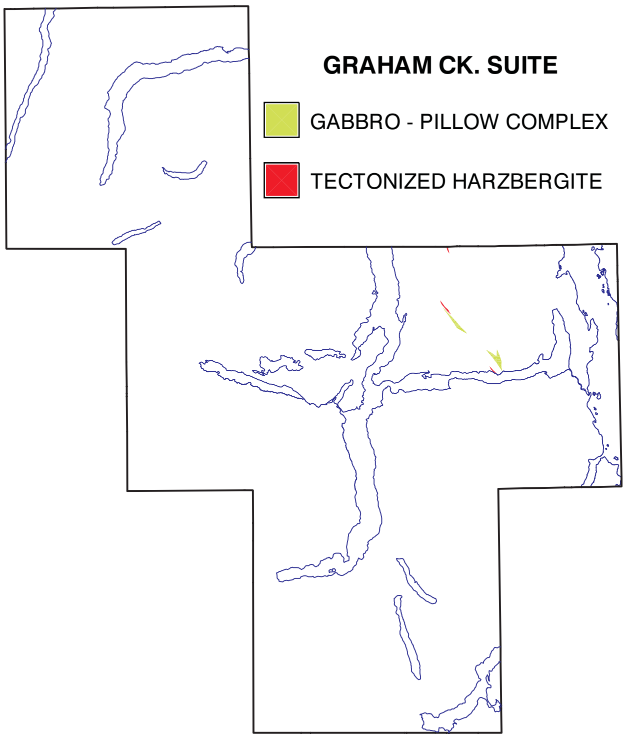


Figure 6-1. Distribution of the Graham Creek Igneous suite in the Tagish area.

Rocks of the Graham Creek Suite crop out in series of tectonic lenses less than 2 kilometres wide within a northwest- trending belt extending from Atlin Mountain to Sunday Peak (Figure 6-1). This belt probably extends northward beyond the area mapped (*cf*. Hart and Orchard, 1996). Lithologic components include tectonized harzburgite, gabbro and pillow basalt that have a consistent spatial association. Usage of this nomenclature is, however, restricted to areas where rocks of the suite are bounded to the east by the Peninsula Mountain or Windy-Table suites. Their western extent is mainly coincident with the probable northern continuation of the Nahlin fault from where it is well defined in the southern Atlin map sheet (104N; Aitken, 1959). Graham Creek rocks are probably correlative with the Atlin Complex, but they are discussed separately here to underscore the possibility that they are potentially an unrelated 'oceanic crustal assemblage' that forms basement to the Whitehorse Trough. Internal stratigraphic continuity, only a moderate degree of internal deformation (exemplified by the well preserved pillow basalts), and an upper contact that is possibly gradational with overlying Laberge Group lithologies, serve to distinguish this package of rocks from the Atlin Complex elsewhere in the map area. Exact relations with adjacent strata are obscured due to the complex structural setting and poor exposure.

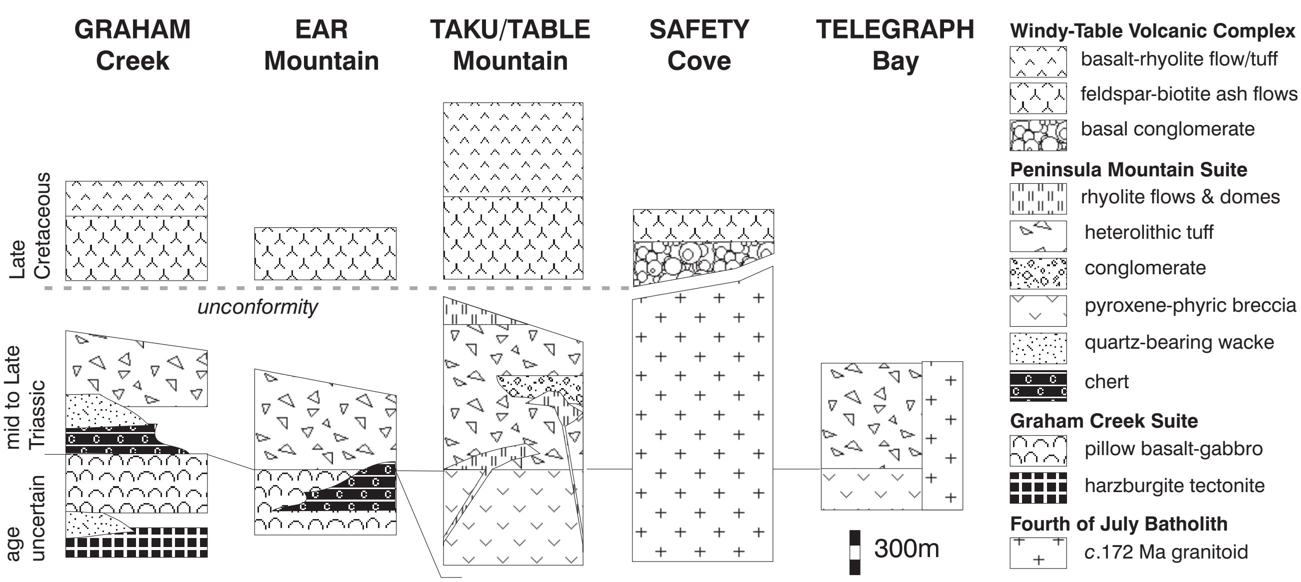


Figure 6-2. Stylized facies interrelationships between the Graham Creek Igneous and Peninsula Mountain suites.

Rocks of this suite were named by Mihalynuk and Mountjoy (1990). Bultman (1979) recognized a gabbro body on the southwest flank of Table Mountain (see Figures 2-1, GM97-1), but otherwise included these rocks with his Peninsula Mountain Formation. Early reconnaissance mapping by Cairns (1911) shows parts of the belt and correlates the rocks with the now obsolete Perkins Group which was thought to range from Devonian to Jura-Cretaceous age.

Tectonized Harzburgite and Serpentinite, MTGu

Tectonized harzburgite and serpentinite are festooned along the western margin of the Graham Creek Suite (Figure GM97-1) where they apparently occupy the lowest structural position within it (Figure 6-2). Immediately to the west are wackes that, on the basis of field criteria, are indistinguishable from those of the Laberge Group.

Generally, harzburgites are intensely listwanitized to produce a rock consisting of quartz, iron and magnesium carbonate and mariposite (chrome mica). Such rocks weather a distinctive bright orange colour and have a hackly surface (Photo 6-1) with quartz and carbonate veins standing above the surrounding weathered carbonate matrix. Thin, irregular stringers (< 0.5 cm) have a random orientation, but straight quartz veins greater than about 0.5 centimetre thick may display an orientation that is typically at high angles to the bounding contacts of the harzburgite bodies. Other than these veins, no regular secondary fabric is developed within the harzburgite, but foliated cataclasites are developed at the faulted margins of these bodies (Photo 6-2c). Locally a pervasive internal fabric is preserved. This is thought to represent an early metamorphic fabric of mantle origin as described in the harzburgites near Atlin by Ash and Arksey (1990b, Photo 6b). Mantle tectonite fabrics are best preserved on the southern flank of Sunday Peak in rocks that are pyroxene rich (80%) and surprisingly fresh (Photo 6-3). Olivine is

Photo 6-1. Tectonized, hackly-weathering harzburgite with later cross-cutting quartz veins.

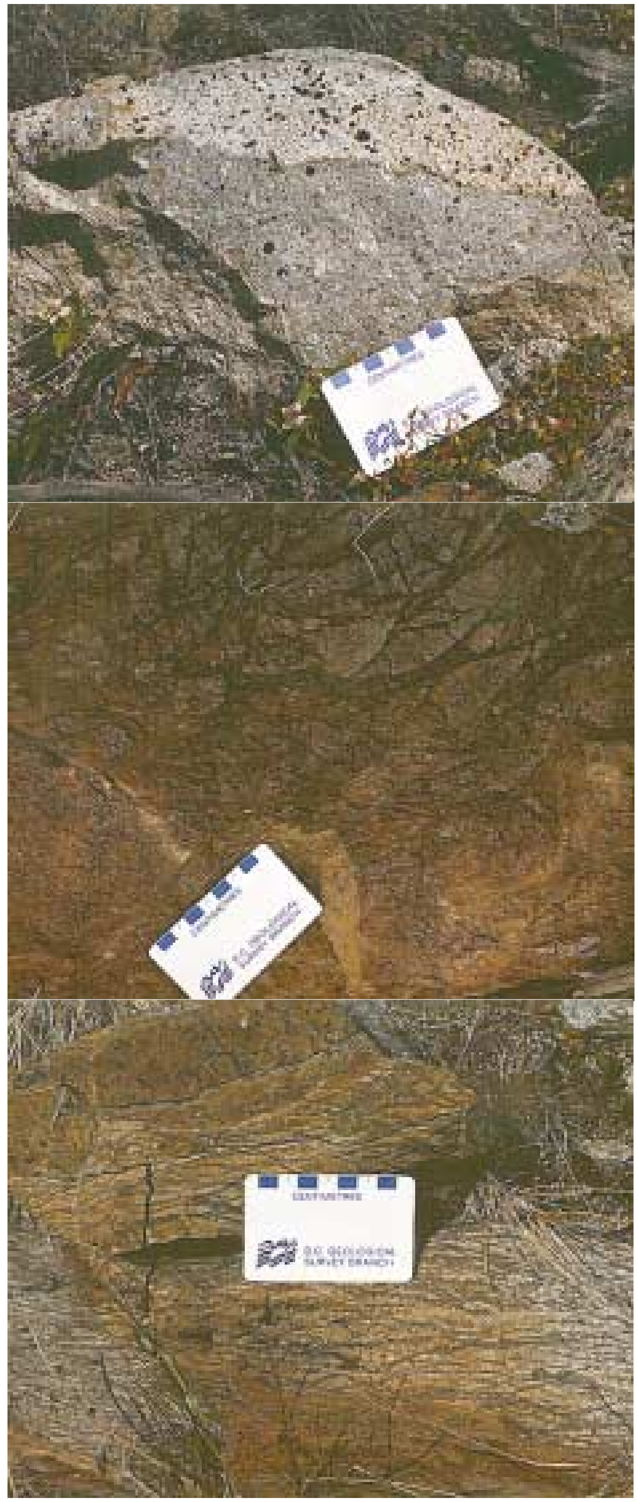


Photo 6-2. (top) Unfoliated potassium feldspar - quartz - porphyry, (middle) adjacent harzburgite tectonite, and (bottom) tectonically admixed zone at the contact of the two.

generally replaced by serpentine (typically antigorite). Serpentinite forms lenses up to tens of metres long. Protoliths may be pods or tectonic slivers of dunite. Such pods are bright green and sparsely or non-vegetated. Chrysotile veinlets up to 1 centimetre thick, but normally less than 3 mm, crosscut the serpentinite; these account for less than 3% of the rock volume.

Varitextured gabbro and pillow basalt, MTGg

Cairnes (1913) and Bultman (1979) mapped medium-grained gabbro that crops out on the southwest flank of Table Mountain. Its rubbly outcrops are extensively altered to a chlorite - actinolite - prehnite (Photo 6-4)- calcite - biotite (or stilpnomelane?) assemblage and are crosscut by microfaults. Locally, pillow basalt relicts are preserved within the gabbro. These are crosscut and assimilated by gabbro. On the eastern edge of the unit pillow basalt is well preserved (Photo 6-5).

Gabbro is comprised mainly of plagioclase (55%, andesine composition) with interstitial hornblende (40%, actinolite-altered). Plagioclase is relatively fresh with minor patches of prehnite, actinolite and chlorite alteration. In contrast to the mafic phases of the Fourth of July batholith, it contains only sparse apatite (euhedral, <1%) and no appreciable sphene.

Some fine-grained zones resemble mafic volcanics and may be disrupted flows or breccias. Gabbro may represent the slowly cooled interiors of massive flow units, or alternatively, dikes or sills within a basaltic sequence.

Massive pillow basalt is interbedded with pillow breccia. Both units are rubbly weathering and, where not covered by lichen, caramel coloured. Fresh surfaces are black with a bluish green tint. Microscopic examination shows the rocks are dominated by quenched feldspar in a devitrified groundmass and pyroxene is accessory (Photo 6-6). Metamorphic grade is subgreenschist with abun-

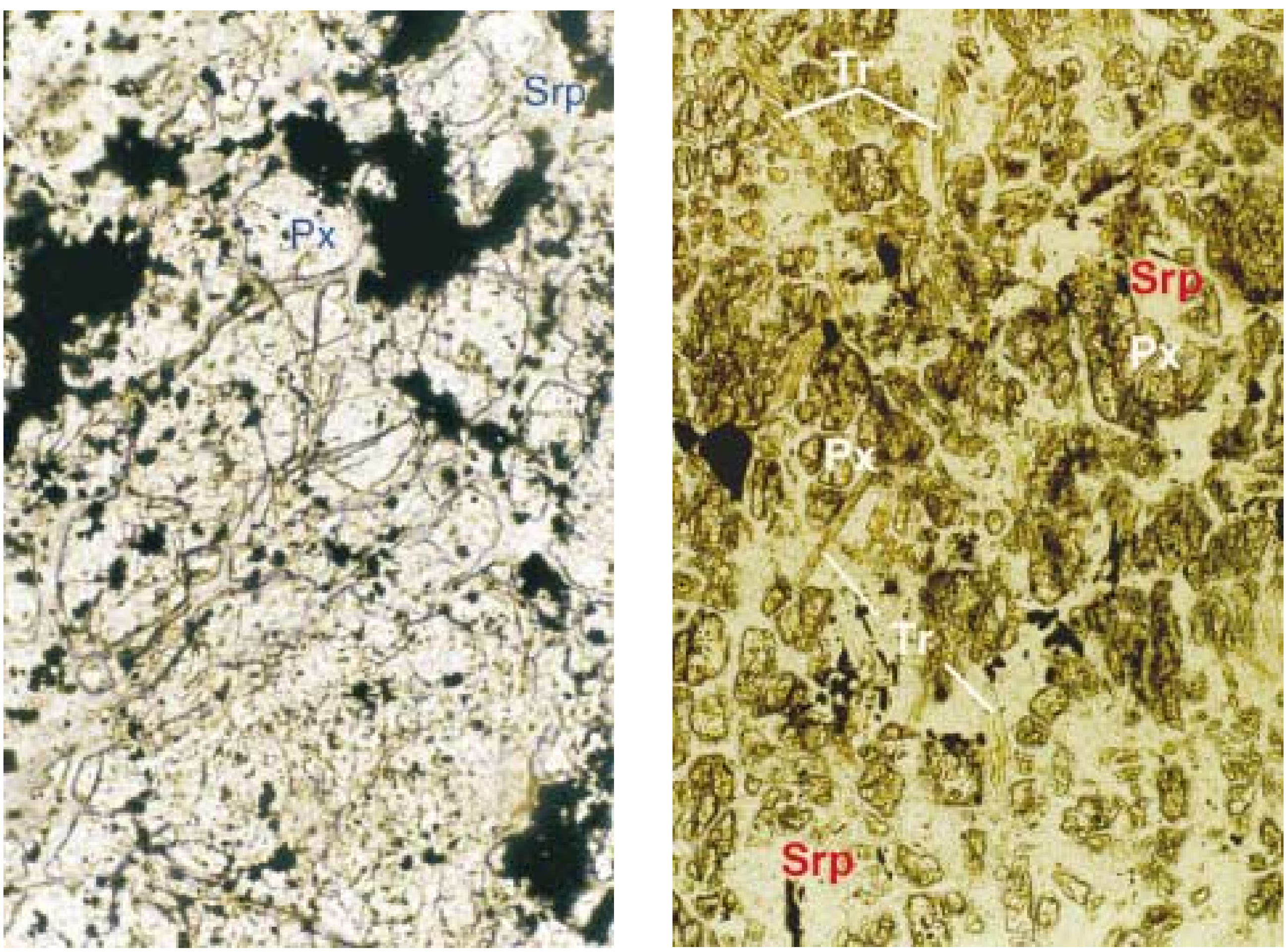


Photo 6-3. Photomicrographs showing (Left) the relatively unaltered state of harzburgites (here a pyroxene-rich portion) from Sunday Peak. Height represents 2.5mm of sample MMI89-21-5a. (Right) Relicts of a single pyroxene crystal (Px) in a matrix of serpentine(Srp) and tremolite (Tr). Scale: height represents approximately 2.5 mm of sample MMI91-7-3.

dant prehnite and rare pumpellyite as the most common authigenic minerals.

In Graham Creek valley, the southernmost outcrops of pillow basalt occur among outcrops of chert, cherty wackes, chert breccia and quartzose wackes. This mixed unit grades into pillow breccia with sparse, interlayered wacke. The zone could be a tectonic rather than a stratigraphic feature, but it is gradational in nature. Furthermore, the composition of wackes within the zone suggest derivation from Peninsula Mountain volcanics, requiring that the volcanic source rocks were not too far removed. Mixing of lithologies at the base of the pillow basalt unit may be the result of debris flow or fault scarp deposition. That major structural contacts exist within adjacent lithologies is unarguable as a significant fault zone crops out in cherty wackes in Graham Creek valley about 2.5 kilometres above its mouth, and there is definitely a fault contact, 5 kilometres northwest, between the harzburgite lenses and both porphyritic intrusions and sediments.

Photo 6-5. Pillow basalts of the Graham Creek Igneous Suite.

Geochemical signature

Rare earth element (REE) analyses indicate that pillow basalt and gabbro of the Graham Creek Suite are typi-

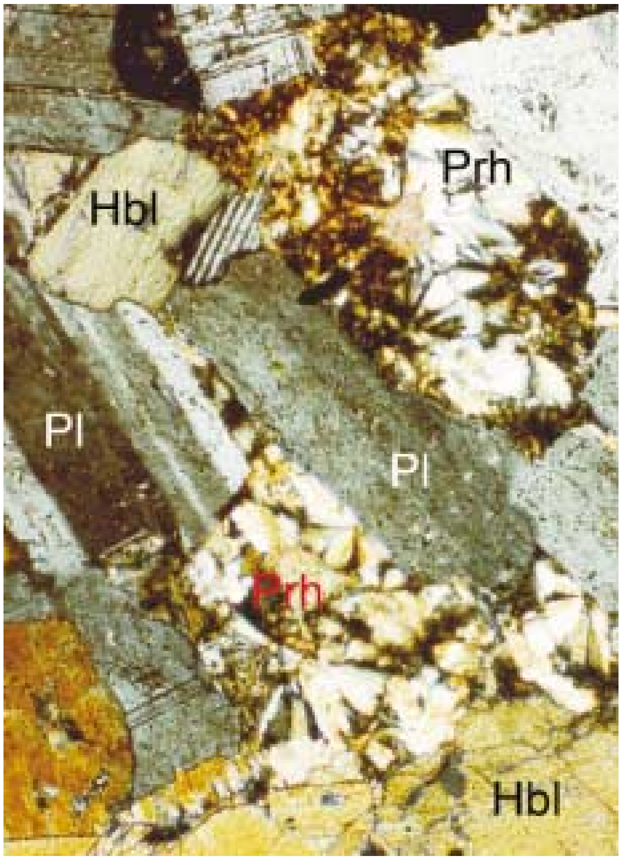


Photo 6-4 Photomicrograph of gabbro east of Graham Creek is less altered than normal. It shows relatively pristine plagioclase (Pl) and hornblende (Hbl). Interstices are altered to Prehnite (Prh). Long dimension represents 2.5mm of sample MMI89-21-4.

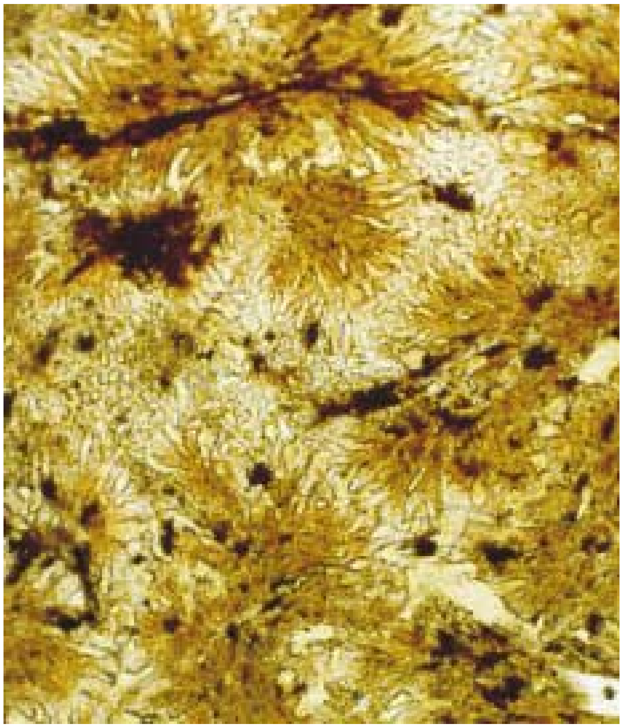


Photo 6-6. Photomicrograph of plane polarized light view of quench feldspar growth in pillow basalt.

cal mid-ocean ridge basalts (MORB; Figure 6-3a). On the Zr-Zr/Y, Ti/100-Zr-Sr/2 and Ti/100-Ar-Y*3 plots (Figures 6b, c, d) the samples overlap or plot in fields of overlap between MORB and island arc basalts. However, the Ti-Cr diagram is designed to discriminate between island arc (low potassium) tholeiite and ocean floor basalt and the samples clearly fall within the latter field.

The MORB signature of Graham Creek suite basalt is consistent with the association with tectonized harzburgite. It is also consistent with REE data from the

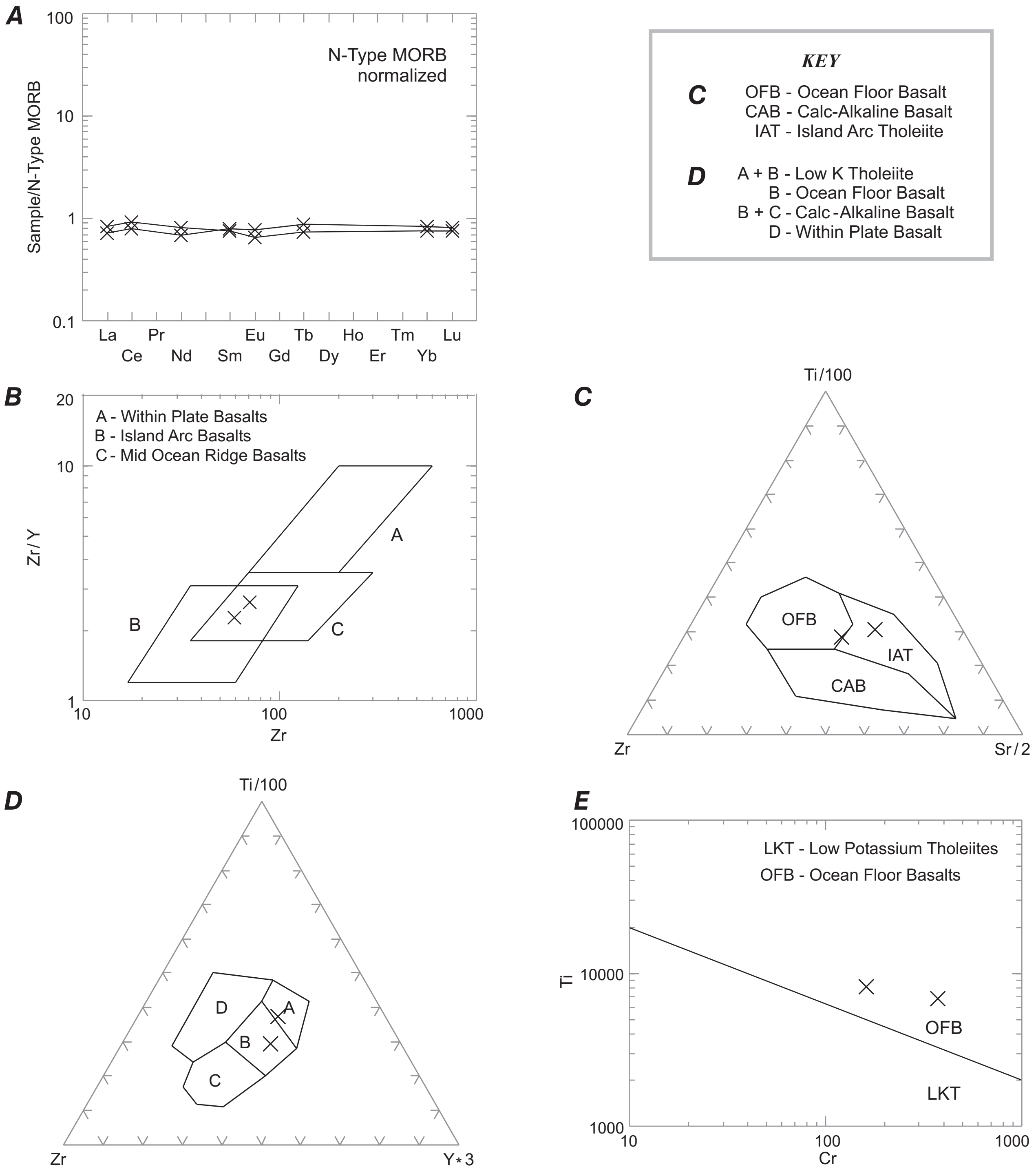


Figure 6-3. Geochemistry of Graham Creek suite basalt: (a) normal MORB normalized rare earth element plot of samples from widely separated areas shows that they are MORB; (b) Zr-Y discrimination plot following the method of Pearce and Norry (1979) shows that the samples plot in the zone of overlap between MORB and island arc basalts; (c, d) trivariate plots of Ti/100-Zr-Sr/2 or Y*3 follow the method of Pearce and Cann (1973) and show that the samples plot in either ocean floor or low K (island arc) tholeiite fields; (e) Ti-Cr plot following the method of Pearce (1975) is used to discriminate between ocean floor and low K (island arc) tholeiites. Samples of this study clearly fall within the ocean floor field.

Atlin Complex near Atlin (Ash, 1994). However, MORB signatures from accreted oceanic terranes are relatively rare. An explanation for this has been that it is mechanically more feasible to obduct young, buoyant, supra-subduction zone oceanic crust (SSZ), than it is to obduct mature oceanic crust generated at a mid-ocean ridge (Dewey, 1976). A fundamental contribution of the Ocean Drilling Program within the last decade has been the recognition of non-accretionary forearcs as the best modern analog for the origin of large ophiolites (Bloomer *et al*., 1995). After initiation of a subduction zone, infant arc volcanism with exceptionally high production rates (equivalent to slow spreading ridges) replaces thinned, pre-existing oceanic crust during formation of a supra-subduction zone ophiolite (Figure 6-4). Thus, both MORB and depleted volcanic arc chemistry can be expected.

Age, Correlations and Tectonic Significance

Original structural and stratigraphic relationships between the Graham Creek suite and both the Cache Creek Complex and the Peninsula Mountain suite are difficult to establish. Syndepositional faulting, original facies complexities, Late Cretaceous and Early Eocene volcanic cover, intrusions of Jurassic to Eocene age, and late structural deformation all obscure original contact relationships. There are, however, lithologic ties between these three assemblages.

All major lithologies within the Graham Creek suite have potential correlatives within the Atlin Complex. Associations of bedded chert, pillow basalt and quartzose wacke are recognized in the Kedahda Formation in the Carcross area (Hart and Pelletier, 1989a). Graham Creek gabbros are lithologically equivalent to the distinctive Nakina Formation, and particularly resemble the Conrad Member in southern Yukon (Hart and Radloff, 1990) which also displays the dual character of both hypabyssal intrusive and extrusive breccia. Interbedded chert and wacke occur in the Cache Creek Terrane near Atlin (see under Wacke in Chapter 5) and are also reported northwest of Dease Lake, in the French Range, where Norian chert is interbedded with hornblende-bearing wackes compositionally similar to the Lewes River Group (Monger, 1969). Arguements against correlation include a lack of dated strata within the Graham Creek suite that are older than Middle Triassic, and a total lack of massive carbonate, a hallmark of the Atlin complex.

Linkages between the Graham Creek suite and the Peninsula Mountain suite are based upon: the occurrence of wacke with clasts derived from the Peninsula Mountain volcanics and also chert with pillow basalt clasts; an apparent upward transition from pillow basalt to hyaloclastite to subaerial volcanics of the Peninsula Mountain suite *sensu stricto*; the occurrence of pillow basalt and interbedded chert overlain directly by coarse intermediate to felsic pyroclastics (near Ear Mountain); and conglomeratic rocks at the base of the Penninsula Mountain succession that appear to be at least in part derived from the Graham Creek suite lithologies.

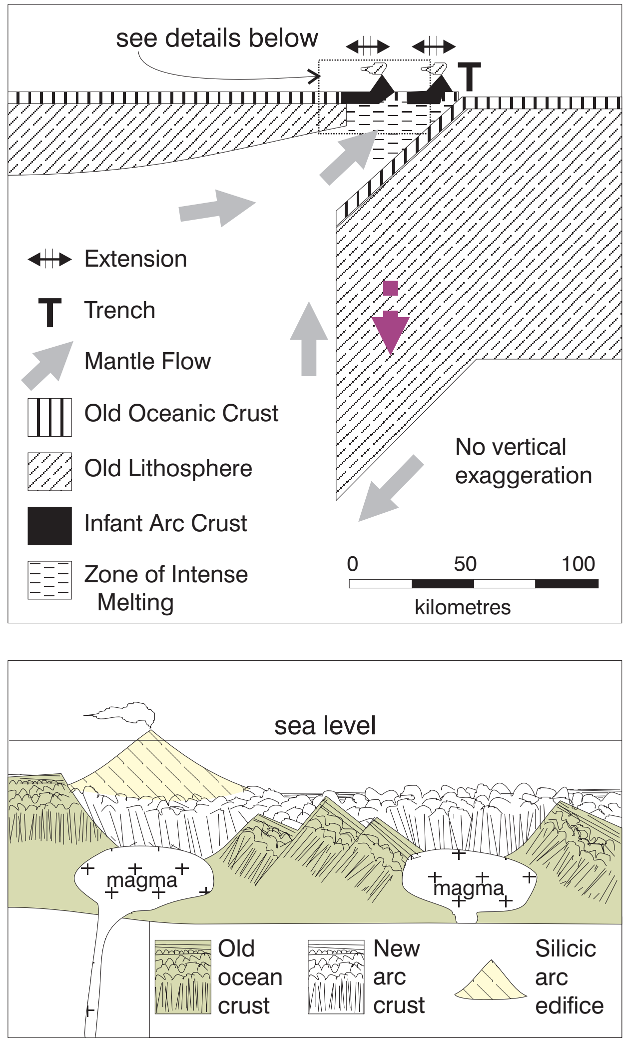


Figure 6-4. A model devised to explain observations during Deep Sea/Ocean Drilling Program legs along juvenile intraoceanic arc segments in the western Pacific. It shows extension and voluminous volcanism during incipient forearc development (modified after Bloomer *et al.*, 1995).

One possible explanation for the occurrence of the Graham Creek Suite is that it is part of a small, juvenile basin in which Laberge sedimentation was localized. If this was the case, a juvenile crustal REE signature would be expected in these rocks. In fact, samples from this suite that have been analyzed thus far display good MORB signatures -unusual, but not unexpected, in ophiolitic assemblages which normally show a supra-subduction zone signature as noted above. Basalts of the Atlin complex display the same MORB signature (C. Ash, personal communication, 1998).

Temporal and lithologic ties between the Atlin Complex, the Graham Creek Suite and the Peninsula Mountain suite suggest that these tectonic elements were loosely associated by Late Triassic time. Contacts between them are disrupted and equivocal, probably reflecting a period of amalgamation that outlasted the Middle to Late Triassic and the initial juxtaposition of these lithologic suites.

On a regional scale, lithologic packages including the Peninsula Mountain suite and the Graham Creek suite resemble huge, fault-bounded lenses. However, the preservation of stratigraphic linkages between them suggests that the magnitude of displacement at their contacts is relatively small (*i.e.* less than tens of kilometres). Displacements between them and the Atlin Complex could, on the other hand, be much greater. It is possible that the Graham Creek suite represents old oceanic crust atop which the Peninsula Mountain suite was built in a forearc setting. Unfortunately, attempts at geochemical discrimination of the Peninsula Mountain suite (see next section) have led to inconclusive results. More work on geochemical characterization and isotopic age dating of both suites are necessary before more confident paleogeograpic associations can be made.

Mineral Potential

Key elements of mesothermal gold belts are mantle-derived ultramafite and deep-rooted structures of crustal scale. The Graham Creek Suite, bounded by strands of the Nahlin fault, contains both of these elements. Graham Creek area is the westmost occurrence of ultramafic oceanic crustal rocks in the map area, and Graham Creek placer gravels mark the westernmost limit of the Atlin placer camp. However, relative to the immediate Atlin area, little placer production is recorded.

Although no lode occurrences are known from areas underlain by the Graham Creek rocks, an ultramafic association is supported by the presence of chromite (of presumed ultramafite origin) in auriferous heavy mineral concentrates from Graham Creek (S.B. Ballantyne, personal communication, 1989; see also Chapter 14). However, in ultramafites underlying the headwaters of more economically important streams of the central Atlin placer camp, no producing lode deposits have been discovered to date. Perhaps the large amount of placer gold near Atlin indicates a fully exhumed source area. Small amounts of placer gold in Graham Creek indicates either a largely uneroded lode source or one that was not well mineralized. Further exploration will be required to test these alternatives and the potential for mesothermal gold deposits in the Graham Creek area.

Chapter 7 Peninsula Mountain Volcanic Suite

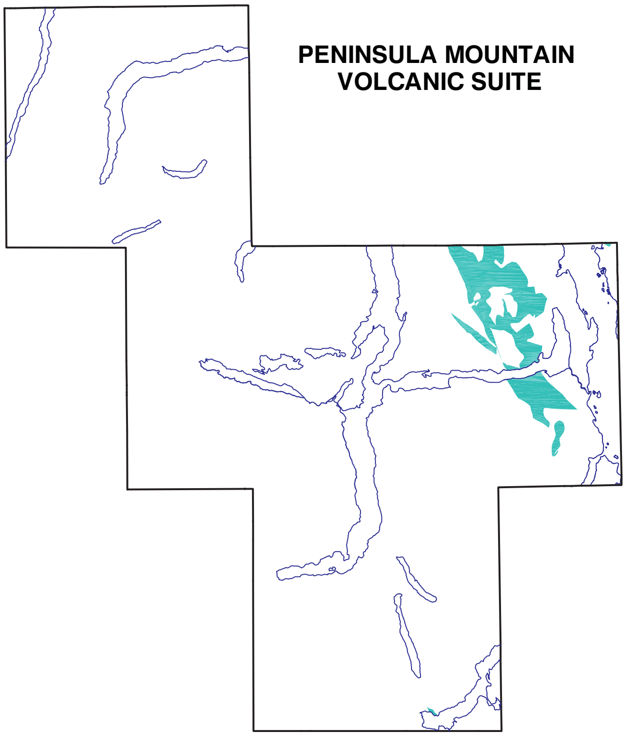


Figure 7-1. Distribution of Peninsula Mountain suite in the Tagish area.

Rocks of the Peninsula Mountain suite were named Peninsula Mountain Formation by Bultman (1979) who mapped a relatively thick succession at Peninsula Mountain on the east shore of Tagish Lake. Prior to that time they were included in the Chieftan Hill Volcanics (Cairnes, 1911, 1913) and later were reassigned by Aitken (1959) to his undifferentiated "Unit A". Mihalynuk *et al*. (1991) erroneously expanded the range of the Peninsula Mountain Formation to include rocks now determined to be Late Cretaceous in age and now assigned to the Windy-Table volcanic suite. Usage of the name 'Peninsula Mountain' is consistent with that originally suggested by Bultman (1979), however, it is referred to here as a "suite" rather than a "formation" which is more consistent with its poorly defined and complex stratigraphy.

Peninsula Mountain rocks occur within a belt 10 kilometres wide, extending from Atlin Mountain (104N/12W) to Sunday Peak (northern edge of 104M\9E; Figure 7-1). Isolated occurrences have also been mapped at Telegraph Bay where they are cut by the Middle Jurassic Fourth of July batholith, and on northwestern Teresa Island where siliceous volcanic rocks are surrounded by other lithologies of the Atlin Complex. Peninsula Mountain rocks on Theresa Island outcrop over too small an area to be represented on Figure GM97-1, or even at 1:50 000 scale (*cf*. Mihalynuk and Smith, 1992b). On Figure GM97-1 they occur as a series of outcrops less than 50metres long within unit CPac.

Peninsula Mountain rocks are compositionally diverse, ranging from cherty wackes and massive chert to volcanic strata of rhyolite through to basaltic andesite. Volcanic components can be difficult to distinguish from overlying volcanic strata of the Windy-Table volcanic suite, but are separated here on the basis of their indurated nature, distinctive epidote-chlorite alteration, locally developed foliation (Photo 7-1), and moderate eastward dips. Peninsula Mountain volcanic rocks include massive to sparsely pyroxene-phyric, dark green flows(?), some with altered, partially digested, cobble-sized clasts; strongly pyritic rhyolite flows and domes; and an epiclastic unit. No significant folding has been recognized. In the absence of extensive isotopic dating, it is not possible to confidently correlate these rocks at all locations (particularly on the east and south flanks of Taku Mountain). However, an inferred age significantly older than the overlying Table Mountain volcanics is

Photo 7-1. Foliation developed within Peninsula Mountain rhyolitic block tuff.

based on circumstantial geological evidence (*see* Age, Correlation and Tectonic Significance section below).

Conglomeratic epiclastics (muTPc)

A conglomeratic epiclastic unit included within the Peninsula Mountain suite weathers light colours but is medium to dark green where fresh. It is well-indurated. The most extensive exposures of this conglomerate are along the north shore of Graham Inlet, more restricted exposures occur south of Ear Mountain. Conglomerate also crops out on the northern flank of Atlin Mountain, but there it is strongly hornfelsed and of uncertain extent, so it is included with undivided Peninsula Mountain suite (muTP, Figure GM97-1).

Near the Atlin Mountain Pluton and other intrusions, the conglomerate unit is bleached to a light grey-green colour. Chlorite, epidote and quartz replace matrix and clasts alike, and in some areas, the unit contains up to 1% pyrite as irregular blebs. Bedding is locally well developed, but is generally vague. Much of the unit may be a tuffite, with coarse ash layers and blocks of acicular hornblende plagioclase porphyry and rare clasts of pyroxene porphyry and flow-banded rhyolite. Elsewhere the unit displays graded bedding from gravel to silt in clastics derived from feldspathic volcanic porphyry. Most clasts are subangular to subround. Some rounded, lapilli to block-sized clasts have alteration halos, and may be partially or entirely replaced by epidote. Rare pyroxene-phyric amygdaloidal basalt flows are interlayered with the conglomeratic epiclastic unit.

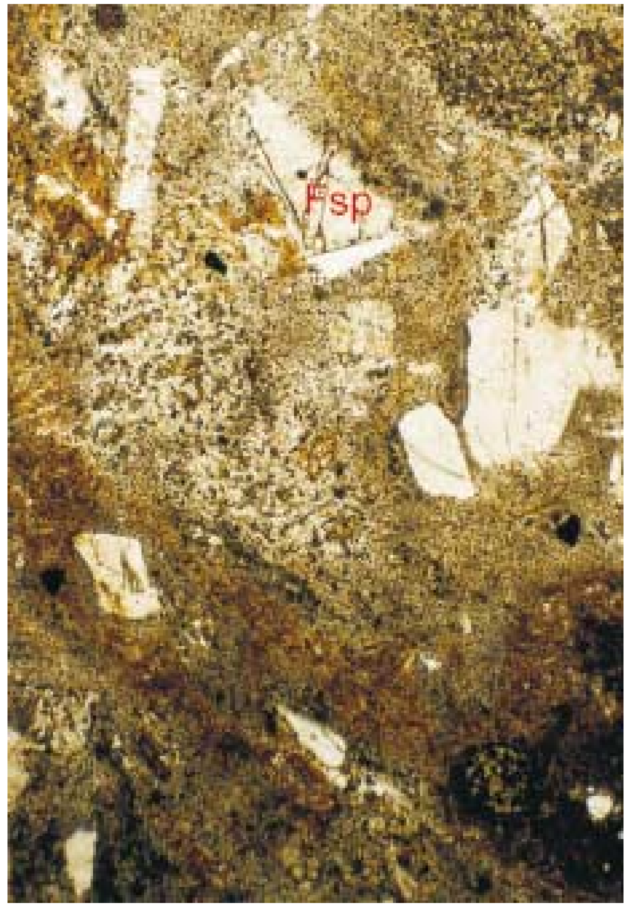


Photo 7-2. Photomicrograph of a felsic volcanic layer that is enclosed in chert. Long dimension of photo represents 4.6 mm of sample MMI90-14-6.

Pyritic Rhyolite (muTPr)

Rhyolite is most prominent near the base of the succession between the bulk of Peninsula Mountain strata and sediments of the Atlin Complex. It occurs as massive banded flows, small pyritic domes that are less than 10 metres in diameter, as a breccia unit (Photo 7-1), and interbedded with epiclastics that contain chert-like cobbles (Photo 7-2). The latter closely resemble rhyolite interbeds in younger strata, and are only tentatively included in the Peninsula Mountain suite.

Along the north shore of Graham Inlet, at the base of Table Mountain, is a very siliceous flow-banded pyritic rhyolite that locally contains centimetre to decimetre-sized spherulites. Up to a few percent pyrite occurs as disseminations, and may also form blebs or stringers 15 centimetres or more in length. Finely disseminated pyrite gives the rhyolite a greasy-grey appearance. Elsewhere it may appear vitreous and can be mistaken for chert.

A knobbly outcrop of light-to medium green, purple or grey, massive, brecciated siliceous volcanic rock occurs along the east side of northern Torres Channel. Pyrite is disseminated throughout. Although it is surrounded by Cache Creek lithologies, similar units are not reported locally from within the Cache Creek Complex, so it is considered to be part of this pyritic rhyolite unit.

Pyroxene-phyric Andesite (muTPv$_1$)

Andesitic breccias with clasts containing medium - grained feldspar and medium to coarse grained pyroxene phenocrysts are the lowest of the units within the central part of the belt. They are vesicular, green and light grey to tan weathering, and epidote-chlorite altered (Photo 7-3). Also included in this unit are dark green, fine grained massive greenstone layers with sparse clasts and phenocrysts; green, tabular feldspar porphyry flows; massive basalt flows; and black tuffs with maroon, green, grey and black lapilli that contain conspicuous pyroxene crystals in a coarse ash matrix. They are crosscut by coarse quartz feldspar porphyritic dikes up to several metres thick that are feeders to dacitic ash flows of the Windy-Table volcanic suite.

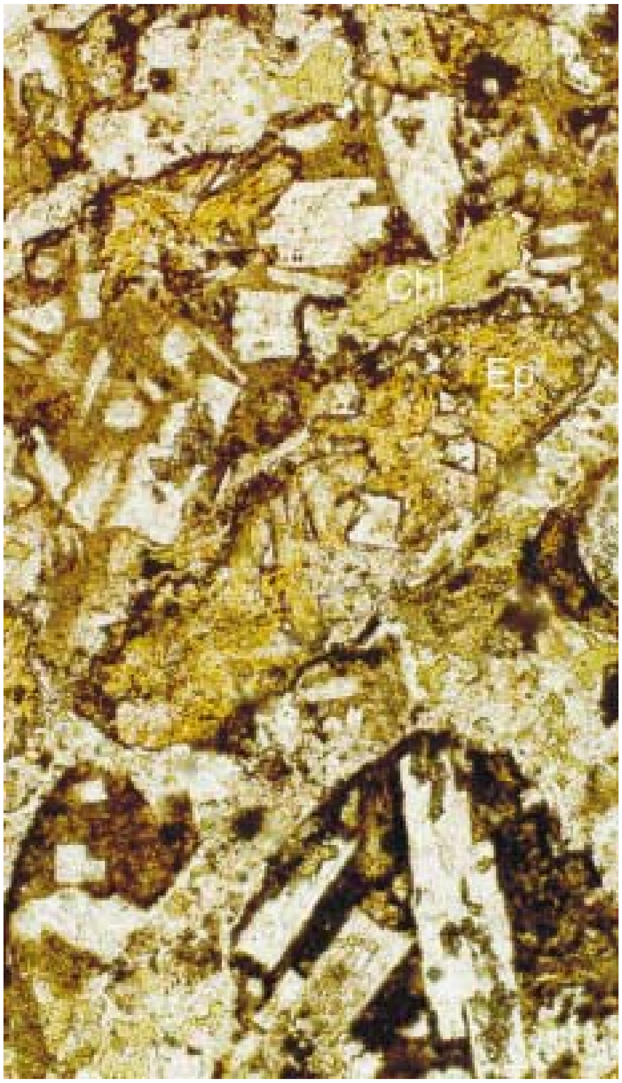


Photo 7-3. Photomicrograph of unit $muTPv_1$ shows plagioclase crystals in ash sized pyroclasts. Some vesicles are infilled with chlorite and parts of the sample are altered to epidote. Plagioclase is turbid and the matrix is totally devitrified. Long dimension of the photo represents 3mm.

Heterolithic Feldspar-phyric Pyroclastics ($muTPv_2$)

Heterolithic feldspar-phyric lapilli tuff and breccia are the most widespread of the Peninsula Mountain lithologies. Although variegated and texturally diverse, these rocks probably span a relatively narrow intermediate compositional range. They are typically green, maroon, rust, or grey weathering, and invariably contain fine to medium-grained subidiomorphic feldspar crystals that constitute 5 to 40 percent of the rock. Feldspar is altered to white, pink and powder green colours, but commonly is fresh enough to display twinning in hand sample. Acicular to prismatic hornblende is less common (up to 5 percent), generally occurring as chloritized relicts. Pyroxene occurs only rarely, but comprises up to 10 percent of a lapilli tuff on Ear Mountain. Commonly, the tuffs display textures such as draped layering, indicative of primary pyroclastic deposition. Rocks of this unit at least locally rest on pyroxene-phyric andesite.

Pillow basalt, minor chert and wacke (muTPp)

Exceptionally well exposed pillow basalts form a northwest-trending belt 3 kilometres from the mouth of Graham Creek. Best exposures are just a kilometre west of the creek. Internal layering is not seen, but contacts with adjacent strata are steep. If the overall orientation of the unit is nearly vertical then its structural thickness is more than 1 kilometre.

Well developed basalt pillows 0.5 to 1.5 metres in diameter (Photo 7-4) occur in thick piles in the upper Graham Creek watershed and form the western limit of Peninsula Mountain suite rocks in the map area. Many

Photo 7-4. Well developed pillows in unit muTPp.

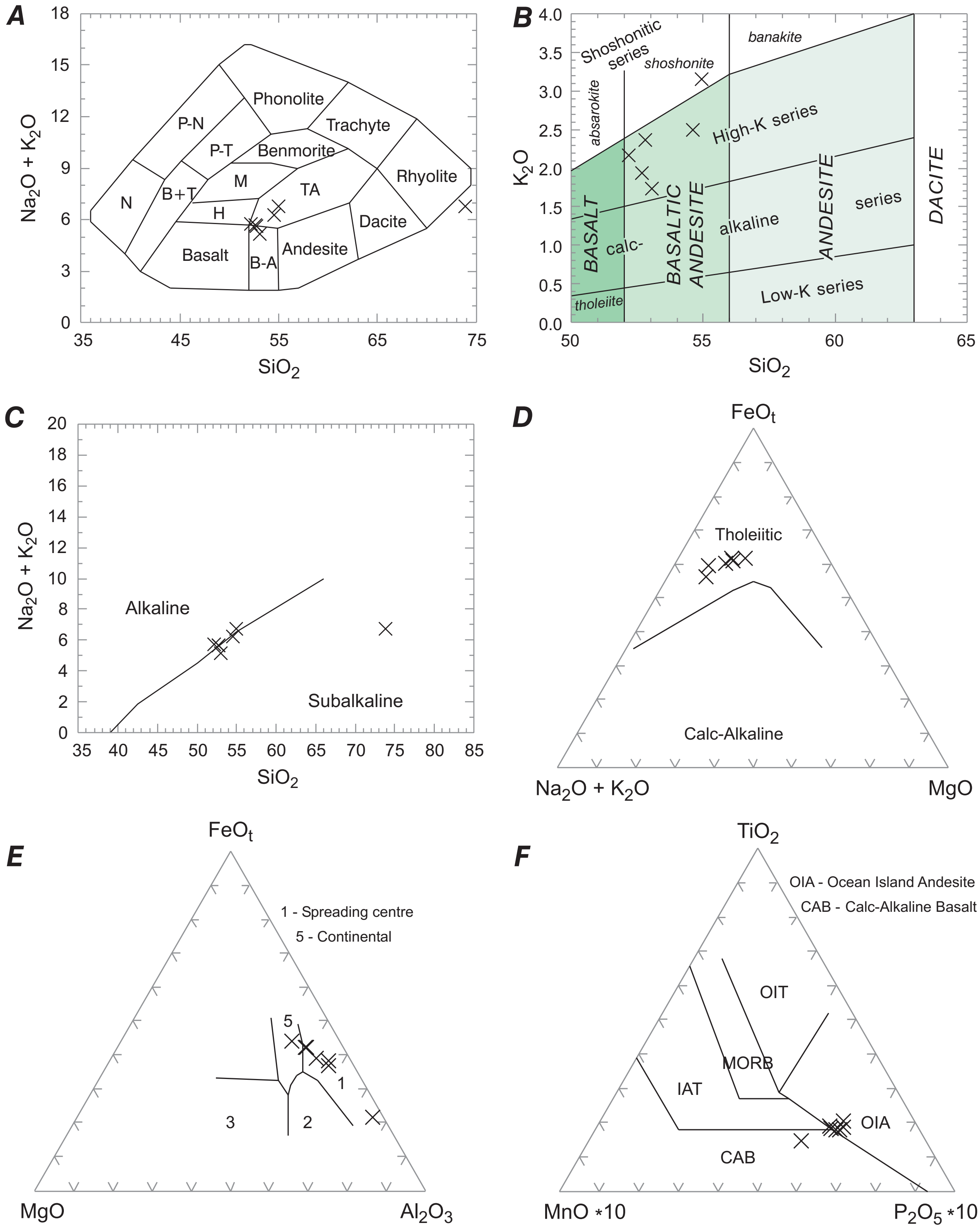


Figure 7-2. Geochemistry of Peninsula Mountain volcanics: (a) alkalis versus silica classification diagram shows basaltic andesite to trachy-andesite composition (fields of Cox *et al.*, 1979); (b) K_2O-SiO_2 plot of orogenic andesites following the method of Gill (1981) shows that most samples are high-K and slightly more basic than most andesites; (c) alkalis-silica and (d) AFM diagrams of Irvine and Barager (1971) show a clear tholeiitic trend; (e) the tectonic discrimination plot of MgO-Al_2O_3-FeOt (Pearce *et al.*, 1977) shows that the samples fall within either the spreading centre or continental basalt fields, and (f) MnO*10-P_2O_5*10-TiO_2 plot (Mullen, 1983) shows most samples to be ocean island andesites.

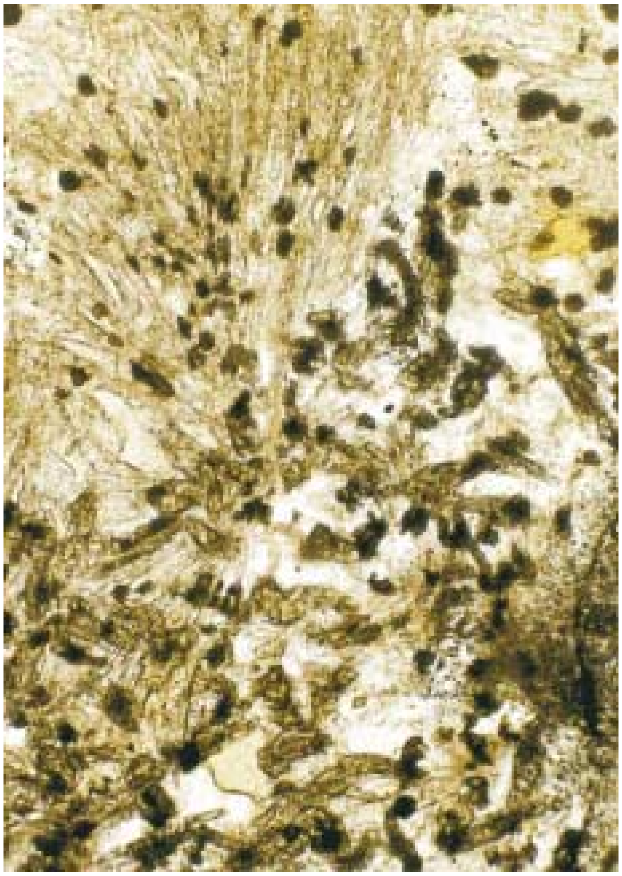


Photo 7-5. Quench-texture plagioclase and devitrified glass rim of a pillow from unit muTPp.

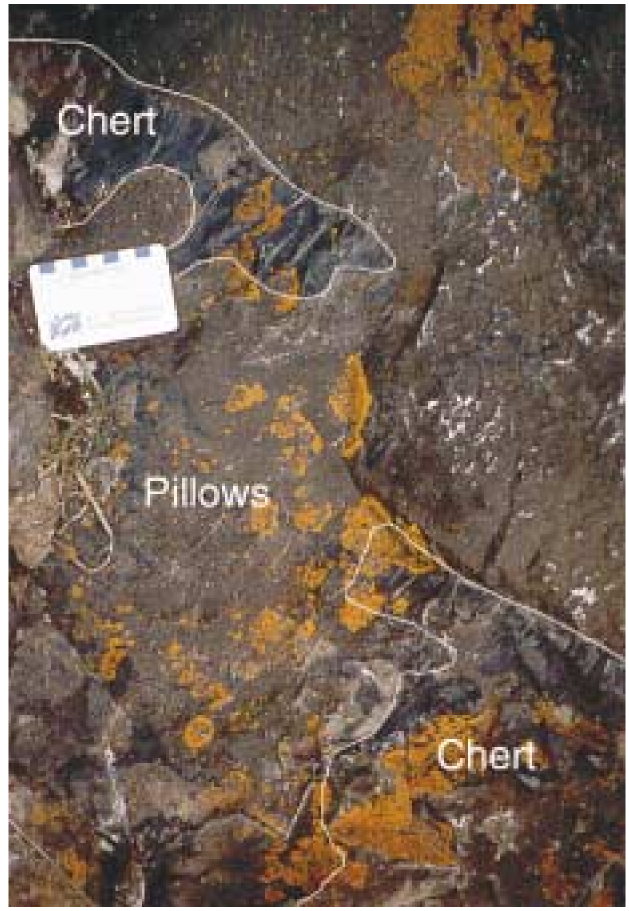


Photo 7-6. Black chert forms irregular masses between pillows of brown basalt .

pillows display largely devitrified glassy rims (Photo 7-5). Pillow interstices may be filled with black chert, lesser cherty argillite and cherty wacke.

Structurally beneath the pillow succession, the same sediments that are found in pillow interstices (Photo 7-6) dominate the stratigraphy and are included in the Permian to Jurassic unit of the Atlin Complex (PJs on Figure GM97-1). Westernmost exposures of pillow basalt contain increasingly greater proportions of interpillow sediments until a section of more than 200 metres of cherty wackes and argillites is exposed (as previously discussed in Chapter 6; Photo 7-7).

A heterolithic fault zone over 50 metres wide cuts the unit near its northeastern limit. It contains blocks of black, grey and pyritic chert; argillite; hornblende feldspar - phyric dike; and coarse - grained, black carbonate (vein material). Locally, these blocks are up to several metres in diameter and have well polished, chlorite-coated margins. Similar pillow basaltsthat crop out south of the fault are separated as part of the Graham Creek suite. Peninsula Mountian suite pillow basalts are much like Graham Creek suite basalts in outcrop, except that they lack an association with gabbros. Geochemically they are distinct. Peninsula Mountain suite tend to be basaltic andesites, whereas Graham Creek suite basalts are MORBs. However, trace element data provide no further distinction between the other tectonic settings in which they may have formed.

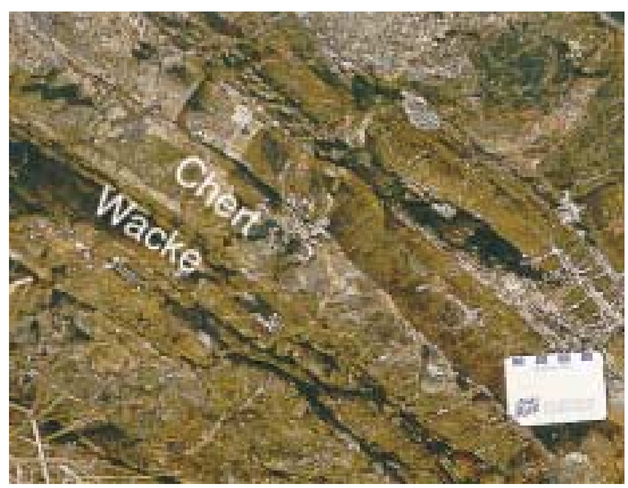


Photo 7-7. Interbedded chert and wacke adjacent to Peninsula Mountain suite pillow basalts.

Geochemistry

Samples of Peninsula Mountain suite that have been analyzed for major and trace elemental compositions are high potassium basaltic andesite to tracyandesite (Figures 7-2a, b). Potassium tends to be subequal to sodium (Figures 7-2a, c), they are iron rich (Figure 7-2d), and have Ti values of around 1.3% (versus 0.8% for typical orogenic andesites compared on a hydrous basis, *see* Table 1.1 *in* Gill, 1981). Discrimination plots (Figures 7-2e, f) are inconsistent, pointing to formation in a spreading centre, ocean island or arc environment. It is also difficult to draw conclusions from REE concentrataions. Plots show light REE enrichments and heavy REE values of 0.6 to 2 times those of typical MORB (Figure 4a). Thelower pattern is like that of high-K orogenic andesites (*cf*. Gill, 1981). In the upper three patterns, heavy REE values ranging up to 300 times chondrite (Figure 4b) are similar to anorogenic andesites in continental settings, although heavy REEs plot with a relatively flat slope are more typical of anorogenic andesites in an oceanic setting.

Too few samples with basaltic composition were analyzed to permit a comparison on the basis of basalt discrimination diagrams (not shown here). However, one data point on the Ti-Zr discrimination and trivariate diagrams of Ti/100-Zr- Y*3 or Sr/2 (Pearce and Cann, 1973) plot in the calc-alkaline basalt field. Two samples plotted following the method of Pearce and Norry (1979) fall in the zone of overlap between MORB and island arc basalts, and one sample plotted on the Ti/1000-V diagram of Pearce (1975) falls in the oceanic field, but very near the boundary with arc basalts.

Clearly, the geochemical data from Peninsula Mountain suite volcanics are too few and inconsistent to provide firm guides for paleogeographic reconstructions. One sample suggests a similarity with high potassium orogenic andesites, whereas three others are most similar to icelandites which are formed on an ocean island in a mid-ocean ridge setting. However, all three samples lack Al, Ca and Mg depletion typical of icelandites. An ocean island setting is consistent with the spatial association of Peninsula Mountain suite with MORBs of the Graham Creek suite and chert-rich oceanic strata tentatively correlated with the Atlin Complex.

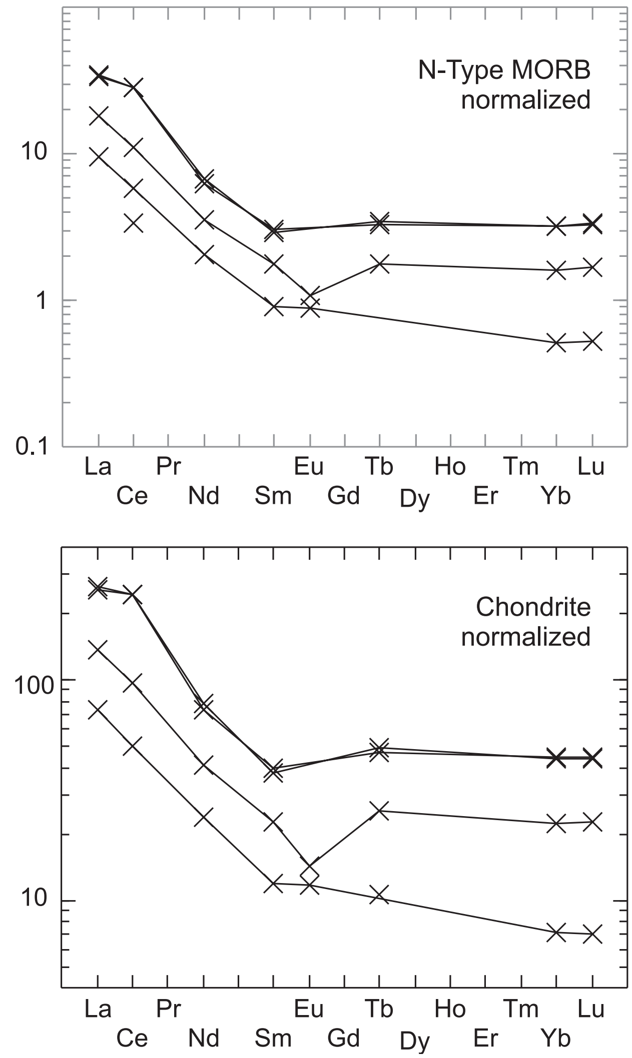


Figure 7-3. Normal MORB normalized (top) and Chondrite normalized (bottom) rare earth element plot of Peninsula Mountain suite samples shows that they are light REE-enriched. This pattern is most like high potassium andesites (*c.f.* Gill, 1981).

Age, Correlation and Tectonic Significance

Stratigraphic relations are essentially as suggested by Aitken (1959) with some added complexities. Peninsula Mountain strata at Table Mountain dip only moderately and little folding is apparent. Lack of deformation within this unit prompted Bultman (1979) to correlate a portion of these rocks with younger, undeformed volcanic strata[1]. However, contact relations with both the Laberge Group and the Cache Creek complex, as well as a locally pervasive foliation (Photo 7-1) on the northeastern margin of the unit point to inclusion of all of these volcanic rocks within the Peninsula Mountain suite.

The Peninsula Mountain suite is probably of Middle to Late Triassic age, but may be as young as Middle Jurassic. The older age is favoured for five reasons. First, the

1 *Fashioned after the example set by Wheeler (1961), Bultman called these relatively undeformed rocks the Hutshi Formation; now recognized as a redundant and, therefore, obsolete name (cf. Hart and Pelletier, 1989a).*

cherts interbedded with pyroclastic volcanics of Peninsula Mountain affiliation contain radiolarians of Middle to Late Triassic age (Table AB2). Coarse volcanic wackes that are most likely derived from the Peninsula Mountain volcanics are intercalated with chert near the site of the fossil-bearing cherts (Photo 7-8). Unfortunately, the radiolarian chert is strongly contorted and the possibility of tectonic intercalation of wackes and chert can not be ruled out. Furthermore, the radiolarian chert may be a structurally isolated lens as it is located near the western strand of the Nahlin fault, and application of this chert - volcanic relationship to other areas may, therefore, be inappropriate. Second, the age of the Peninsula Mountain site is thought to be at least as old as the Middle Jurassic Fourth of July batholith that has been recently dated (Mihalynuk *et al*., 1991). This relationship is confirmed by thermal alteration of similar volcanic rocks in the aureole of the batholith at Telegraph Bay. Third, Bultman (1979) reports southwestern exposures of Peninsula Mountain volcanics that dip steeply beneath the Laberge Group, as well as exposures near Tutshi Lake that sit beneath a later, subhorizontal volcanic package. Fourth, similar volcanic strata north of the study area at Mount Minto, yield a cluster of old fission track cooling ages that range up to 235 ± 58 (next oldest is 193 ± 18Ma; Donelick,1988). Fifth, these rocks are in general more deformed, indurated and more widely epidote-chlorite altered than the Windy-Table suite dated at circa 81 Ma (see Chapter 12).

Chapter 8 Stuhini Group

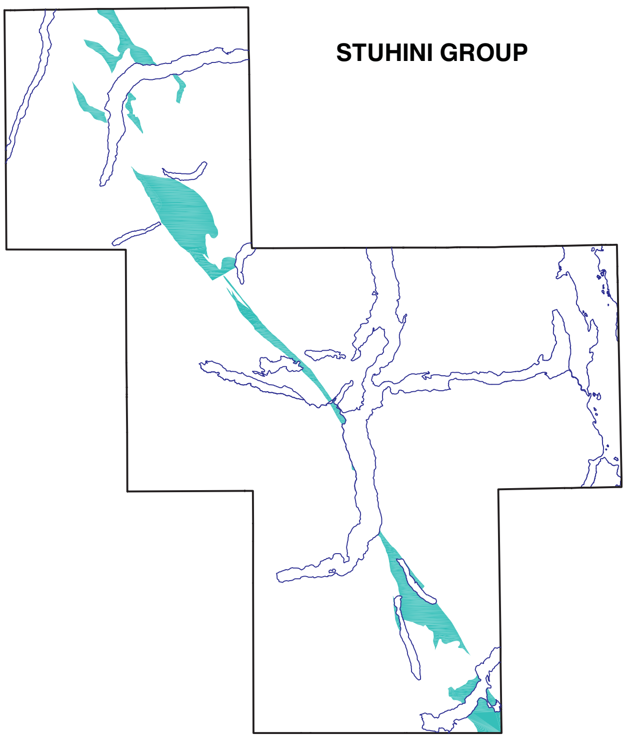


Figure 8-1. Distribution of Stuhini Group strata in the Tagish area

Stuhini Group strata crop out in a northwest-trending belt 0.5 to 8 kilometres wide that extends the length of the study area (Figure 8-1). The belt is continuous to at least the Tulsequah area where the strata were named by Kerr (1948) in the type area of Stuhini Creek, although much of the Tulsequah area originally mapped as Stuhini Group is now recognized to be Paleozoic in age (Mihalynuk *et al*., 1994a, b). To the north, strata correlative with the Stuhini Group are named the Lewes River Group (see, for example, Wheeler, 1961; Hart *et al*., 1989a). Early workers in the Yukon included volcanic components of the Lewes River Group with the younger "Mesozoic" Hutshi Group (Bostock and Lees, 1938) or with a "Triassic or older" division (Tozer, 1958). Lewes River Group stratigraphy in the southern Yukon is dominated by limestone and greywacke except for a belt in the western Whitehorse area which Wheeler (1961) considered as part of a volcanic arc. Pyroxene-rich breccia and flows of these arc strata are termed the Povoas Formation by Hart and Radloff (1990), and overlying coarse epiclastic strata are called the Annie Member of the Aksala Formation (Figure 8-2). These volcanic strata are directly correlative with Stuhini Group rocks of the map area, and are distinguished only by which side of the 60°N border they occur. However, on regional compilations, such as that of Wheeler and McFeeley (1991) and Wheeler *et al*., (1991), the Lewes River Group takes on special significance. They propose that the Upper Triassic Lewes River Group sits above, or is interfingered with, the upper portions of the Cache Creek Terrane. However, no evidence of this relationship is present in the Tagish area.

Stuhini Group lithologies are diverse: basic to intermediate subalkaline volcanic flows, pyroclastics and related arc sediments. Characteristic lithologies include coarse augite porphyry and bladed-feldspar porphyry (Souther, 1977; Mortimer, 1986) as well as widespread upper Norian carbonate known as the Sinwa Formation (Souther, 1971). Major lateral facies variations, deposition on surfaces with considerable paleotopographic relief and later disruption by faults preclude assigning a consistent stratigraphic position for most units. Nearly identical lithologies can occur at almost any place within the Stuhini stratigraphy. As a result of its stratigraphic variability, no formation names have been proposed in this report, although some have been adopted from Hart and Radloff (1990). Units with adopted formation names can be traced in at least a discontinuous fashion through the map area from its southern limit to beyond its northern limit where they are mapped in southern Yukon (Hart and Pelletier, 1989a, b; Hart and Radloff, 1990).

Two major arc divisions are developed in the Tagish area. A poorly exposed lower, foliated division is intruded by *circa* 220 Ma plutons which are nonconformably overlain by upper division strata (Figure 8-2). One of the best sections through the Stuhini Group is at Willison Bay where a nearly complete, relatively undisturbed section of upper division strata is preserved. At the base of the upper division, a granitoid-rich boulder conglomerate gives way upward to pebble conglomerate rich in metamorphic fragments and finally into wackes and argillites. These rocks are succeeded by a thick succession of augite-phyric pillow basalts interlayered with fossiliferous siltstone, and overlain by phreatomagmatic breccia. Topping the succession is quartz-rich volcanic sandstone and conglomerate capped by upper Norian limestone. To a first approximation, Stuhini Group volcanic strata appear to become more felsic with decreasing age.

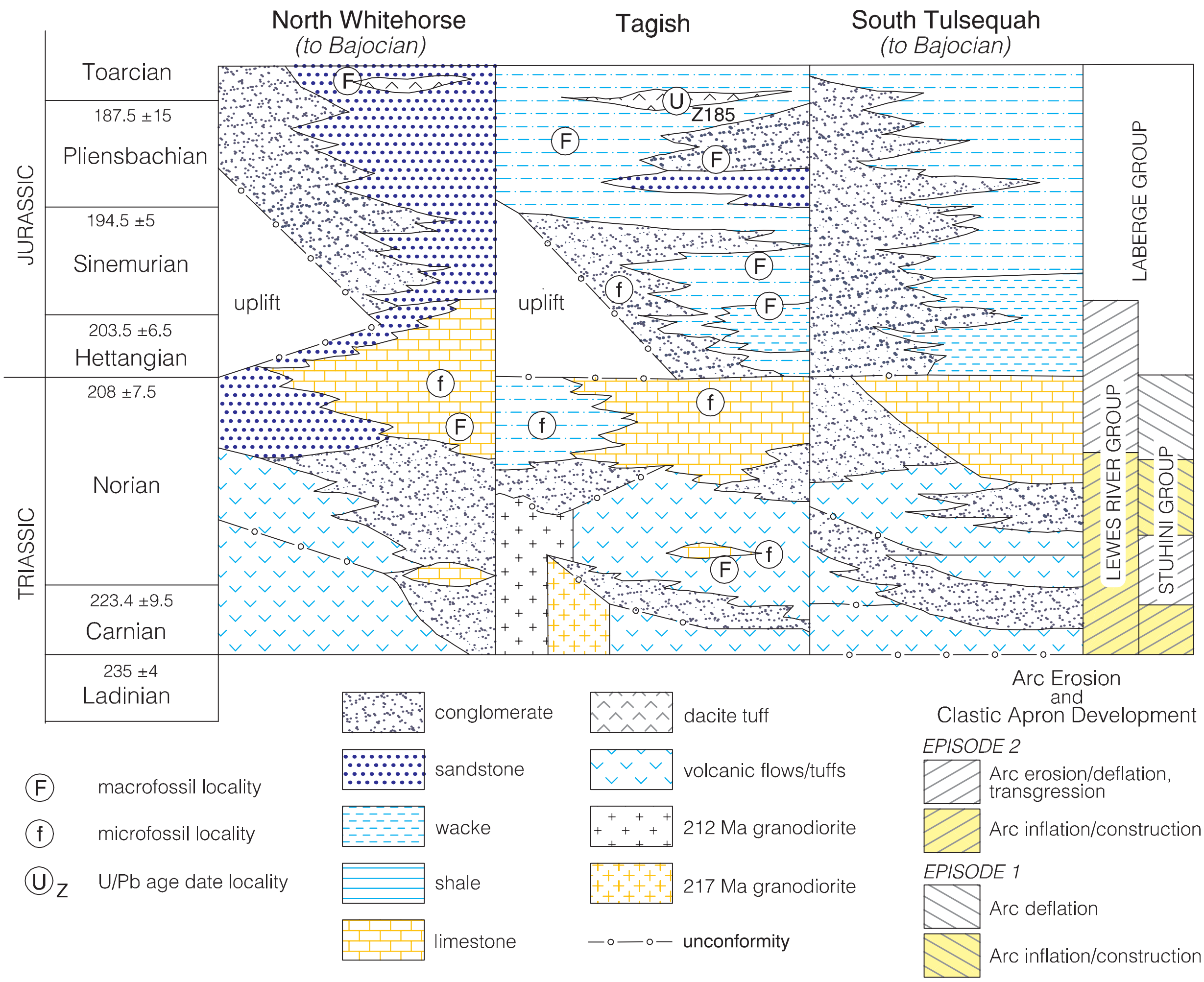


Figure 8-2. Highly generalized Stuhini and Laberge Group stratigraphy representing the area between Whitehorse (Wheeler, 1961; Hart and Pelletier, 1990) and Tulsequah (Souther, 1971; Mihalynuk *et al.*, 1995a, b). A two-stage development of the Stuhini arc is apparent, as are western volcanic-dominated and eastern sediment-dominated domains.

Basal Contacts & Lower Arc Division

Contacts between the Stuhini Group and metamorphic strata of the Boundary Ranges Metamorphic Suite are not well exposed in the map area. It is possible that parts of the Boundary Ranges suite have Stuhini Group rocks protoliths, and that the contact coincides with an isogradic or structural boundary. At one locality just north of Tutshi Lake, probable Stuhini strata appear to rest unconformably on muscovite-chlorite schists. However, no metamorphic clasts are seen above the contact, which is occupied in part by a carbonate-cemented breccia, that may indicate a fault (Mihalynuk and Rouse, 1988a). A contact between basal Stuhini conglomerate and underlying schists is described in the Tulsequah area by Souther (1971), but this relationship could not be confirmed by recent reconnaissance mapping in that area (Mihalynuk *et al.*, 1996).

At Willison Bay, Stuhini Group strata sit nonconformably above granodiorite dated as 220 ±5 Ma (K-Ar hornblende, recalculated after Bultman, 1979) and 216.6 ±4 Ma (U-Pb isotopic data, Mihalynuk *et al.*, 1997; Appendix A). Intrusion of this granodiorite marks the temporal boundary between lower and upper divisions of the Stuhini arc (Figure 8-2). Only remnants of the lower division are exposed within the map area, but better exposed relicts of the lower arc succession occur where the stratigraphy is thicker both south and north of the study area (see Age, Correlation and Tectonic Significance later in this chapter).

Evidence for the lower arc division occurs in three forms: deformed screens within the *circa* 217 Ma intrusions; deformed strata adjacent the Llewellyn fault; and cobbles within Carnian conglomerate (also called "basal conglomerate" by Mihalynuk and Mountjoy, 1990). Screens and sheared rocks along the fault are dominated by chlorite-epidote schist with relict textures showing pyroxene-phyric clasts. These are probably remnants of a volcanic edifice into which the ?comagmatic, 217Ma plutons intruded. Clasts in the Carnian conglomerate include epidote-chlorite-altered, variegated feldspar-phyric lapilli tuff, dark brown or green pyroxene porphyry, and boulders of volcanic conglomerate as well as 217Ma intrusive phases (Photo 8-1). Second generation conglomerate clasts in particular show that parts of the Stuhini arc had been eroded and redeposited before it was eroded again to form the Carnian Conglomerate at the base of the lower division.

Carnian Conglomerate (Povoas, uTSc)

Conglomerate forms either discontinuous lensoid to sheet-like subunits or relatively continuous, thick sheets throughout the Stuhini stratigraphy. A sheet that commonly occurs at the base of the exposed Stuhini succession is well developed between Tagish and Atlin Lakes where it reaches thicknesses in excess of 800 metres. It has been previously mapped as a "basal conglomerate" in the Willison Bay area (Mihalynuk and Mountjoy, 1990; Mihalynuk *et al*., 1990), but it is probably an onlap unit that actually sits some distance above the base of the

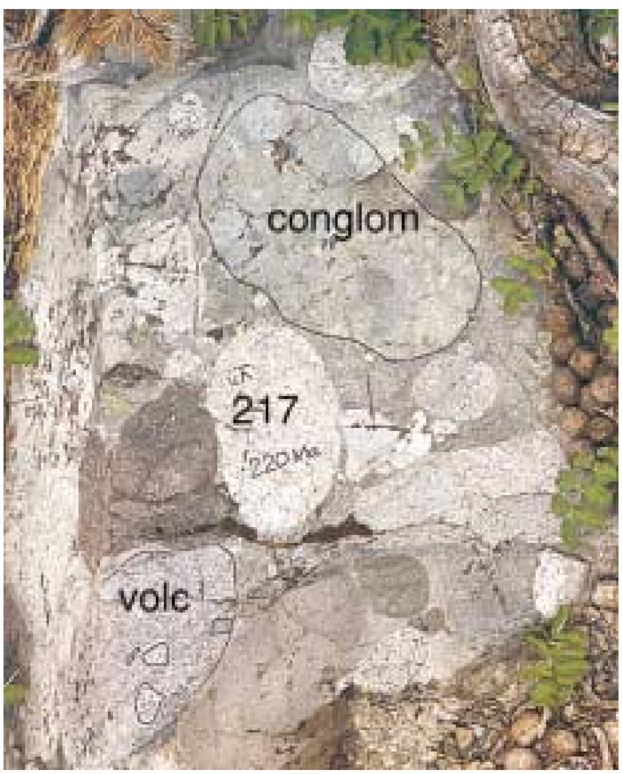


Photo 8-1. A typical outcrop of Upper Triassic Stuhini Group conglomerate. Clasts include those from the *circa* 217Ma Willison pluton (labelled 217), altered lapilli tuffs (volc)and recycled conglomerate(conglom). All are products of an earlier phase of Stuhini arc development.

Stuhini Group, marking the base of the upper division. Similar conglomerate forms mappable units that are variably distributed throughout the Stuhini stratigraphy. The Povoas Conglomerate of southern Yukon is compositionally similar and considered correlative. Hart and Radloff (1990) concluded that it probably rests unconformably above most of the Povoas Formation (mainly augite porphyries). In the Tulsequah map area Souther (1971, p.19) describes similar Stuhini Group conglomerate resting unconformably on contorted phyllite and quartzite; there it has been called the King Salmon Formation. In the Tagish area, Bultman (1979) termed these rocks unit A of the Stuhini Group. On The Cathedral, north of Willison Bay, conglomerate that sits nonconformably on potassium feldspar megacrystic granodiorite is comprised almost entirely of boulders and mineral grains derived from it. Just to the south, this contact has been disrupted by faulting.

Conglomerates occur as both clast and matrix - supported varieties. Most are massive and comprised of indistinct lensoid or sheet-like subunits, but locally bedding is well displayed. Matrix material is generally medium to coarse grained, feldspathic and lithic wacke that is dark grey to green; it may be pyritic and rusty weathering. In places massive epiclastics dominate the conglomerate unit.

With minor exceptions, clasts are well rounded and 2 to 20 centimetres, ranging up to 2 metres, in diameter. Lithologies are generally dominated by porphyritic volcanic rocks including pyroxene, hornblende and feldspar-phyric tuffs and possibly flows. Due to the generally dark green to grey matrix, light-coloured felsic intrusive clasts are most conspicuous. They run the compositional spectrum from alaskitic micropegmatite to granite to granodiorite to monzonite to diorite, and include foliated and non-foliated gabbro and hornblendite. However, circa 220 Ma potassium feldspar megacrystic granodiorite and granite are most common. Metamorphic clasts are locally abundant and are widespread as a minor constituent (Photo 8-2); commonly these occur as granules.

Willison Bay

In the conglomerate at Willison Bay, metamorphic clasts increase in abundance upward from the base of the unit, but no systematic change in the composition of metamorphic clasts is apparent. In order of abundance, they include muscovite-biotite schist and phyllite, chlorite-muscovite schist, amphibolitic gneiss and rare marble. No evidence of aluminosilicates has been observed within the metamorphic clasts, either in hand specimen or in thin section. Sparse clasts of volcanic conglomerate (or tuff with rounded lapilli) consist mainly of variegated fine to medium-grained feldspar porphyry that is typically moderately to strongly chlorite-epidote altered, in contrast to the less altered conglomerate ma-

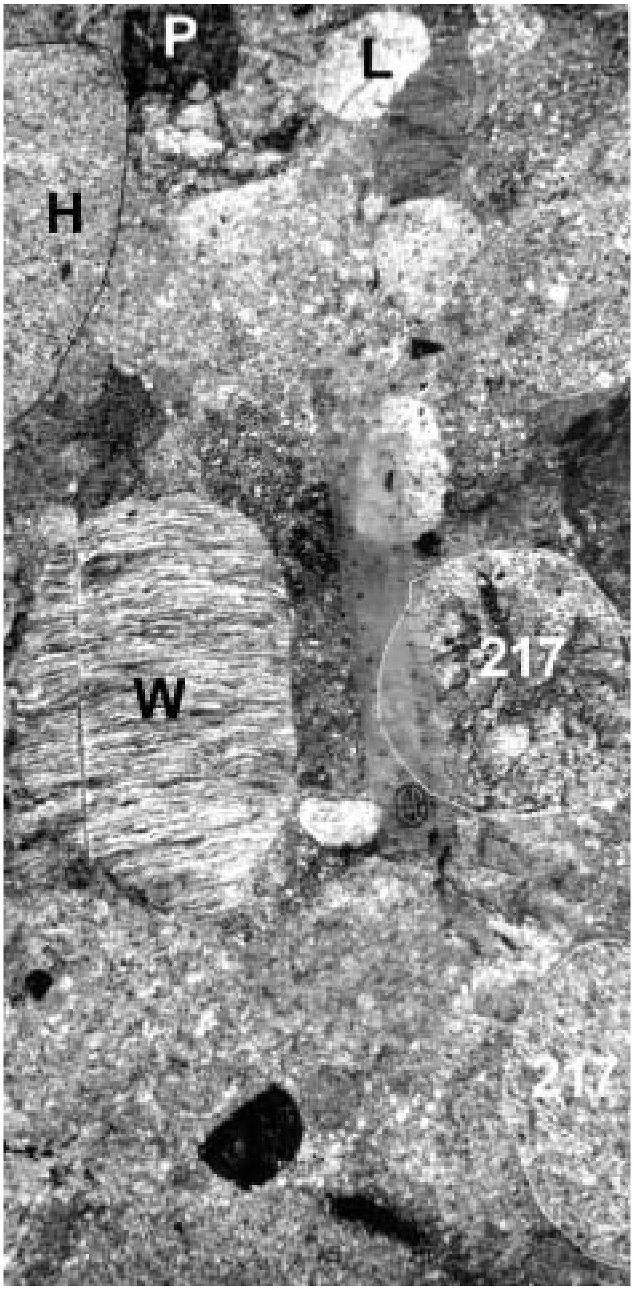


Photo 8-2. Stuhini Group conglomerate rich in metamorphic clasts like the Wann River gneiss (W) as well as *circa* 217 Ma Late Triassic granodiorite (217), limestone (L), hornblende and pyroxene-phyric volcanics (H, P) in a medium to coarse-grained volcanic matrix (6 inch ruler for scale).

trix. Other clast types include wacke, shale, aphanitic volcanic rocks and quartz. Bultman (1979) also noted the presence of appreciable chert clasts, but none were observed within the map area.

At the top of the Willison Bay unit is an approximately 20-metre partially covered interval that includes a pyritic sharpstone conglomerate comprised largely of silicified metamorphic clasts. Mean size is 2 to 3 centimetres within a mica-rich matrix. An overlying, disrupted, dominantly grey-green cherty wacke and argillite unit contains irregular andesitic to basaltic blocks that may be pillow breccia, layers of feldspar and sparse pyroxene-phyric volcanic material, and well bedded maroon tuff that record the onset of renewed volcanism.

Tagish Lake to Moon Lake

An orange to tan-weathering, clast-supported conglomerate separates Stuhini Group strata and Sinemurian Laberge Group argillites. It forms a laterally continuous belt extending from Tagish Lake to Moon Lake. Compositions vary from one entirely dominated by carbonate clasts to one dominated by intrusive and volcanic clasts and thickness varies from zero to several hundred metres. At two widely separated places, where it is not developed, there are instead dark grey, orange-weathering, scoria-rich carbonate lenses up to 10 metres thick. These lenses have been analysed for microfossils, but are apparently barren. Thus, it is not known whether this conglomerate is of Late Triassic or Early Jurassic age.

Bennett Lake

A conglomerate unit that straddles Bennett Lake was previously mapped as Paleozoic to Triassic in age (Mihalynuk and Rouse, 1988b) but is now known to be at least as young as Late Triassic. This unit sits above foliated Late Triassic granodiorite and contains abundant clasts of both granodiorite, and highly stretched quartz-rich metasediments (Photo 8-3). Locally it is foliated.

Pyroxene-phyric Basalt & Sediments (uTSp)

Coarse pyroxene-phyric basalt is a characteristic lithology of the Stuhini Group. These basalts commonly display evidence of subaqueous eruption and may be well pillowed, such as at Willison Bay. Elsewhere they may comprise massive flows with interflow marine sediments, as both southeast of Racine Lake and at Willison Bay. In the Willison Bay area, grey to black and green-mottled, resistant, massive and pillowed flows of basaltic composition rest with apparent conformity on conglomerates and associated sediments. They typically contain variable proportions of medium grained, subhedral to euhedral pyroxene and feldspar (up to 20% each) and fine grained plagioclase in an altered glass matrix (Photo 8-4). Flow and pillow interiors are vesicular. Individual flows are typically 2 to 5 metres thick, but may be in excess of 20 metres. Pillows are normally from 0.3 to 2 metres in diameter. Locally, the basalts are cut by gabbroic dikes.

Photo 8-3. Photomicrograph of possible Late Triassic conglomerate atop Late Triassic granodiorite. Highly strained quartz-rich clasts are predominant, but no nearby source of the clasts has been recognized. Length of photo represents 2.5mm of sample.

Interlayers of siltstone and siliceous argillite mark periods of brief, local volcanic quiescence. These weather rusty, are normally less than 3 metres thick and drape over irregular pillowed flow tops. Compared to the over and underlying basalts, they are recessive, although they are compact and hard, with a subconchoidal fracture. Fine parallel beds are characteristic, but rare ripple cross stratification has been observed. These sediments are rich in bivalves, particularly *Halobia* of Carnian to Norian age. Contacts between sedimentary layers and the overlying basalts are irregular as a result of scouring and uneven loading by successive flows. Norian conodonts were recovered from interpillow micrite (Appendix B). Pillow morphologies and structures in sedimentary interlayers indicate a right-way-up stratigraphy.

Coarse augite-phyric breccia and flows are common between Brownlee and Racine lakes. Due to the proximity of the Llewellyn fault, they are typically foliated. Where exposure is good, they are interlayered with wackes and other fine-grained sediments. In places they are juxtaposed with conglomerates, but contacts have not been observed and this could be due to structural interleaving.

Possible subaerial equivalents of the pyroxene-phyric flows, breccia and tuff occur in the Fantail Lake area where they are well exposed just east of the Llewellyn fault on the ridges south of Brownlee Lake. In other locations, as south of Moon Lake, voluminous piles of coarse, black breccia were deposited.

Subaerial deposits between Fantail and Brownlee Lakes exceed 300 metres in thickness. Breccias are resistant, rounded to blocky weathering, dark green and monolithologic, composed dominantly (50 to 80%) of blocks and bombs(?). Idiomorphic pyroxene phenocrysts (20 to 40%, up to 1.5 cm diameter) are conspicuous in both clasts and matrix (Photo 8-4). Plagioclase occurs as subhedral phenocrysts of lesser, but variable abundance and size. Matrix and phenocryst alteration includes chlorite and lesser epidote. Near Moon Lake, bright maroon, well bedded pyroxene crystal tuffs are believed to be of subaerial origin.

A change from subaqueous to subaerial or at least to shallow subaqueous environments is indicated in the Willison Bay section by incompetent coarse breccias abruptly overlying pillow basalts. These breccias are thought to be phreatomagmatic in origin.

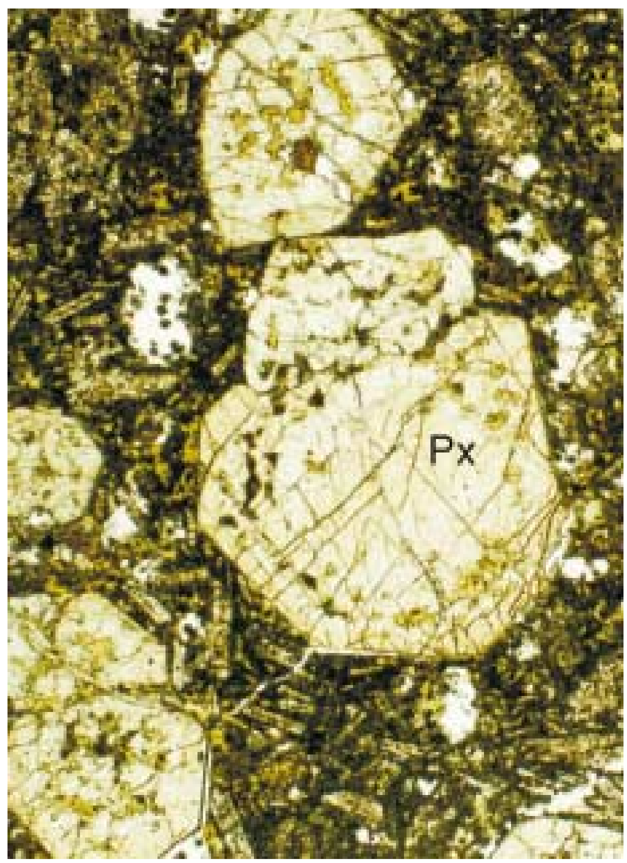


Photo 8-4. Photomicrograph of typical pyroxene-phyric basalt of the lower Stuhini Group. Long dimension of photo represents 2.5mm of sample.

Photo 8-5. Colonial coral from the carbonate debris unit below the Sinwa Formation at the south end of Copper Island (shown actual size).

Phreatomagmatic Breccia (uTSpb)

Phreatomagmatic breccias are recognized only at the south end of Atlin Lake (including Willison Bay) where Bultman (1979) mapped them as 'Unit C'. These breccias contain conspicuous, poorly lithified, dark brown to black, monolithologic blocks in a dusty green to tan, crystal-rich matrix. Both clast and matrix-supported varieties occur. Breccia fragments are angular, vesicular and rich in coarse pyroxene and serpentinized olivine (Photo 8-6). They range in size up to 50 centimetres, but are normally less than 20 centimetres in diameter. Matrix material is a crystal-lithic tuff of the same overall composition as the blocks. Strain has been preferentially partitioned into this unit due to its incompetence. It is cut by abundant quartz and carbonate-coated fractures generally having offsets of only a few centimetres.

Compositional similarity to underlying effusive pillow basalts can be seen by a comparison of their oxide geochemistry (*see* Age, correlation and tectonic significance below). Changes from dominantly effusive to pyroclastic volcanism may reflect a shift to a more hydrous magma, or alternatively, could result from a decrease in the depth of subaqueous eruption and reduced confining pressure that led to violent, steam-generated explosive eruptions. This sequence of events could result if the rocks were part of an emergent volcanic pile that was built up to within about 300 metres of the water surface, where abundant generation of steam is possible (Tanakadote, 1935). Overlying cross-stratified epiclastics and coralline boundstones (Photo 8-5) support the interpretation of an up-section transition to shallower water conditions.

Heterolithic Lapilli Tuffs (uTSv)

Dark green to grey or maroon heterolithic lapilli tuff is a common lithology, occurring at several horizons within the Stuhini Group. Angular, scoriaceous fragments to rounded volcaniclasts comprise 20 to 80% of the rock. Fragments are aphanitic or feldspar, pyroxene and hornblende porphyritic (crystals less than 3 mm). Alteration of the unit is locally intense producing epidote-chlorite clots that mantle phenocrysts. Some fragments have trachytically aligned plagioclase phenocrysts and microlites.

Limestone Boulder Conglomerate (uTSl)

This conglomerate is orange to yellow weathering, clast supported and varies from a conglomerate comprised exclusively of limestone boulders to one with a large proportion of intrusive and volcanic clasts. Clasts other than limestone increase in abundance to the east. The conglomerate may be several hundred metres thick and is persistent laterally. In places, however, it is not developed. For example, at Kirtland its stratigraphic position is occupied by a dark grey, orange-weathering, foliated carbonate with scoria-rich layers (less than 10 m thick) that is overlain by epiclastics. The lithologies and succession at Kirtland are identical to a section on the ridges southwest of Moon Lake. It is not known if this conglomerate is Upper Triassic or Lower Jurassic as it separates strata of definite Upper Triassic Stuhini Group affiliation and Pliensbachian argillites of the Laberge Group.

Epiclastic Strata (uTSvc)

Accumulations of epiclastic strata are common within the Stuhini Group. Units vary in thickness and clastic character from thin beds between individual cool-

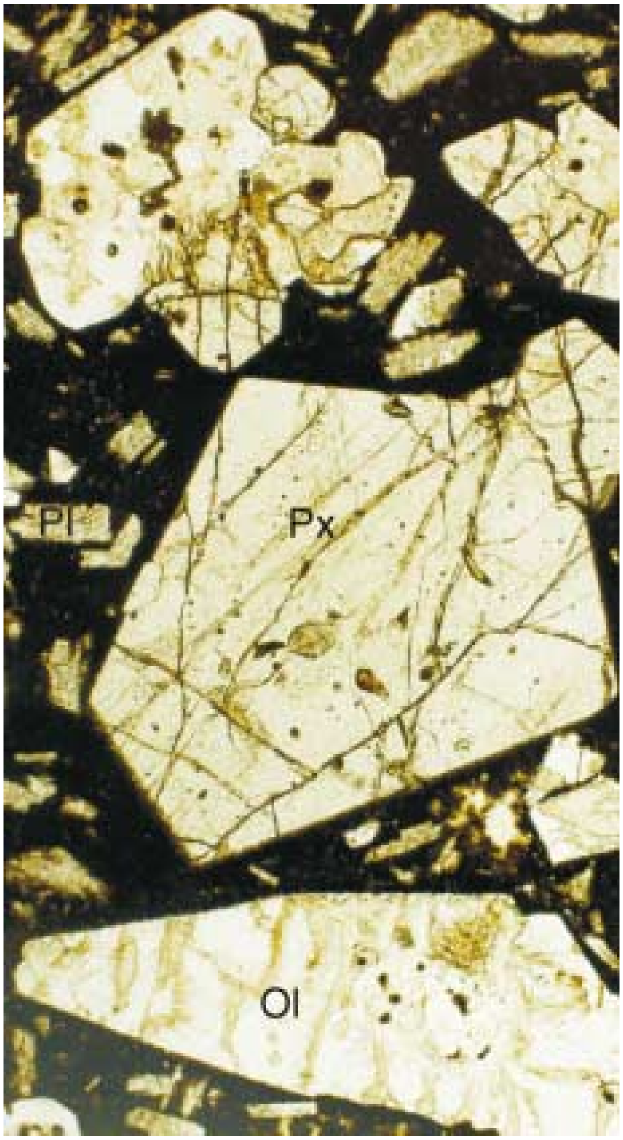


Photo 8-6. Photomicrograph of phreatomagmatic pyroxene porphyry unit, Willison Bay. Olivine as idiomorphic phenocrysts was also abundant, but has been replaced by serpentine. Long dimension of photo represents 2.5mm of sample DLO89-5-3.

ing units to significant mappable units (in south and central 104M/8 and northeast 104M/15), and from wacke to cobble conglomerate. These units were derived mainly from volcanic rocks of the Stuhini Group, however, rare exotic clasts are present. In contrast, the older Carnian conglomerate (unit "uTSc" above) is composed in large part of clasts derived from lithologies other than Stuhini arc rocks.

Epiclastic strata can be grossly subdivided into two main types: those dominated by quartz-bearing coarse volcanic sandstone, and those of more variable grain size including wackes to conglomerates that are commonly rich in hornblende. Both are diachronous.

Coarse, quartz-bearing, dominantly volcanic sandstones crop out between the basalt flow/breccia unit and the Upper Norian Sinwa(?) carbonate in the Willison Bay area. This unit is discontinuous and varies greatly in thickness, it apparently ranges up to 800 metres. Lensoid beds of this type are also common within and above the Carnian (basal) conglomerate unit and locally are continuous enough to constitute mapable units (see Figure GM97-1: The Cathedral area).

Clasts, commonly up to cobble size and less often to boulder size, are dominantly porphyries of various types. Phenocryst assemblages are: plagioclase (subhedral, less than 5 mm, 60%) and hornblende (10%) in a light mauve to pink groundmass; plagioclase, quartz and biotite; plagioclase, sanidine and quartz; fine-grained plagioclase and pyroxene. Compositions include dacite, latite, andesite and basalt; intrusive clasts range from granite to diorite. The volcanic clasts typically contain authigenic chlorite and epidote.

Epiclastics appear massive where poorly exposed, but on clean exposures they display planar bedding, grading and large scale, low-angle (2 to 5 m) trough cross stratification. Irregular distribution of the epiclastic strata probably results from their deposition in small disconnected basins in a topographically variable volcanic terrain.

One of the best exposures of this rock type is a distinctive maroon epiclastic to coarsely conglomeratic unit just below the Sinwa limestone on southern Copper Island. It appears to be a mixture of stratigraphically higher and lower units: it contains blocks of a distinctive underlying phreatomagmatic unit and of an overlying fossiliferous carbonate (Photo 8-5). These outcrops probably represent debris flows deposited in front of a migrating Sinwa Formation reef front. Abundant quartz and quartz-feldspar-phyric dacite clasts in the unit are believed to be derived from the youngest of the Stuhini Group volcanic rocks. These rocks are included with the volcaniclastic unit on Figure GM97-1.

One locally mappable unit consists of wacke and conglomerate that is rich in hornblende. This unit is most common at the same relative stratigraphic position as other major epiclastic accumulations (Figure 8-2). Hornblende-rich volcanic sandstone and wacke (wacke here indicating at least 15% clay minerals in the matrix), are best exposed just north of the bend in Tutshi Lake (included in unit uTSc on Figure GM97-1). At this locality, the matrix contains a large proportion of hornblende and clasts are dominated by grey-green to mauve hornblende-feldspar porphyritic volcanic breccia. Locally there are clasts of hornblende granodiorite up to 1 metre in diameter, and cobble-sized syenite, limestone and cherty clasts. Sets of wacke beds locally attain thicknesses of up to 1100 metres. Although the unit is lumped with uTSc on Figure GM97-1 in order to reduce the number of units, it would be more accurate to map this and other conglomerate units above the "basal conglomerate" as separate units as was done by Mihalynuk and Rouse (1988a, b).

Argillite (uTSa)

Argillite or silty argillite occurs at several localities within the Stuhini Group. It is interbedded with siltstone as intraflow sediments within the "pyroxene-phyric basalt" unit with which it is included; it dominates the matrix of wackes, and is included with "epiclastic strata". It also occurs above the Carnian conglomerate unit and adjacent to carbonate of possible Sinwa Formation. It is most widespread adjacent to the carbonate and forms a more or less continuous and correlatable unit. Locally, it is exposed both above and below the carbonate unit, and in both cases, is well laminated to irregularly bedded and dark brown to black. It can be pyritic, but this is not necessarily characteristic.

Argillite is perhaps best exposed near Brownlee Lake where it is deformed within the Llewellyn fault zone. Massive argillites are maroon, green and brown, and weather into angular gravel-sized fragments. These rocks are easily mistaken for aphanitic intrusives except that in rare instances weathered surfaces preserve original sedimentary layering. Immediately adjacent to the fault these rocks are transformed into chlorite schist which may be tectonically mixed with fault material derived from other lithologies. These argillites grade "upwards" (tops uncertain) and eastwards into clastic rocks of volcanic provenance. Volcanic sandstones and wackes are brown to grey, recessive weathering, calcareous, fissile and common throughout the Stuhini stratigraphy. On the ridges northwest of Brownlee Lake wackes sit "above" (east of) the augite porphyries, but south of Brownlee Lake the opposite relationship is observed. Foliation of this unit generally increases towards the Llewellyn fault with 1 to 2 metre wide zones of high strain up to several hundred metres away from the main fault trace.

Argillite is not exposed on the shores of Willison Bay adjacent to the carbonate unit, but on the ridges to the north, an argillite tens of metres thick crops out above(?) coarse-grained epiclastic strata that enclose lenses of carbonate. At eastern Tutshi Lake, argillite below the carbonate unit becomes increasingly calcareous on approaching the carbonate. Above the carbonate, argillite is locally in apparent stratigraphic contact, but where it is missing, its position is occupied by wacke or carbonate-clast-rich conglomerate.

Argillite deposition was appears to have been more-or-less continuous, but thick argillite accumulations only occur where more rapid sedimentation of coarse clastics or volcanic strata did not overwhelm the fine clastic component.

Carbonate (Sinwa Formation?, uTSs)

A poorly bedded and generally fossil-poor carbonate consistently marks the contact between rocks of the Upper Triassic Stuhini and Lower Jurassic Laberge groups. It can be traced at this stratigraphic interval for over 320 kilometres from the Tulsequah area (see Chapter 13, Photos 13-12, 13) to near Whitehorse. This unit resembles, but may not correlate with carbonate layers that immediately underlie fine-grained, Lower Jurassic clastic strata of the Inklin Formation. Between the Tulsequah and Cry Lake map areas, however, these carbonate units are together carried in the hangingwall of the King Salmon thrust over coarse-grained strata of the Lower Jurassic Takwahoni Formation (Thorstad and Gabrielse, 1986). In the Tagish area, Bultman (1979) mapped these carbonates as Upper Triassic Sinwa Formation based upon lithologic similarity and along strike continuity with rocks mapped at the type locality in the Tulsequah map area (Souther, 1971). Northern parts of the belt are directly correlative with the "Hancock Member" which attains thicknesses of 600 metres in southern Yukon (Hart and Radloff, 1990).

Samples collected for microfossil analysis yield a latest Norian conodont fauna (M.J. Orchard, written communication 1988, 1989, 1990, 1991, Table AB2), but only at localities sampled north of the Tulsequah map area (104K). Samples collected from between Racine Lake and southern Atlin Lake stand a greater chance of being devoid of conodonts as one progresses southward. This is particularly intriguing since carbonates at southern Atlin Lake (Willison Bay) preserve good bedding, a rarity in the carbonate belt, so the lack of conodonts cannot be attributed to recrystallization or deformation. Furthermore, sparse interpillow micrites from lower in the section yield Carnian conodonts (C-153954). Macrofossils obtained from the Sinwa Formation in the eastern Tulsequah map area(104K) confirm a Late Triassic age; however, rarely do these samples yield conodonts (H.W. Tipper personal communication, 1991). Perhaps the southern part of the Sinwa carbonate was deposited in an environment in which the conodont animal did not thrive. Alternatively, perhaps the southern and northern carbonate belts are not correlative.

Age, Correlation and Tectonic Significance

Christie (1957) recognized that much of the Stuhini Group in the Bennett Lake map area (104M) is Triassic. However, correlative rocks to the immediate east, in southwestern Atlin (104N) map area, were originally thought to be Pennsylvanian and/or Permian in age, based upon identification of fossil corals and bryozoa from a ferruginous limestone bed (Harker *in* Aitken, 1959). Reevaluation of the poorly preserved fossils indicated a probable Upper Triassic age (Harker and Tozer *in* Souther, 1971, p. 23). Within the southern study area, at Second Narrows, a presumably correlative ferruginous limestone bed is intercalated with volcaniclastic strata and pyroclastic rocks of the Stuhini Group. A colonial coral fauna collected from this locality in 1989 was of indeterminate age (C-153948 - Table AB1; Photo 8-5) although Late Triassic conodonts are reported (M. Orchard, written communication, 1999).

To the south, in the Tulsequah area the Stuhini Group sits unconformably on deformed, poorly dated rocks thought to be mainly Lower and Middle Triassic (104K; Souther, 1971). Fossils obtained from the Stuhini succession there include the finely ribbed bivalve *Halobia*, of Carnian age, and the Norian bivalves *Monotis* and *Halorites* (Souther, 1971, p. 22).

New fossil ages from Stuhini Group strata of the Tagish area reported here are entirely Carnian and Norian. New isotopic data from plutons that are presumably comagmatic with the arc volcanics also confirm a Late Triassic age, but in detail somewhat contradict the fossil ages (*cf.* Mihalynuk *et al*., 1997). In the most complete Stuhini section, exposed at Willison Bay, strata dip consistently to the east away from the Willison Bay granodiorite, which is nonconformably overlain by conglomerate ('basal conglomerate' of Mihalynuk and Mountjoy, 1990) in which clasts of the granodiorite figure prominently. The Willison Bay pluton is dated at 220 ±5 Ma and 216.6 ±4 Ma (recalculated K-Ar, hornblende, Bultman, 1979; U-Pb, zircon, Table AA5). The overlying conglomerate fines upward and then gives way to siltstone and basalt. *Halobia* from siltstone interbedded with the basalt (C-153962) and conodonts extracted from interpillow micrite within unit uTSp suggest that the unit is Carnian (C-153954; Appendix B), that is, between 235±4 and 223.4±9.5 Ma according to the time scale of Harland *et al.* (1990); significantly **older** than the absolute age of the underlying pluton. Assuming that the age data are reliable, an apparent older-over-younger relationship exists. Four explanations are possible: incorrect fossil identifications, thrust fault duplication, recumbent isoclinal folding, or a poorly constrained time scale.

The fossils are well preserved and identifications are confident; fossils are not a likely cause. No candidate thrust fault or recumbent fold can be identified in the Willison Bay area. Depositional "way up" indicators are common within the section and none indicate overturned strata on the scale of a large recumbent fold. Similarly, fossil age control and gradational contacts do not support thrust-related older-over-younger relationships. Small-scale isoclinal folding of argillite along southeast Willison Bay and a partly foliated and partly covered interval along strike northwest of the bay, were originally thought to mark the locus of a significant thrust fault that placed older Stuhini strata over younger, possibly post-Stuhini conglomerate. Even though some motion was undoubtedly accommodated along this disrupted zone, four lines of evidence support an older not younger relative age for the conglomerate. First, the upper parts of the conglomerate grade into wackes with a pyroxene crystal component that increases towards the overlying pyroxene-phyric flows. Second, maroon tuffaceous layers also become increasingly common until pillowed flow units are encountered. Third and most importantly, interflow turbiditic siltstones containing Carnian *Halobia*, also contain rare clasts identical to the Willison Bay granodiorite, indicating a gradational upward-younging transition from conglomerate to Carnian flows. Fourth, conglomerate units indistinguishable from the 'basal' conglomerate occur on the ridges between Nelson and Edgar lakes where they are locally intercalated with primary volcaniclastic strata. Thus, in places they are the same age as some Stuhini volcanic units.

Further, regional-scale intrusive relationships do not support thrust or structural overturning or duplication. Just south of the map area, dikes resembling the 217 Ma granodiorite intrude volcanic strata of the Stuhini Group and along its southwest side the Willison Bay granodiorite "... intrudes metamorphic rocks... along an irregular contact along which large fingers of granodiorite extend into the metamorphic rocks" (Bultman, 1979, p. 26). These "metamorphic" rocks were mapped by Werner (1978) as Stuhini Group, an observation confirmed by later reconnaissance mapping in the Hoboe Creek area (Photos 4-2). Locally, Stuhini pillow basalt and tuff are strongly foliated and easily mistaken for the Boundary Ranges metamorphic rocks, except that relict textures are widespread. Thus, it appears that the Willison Bay granodiorite as a whole is intrusive into the mainly basaltic lower portions of the Stuhini Group and neither it nor nonconformably overlying strata have been translated with respect to the lower the Stuhini stratigraphy. Rather, the lower parts of the Stuhini Group were intruded by the 217 Ma granodiorite, and then uplifted and eroded to provide clasts for conglomerate higher in the sequence. This conglomerate was deposited on an erosional surface with high relief, consequently the 'basal' conglomerate marks the base of the younger of two Stuhini arc-building episodes. If field and isotopic relationships are correct, then the absolute age limits of Late Triassic stages as shown in Harland *et al*. (1990) are in need of adjustment. In particular, the Carnian must be as young as 216.6 ±4Ma (221 +0/-8Ma; see Mihalynuk *et al*., 1997 for a more detailed discussion).

Geochemistry

Basaltic units within the Stuhini Group are atypical relative to most basalts of the alkaline, tholeiitic or calc-alkalic suites. With the exception of one sample that plots in the dacite field, the others plot as basalt on the alkalis-silica plot of Figure 8-3a (the "dacite" is a sample of

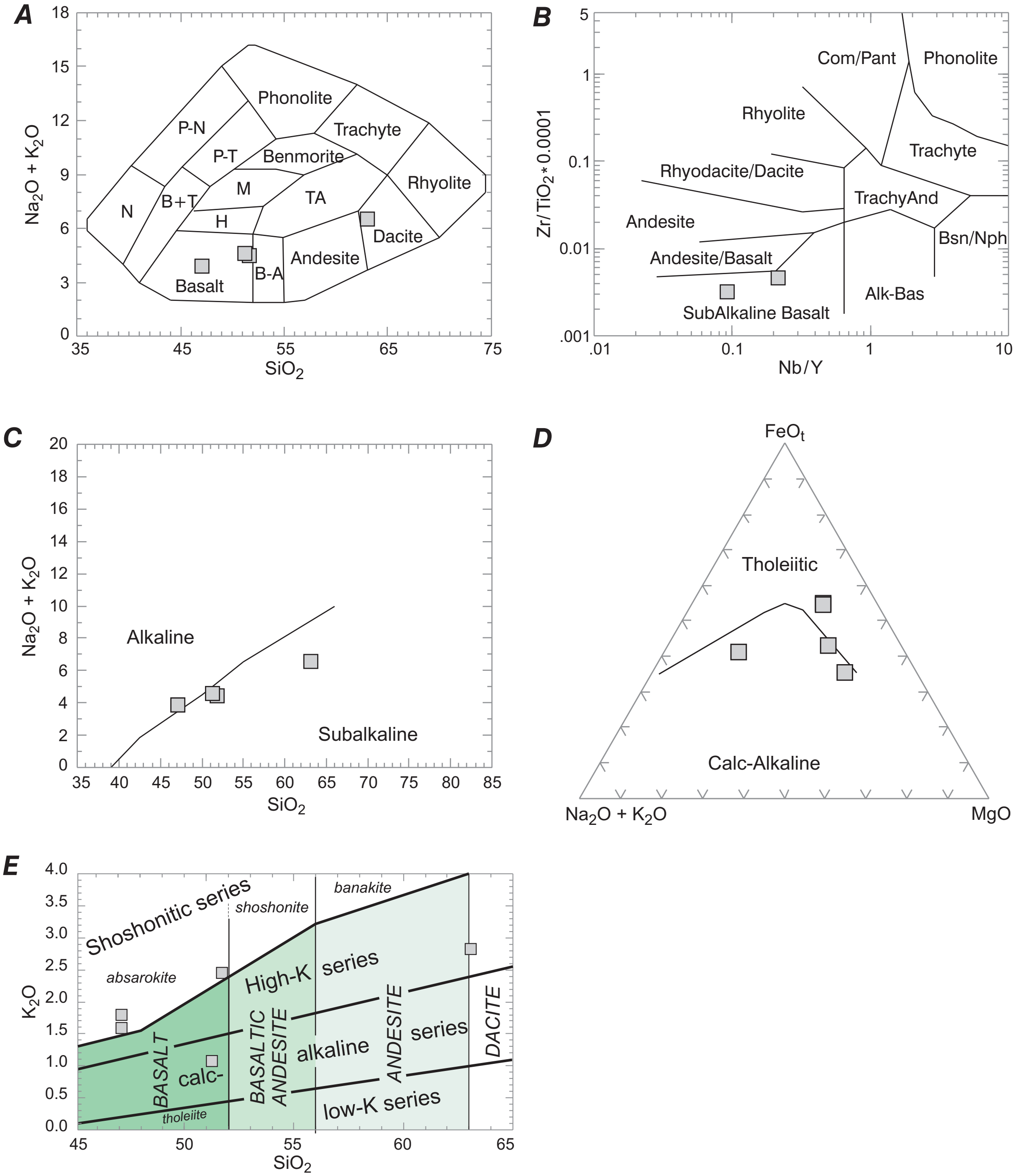


Figure 8-3. Geochemistry of the Stuhini Group: (a) alkalis versus silica classification diagram shows a dominantly basaltic composition with one dacite (fields of Cox *et al.*, 1979); (b) Zr/TiO_2*0.0001-Nb/Y plot of Winchester and Floyd (1977) shows that the samples are subalkaline basalts. This is echoed by the Zr/TiO_2-SiO_2 plot (not shown). (c) alkalis-silica and (d) AFM diagrams of Irvine and Barager (1971) show that the samples are subalkaline and of mixed tholeiitic and calcalkalic series. (e) K_2O-SiO_2 plot shows that most samples belong to the shoshonitic series (field divisions of Ewart, 1982); typical basalts contain less than 1 wt% K_2O at 50 wt% SiO_2.

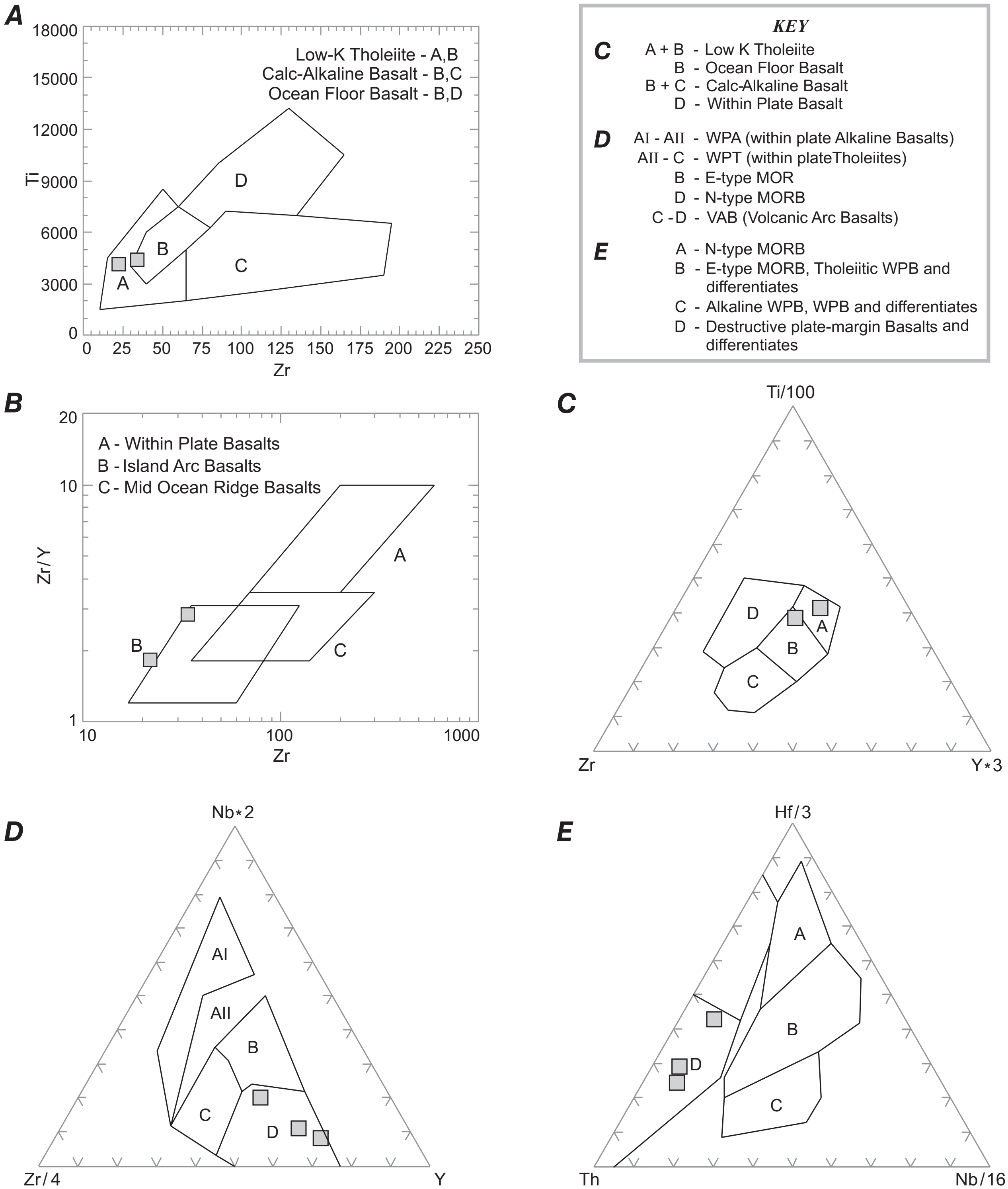


Figure 8-4. Geochemistry of Stuhini Group basalt: (a) Ti-Zr plot of Pearce and Cann (1973) is an ineffective discriminant; (b) the Zr-Y discrimination plot following the method of Pearce and Norry (1979) shows that the samples plot as island arc basalts; (c) the trivariate plot of Ti/100-Zr-Y*3 follows the method of Pearce and Cann (1973), and like (a) is an ineffective discriminant; (d, e) plots of Nb*2-Zr/4-Y and Hf/3-Th-Nb/16 following the method of Meschede (1986) and Wood (1980) both indicate that the basalts were formed at a destructive plate margin, consistent with (b).

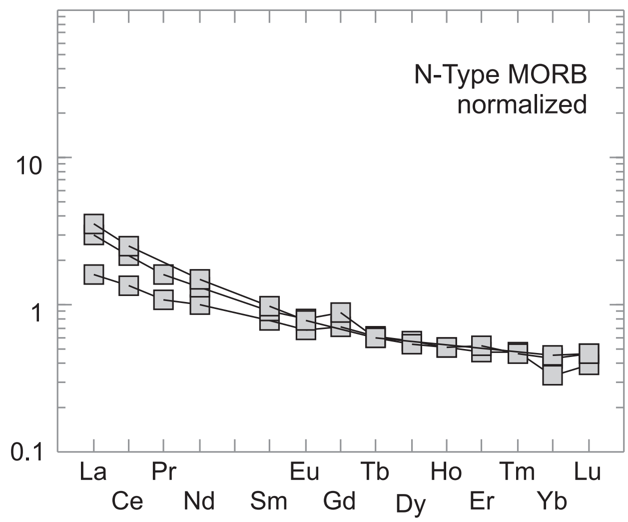


Figure 8-5. N-type MORB normalized REE plot shows light element enrichment and heavy element depletion typical of a subduction zone environment.

glassy pillow basalt rim which has apparently been silicified at the expense of Mg and Ca). Stuhini basaltic units are similarly classified by the Zr/TiO_2*0.0001-Nb/Y plot of Figure 8-3b as subalkaline basalts (and also by the companion plot: Zr/TiO_2-SiO_2 plot which is not shown). They are also shown as subalkaline on the alkalis-silica diagram of Figure 8-3c; although, a clear affiliation with either the tholeiitic or calc-alkalic series is not apparent in Figure 8-3d. These rocks may be classed as subalkaline, but they are unusually rich in potassium (Table AD1) as shown in Figure 8e (which is the K_2O versus SiO_2 classification of Ewart, 1982); and their "subalkaline" character can be attributed to unusually low Na_2O contents. Subalkaline basalts normally have K_2O contents that are 25% and less commonly up to 50% of their Na_2O contents. Even in basalts of the alkaline series, Na_2O is generally subequal to or greater than K_2O. Furthermore, in the submarine environment in which these rocks were deposited, sodium enrichment can be expected due to interaction with sea water. Potassium metasomatism is not indicated petrographically, nor does it seem probable since the samples analyzed are separated by tens of kilometres. Stuhini basalts are most like absarokites of the K-rich basalt series. They are typically porphyritic, often crowded with phenocrysts of augite and plagioclase, but unlike many basaltic rocks of the shoshonitic series, they lack abundant olivine phenocrysts. One exception is unit uTrSpx which contains perhaps 20% subidiomorphic olivine pseudomorphically replaced by serpentine (Photo 8-6) in addition to 25% idiomorphic clinopyroxene. Petrographically rocks of unit uTSpx are ankaramites.

Tectonic discrimination diagrams shown in Figure 8-4b, 4c and 4d confirm field observations which support a volcanic arc origin for the Stuhini Group. On Figure 8-4b the basalts plot in the island arc field (method of Pearce and Norry, 1979) and on Figures 8-4d and 4e they plot in the destructive plate margin field (method of Meschede, 1986, and Wood, 1980). On Figures 8-4a and 4c the basalts plot as low potassium tholeiites (method of Pearce and Cann (1973), however, they are clearly too potassic for this to be the case (compare Figure 8-3e). A reliance on zirconium concentrations in these plots is problematical because the basalts analyzed have abnormally low Zr values (20-40 ppm range) which pull the plotted points towards the tholeiite fields.

Too few analyses of Stuhini Group basalts exist to enable confident geochemical characterization. However, the pyroxene porphyritic varieties analyzed are ankaramitic absarokites unusually low in Zr and Na_2O. Samples analyzed were collected from three localities spaced relatively evenly along the southern 70 kilometres of the belt in which Stuhini Group rocks crop out. Lithologically, these rocks characterize the least pyroxene porphyritic varieties of the pyroxene porphyry unit and are believed to be representative.

A comparison of Stuhini Group basalt geochemistry with that of Tertiary to Recent orogenic basalts compiled by Ewart (1982) reveals no analogues, attesting to their unusual character. However, coeval basalt of the Nicola Group in south central British Columbia (Mortimer, 1987) are similar both petrographically and geochemically. Highly porphyritic ankaramitic absarokite from the central and eastern Nicola belts show $K_2O > Na_2O$ (Na_2O ranges from 1.92 to 3.42 Wt %) and low Zr (41 to 49 ppm) contents (Mortimer, 1987), although neither Zr nor Na_2O values are as low as in Stuhini basalts.

The Stuhini arc

Stuhini Group strata record a dynamic environment most simply interpreted as two major arc-building (arc inflation) episodes. Each constructional episode was followed by a period of transgression and widespread erosion. These episodes are most readily observed in the Tagish a rea, but details of the complex interplay of arc facies locally obscures this two-phase development. However, generalized stratigraphic sections from the Tulsequah (Souther, 1971) and Whitehorse (Wheeler, 1961; Hart and Pelletier, 1989a) areas are consistent with a two-phase arc evolution as illustrated in Figure 8-2. In each area the volcanic arc axis appears to lie west of sediment-dominated arc facies.

The early arc constructional phase is poorly characterized. Exposure is limited and regionally strata dip east and the deepest and oldest Stuhini strata farthest west, adjacent to the Llewellyn fault, have been subjected to ductile deformation. In some localities these strata may include pre-Stuhini rocks, although the section is dominated by medium to coarsely pyroxene-phyric basalt breccias and variegated, fine to medium feldspar-phyric lapilli tuffs of Stuhini aspect. Small areas on the south end of Willison Bay may be underlain by these rocks where they are intruded by leucogabbro associated with the Willison Bay pluton. Similar foliated heterolithic and augite-phyric tuff between Skelly and Racine lakes may also be correlatives. Early arc inflation culminated at about the same time as when the Willison Bay pluton was intruded. Dissection of the arc exposed the pluton and resulted in deposition of a thick conglomerate blanket under submarine conditions. Further subsidence is recorded by a gross fining-upward of sediments and deposition of quartzose turbidites that contain *Halobia* of Carnian age. Effusive volcanism produced voluminous pyroxene-phyric pillow basalt that overwhelmed sedimentary clastic input. Carbonate deposition was sporadic as indicated by sparse interpillow micrite.

A second phase of arc inflation and accumulation of pillow basalts led to shallow water conditions that resulted in widespread phreatomagmatic eruptive activity. Subsequent volcanic strata are dominantly subaerial or littoral, and andesitic to dacitic. Quartz-phyric units occur at the highest stratigraphic levels. Deposition of thick epiclastic units followed cessation of volcanism and a return to subaqueous conditions in Norian time. Clasts and olistoliths of carbonate within the epiclastic strata indicate the establishment of carbonate sedimentation and formation of unstable carbonate banks. Ultimately these banks built up to form the succeeding “Sinwa” Formation. In places carbonate deposition was in relatively restricted lagoons or forearc sub-basins; elsewhere high energy, possibly storm-generated carbonate talus and conglomerate are typical. In both situations, the depositional environment appears to have been a relatively hostile one in which few organisms, including conodonts, flourished.

Mineral Potential

In may parts of British Columbia the Late Triassic epoch is an important time for copper mineralization. In the Tagish area, mineralization of this age is limited to small basaltic copper occurrences west of Edgar Lake and on southern Copper Island. Upper Triassic strata do however host several mineral occurrences, and in some cases may have provided fertile source rocks for later mineralizing events. Copper-gold skarn mineralization in northeast Tutshi Lake map area, for example, is hosted by Upper Triassic carbonate and conglomerate. Similar mineralization occurs in correlative hostrocks in the Whitehorse copper belt to the north.

Why the Upper Triassic rocks tend to be enriched in copper is uncertain. One reason may be related to high pyroxene contents that characterize the Stuhini Group (as well as coeval volcanics of the Takla and Nicola groups). Careful investigation of similar rocks in the Solomon Islands (Stanton, 1991) shows that copper is partitioned into the melt as olivine and pyroxene crystallize until whole-rock silica reaches about 52%, after which copper is lost through devolatilization. Thus, residual basaltic andesite or quartz dioritic magmas should be copper enriched. Unfortunately, no isolated quartz diorite stocks of Late Triassic age have been recognized in the map area.

Occurrences in rocks of probable but unconfirmed Late Triassic age include a foliated, carbonate-hosted silver-lead-zinc-copper-gold prospect near Moon Lake (Chapter 16) and polymetallic veins along the Llewellyn fault (Brown, Chapter 16). Both showings are likely related to Cretaceous movement on the Llewellyn fault zone.

Bedding parallel and high angle faulting localized at the contact between Norian carbonate and calcareous siltstone of the Laberge Group may have provided an environment suitable for the formation of Carlin-type mineralization (“carbonate-hosted disseminated Au-Ag” in Lefebure and Höy, 1996). However, existence of radiogenic basement rocks appears to be an important metallogenic ingredient in the Carlin trend as it parallels the 0.706 initial strontium isopleth. The Norian carbonate roughly parallels the Mesozoic and Cenozoic 0.705 isopleth (Armstrong, 1988), indicating that the basement rocks are slightly less radiogenic than those of the Carlin trend.

Chapter 9 Laberge Group

Strata of the Lower Jurassic Laberge Group are dominated by immature marine clastics preserved in a northwest-trending fold and thrust belt. They are regionally metamorphosed to prehnite-pumpellyite and epidote-albite facies and, adjacent to plutons, are hornfelsed to higher grade. Within the Tagish map area they are mainly confined to a central belt that outlines the extent of the collapsed Whitehorse Trough (Figure 9-1). These strata extend north and south of the map area from southern Yukon to the Dease Lake area in British Columbia and are believed to be an overlap assemblage that links terranes in the map area by Early Jurassic time (Wheeler *et al.*, 1991; next section and Chapter 15).

Previous work and nomenclature

Cairns (1911) used the "Laberge series" to denote conglomerates, greywackes and argillites along the shores of Lake Laberge that were thought to be of JuraCretaceous age. Wheeler (1961) applied the lithostratigraphic name "Laberge Group" to correlative strata in the Whitehorse area and recognized them as part of a regional northwest-trending belt of basinal rocks (Whitehorse Trough) that are restricted to the Lower and early Middle Jurassic. Wheeler divided the trough into three facies belts: a western, proximal coarse conglomerate fringing the dissected Lewes River arc; a central, fine-grained distal argillite in the medial Whitehorse Trough; and an eastern conglomerate belt of uncertain provenance. To the south, in the Tulsequah area, Souther (1971) divided the Laberge Group into the proximal, fossiliferous, shallow water Takwahoni, and deep water, fossil-poor, Inklin formations.

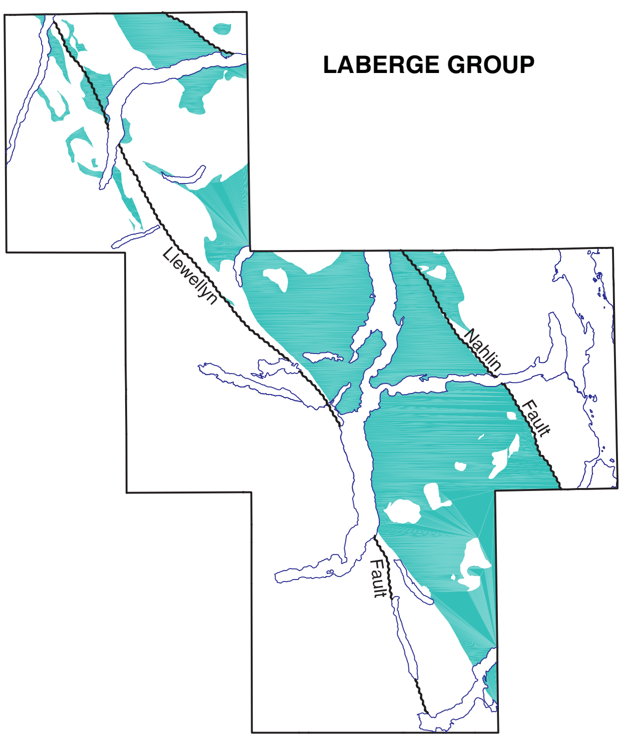


Figure 9-1. Distribution of Laberge Group strata within the Whitehorse Trough and major structures that may have affected sedimentation.

More recently, workers have used Takwahoni and Inklin formation names to distinguish strata of different provenance. For example, Wheeler and McFeely (1991) use Takwahoni to distinguish clastics derived from Stikinia, and Inklin for those with Cache Creek and Quesnel Terrane provenance. Still other workers (H. Gabrielse, personal communication, 1992) suggest that the Inklin Formation should be restricted to Lower Jurassic strata such as those in the hangingwall of the King Salmon thrust, that display a penetrative foliation.

While recent usages may be applicable on a broad scale, they are not well suited to the map area. Inklin strata shown by Wheeler and McFeely (1991) within the map area display neither a pervasive penetrative fabric, nor strong evidence of Cache Creek derivation. Locally they are rich in clasts that are most likely derived from the Stuhini arc, historically considered part of the Stikine Terrane (see under Laberge Provenance and Paleoflow).

An informal definition of the Takwahoni and Inklin formations, proposed by H.W. Tipper (personal communication, 1992), is most suited to the Laberge Group of the map area. That is: the name "Takwahoni Formation" is applied to Stikinia-derived, conglomerate-rich clastic rocks that are not older than late Pliensbachian and may be as young as early Bajocian. The name "Inklin Formation" is applied to a mainly fine-grained clastic succession with locally abundant wackes and thin conglomeratic units. Inklin strata are known to range in age from Sinemurian to late Toarcian and may span Hettangian to early Bajocian time. One unit that may be regionally correlatable, and in places may mark the transition from one formation to the next, is a coarse conglomerate at the base of the Pliensbachian. Allogenic Inklin strata are derived from Stikine, Cache Creek and Quesnel terrane sources.

Sinemurian argillite along the western margin of the Whitehorse Trough commonly displays a well developed, penetrative platy parting and thus fits the Inklin Formation criteria of both Tipper and Gabrielse. However, these same units contain porphyritic volcanic clasts and upper Norian carbonate clasts (Table AB2) almost certainly derived from the underlying Stuhini Group and thus are not compatible with the Cache Creek terrane derivation implied by Wheeler *et al.* (1991).

Detailed studies of Whitehorse Trough sedimentation within and to the immediate north of the Tagish area have been the focus of thesis work by Bultman (1979) and Dickie (1989) respectively. Provenance, paleoflow and paleontologic studies by Johannson (1994 and Johansson *et al.*, 1996) focused on the strata bordering southern Atlin Lake, including the southeastern-most corner of the Tagish map area.

Depositional Setting

Sedimentological studies by Bultman (1979) and Dickie (1989) concluded that Laberge Group strata within their study areas are products of coalescing subaqueous fans. Dickie (1989) detailed distinct, long-lived depocentres and further refined the depositional environment. Rather than typical low-gradient submarine fans, Dickie outlined a series of steep, arc-flanking cones similar to modern fjord-type fans (Prior and Bornhold, 1988).

Not all Whitehorse Trough deposition was of deep water character. Local shallow water facies are indicated by the presence of hummocky cross-stratification with bioturbated interbeds. Trace fossil ichnofacies *Skolithos,* identified in these rocks (Dickie, 1990; personal communication 1990), are apparently restricted to littoral and sublittoral marine environments (Frey and Pemberton, 1984). Shallow water sedimentary features and trace fossils indicate periodic rapid sedimentation rates which locally exceeded subsidence rates.

Thickness and Contact Relationships

Inklin Formation rocks which underlie much of the Tagish area are crosscut by numerous granitoid stocks. In addition, widespread folding and thrust faulting, which are probably much more prevalent than indicated on the map and cross-sections of Figure GM97-1, make thickness difficult to assess. Correlation from one place to another is hampered by dramatic facies changes and lack of lithologic or biostratigraphic marker horizons. Thickness estimates of previous workers range up to 7000 metres, but as Table 9-1 shows, most authors agree that thicknesses of 3000 metres or more are typical.

Stratigraphic successions within the map area are typically interrupted. In the Tutshi Lake area, only 630 metres of continuous Laberge strata that are not structurally thickened can be identified (Mihalynuk and Rouse, 1988a). Thickness diminishes to the west until the Laberge stratigraphy is missing and volcanic rocks of presumed Lower to Middle Jurassic age rest on metamorphic rocks of the Boundary Ranges (Figure 9-2). Westernmost exposures of Laberge strata south of Tutshi Lake occur within a small syncline where only a few hundred metres of section is represented. True maximum thickness is much greater. North of Graham Inlet, thicknesses in excess of 3500m are indicated on cross-sections G-G' and I-I' of Figure GM97-1. At least 2500m of **rela-**

Table 9-1 Estimated Laberge Group thicknesses

Author	Thickness in metres	Area
Cairns, 1912	1500	Wheaton River
Cockfield and Bell, 1926	>3050	Whitehorse
Bostock, 1936	2750	Carmacks
Wheeler, 1961	2425	Whitehorse
Souther, 1971	3100 Inklin; 3350 Takwahoni	Tulsequah
Bultman, 1979	5000-7000	Bennett-Atlin
Dickie, 1989	>3000	Whitehorse average, locally thicker
Johannson, 1994	1000-1200 Sinemurian 1500-2000 Early Pliensbachian >1000m Late Pliensbachian 3500-4000m total Inklin	southern Atlin Lake

tively undeformed strata occur in the Rupert Creek syncline as shown in the section j-j' drawn across its south end.

Unequivocal contacts between the Laberge Group and older rocks are seen at only a few localities in the map area. Extreme shortening across the Whitehorse Trough has resulted in decoupling of this contact and it is generally marked by a zone of brittle deformation as emphasized by Bultman (1979, see also Table 9-2). However, at two localities in the Tutshi Lake area, fossiliferous Laberge or Laberge-like strata rest unconformably on metamorphic rocks. On the ridges north of Skelly Lake, coarse clastic strata of Laberge Group character rest with angular unconformity on Boundary Ranges metamorphic rocks. A basal conglomerate contains rounded clasts of marble, strained quartz and muscovite schist, typical of the immediately underlying units, and a coarse wacke matrix that contains well preserved belemnites (Photo 9-1). North of Paddy Pass another convincing example of Laberge wackes overlying metamorphic rocks is well exposed. At this locality coarse clastics of Laberge affinity fill the spaces between metre-scale blocks of schist. Up-section from this contact, rocks grade into folded strata, clearly of Laberge Group character. Across Paddy Pass to the south, the contact is manifest on the mountainside as a change in colour from dark grey-green to reddish brown.

The contact with Stuhini Group strata is exposed southeast of Edgar Lake, where it is marked by a fault (probably a thrust), and west of Racine Lake and south-

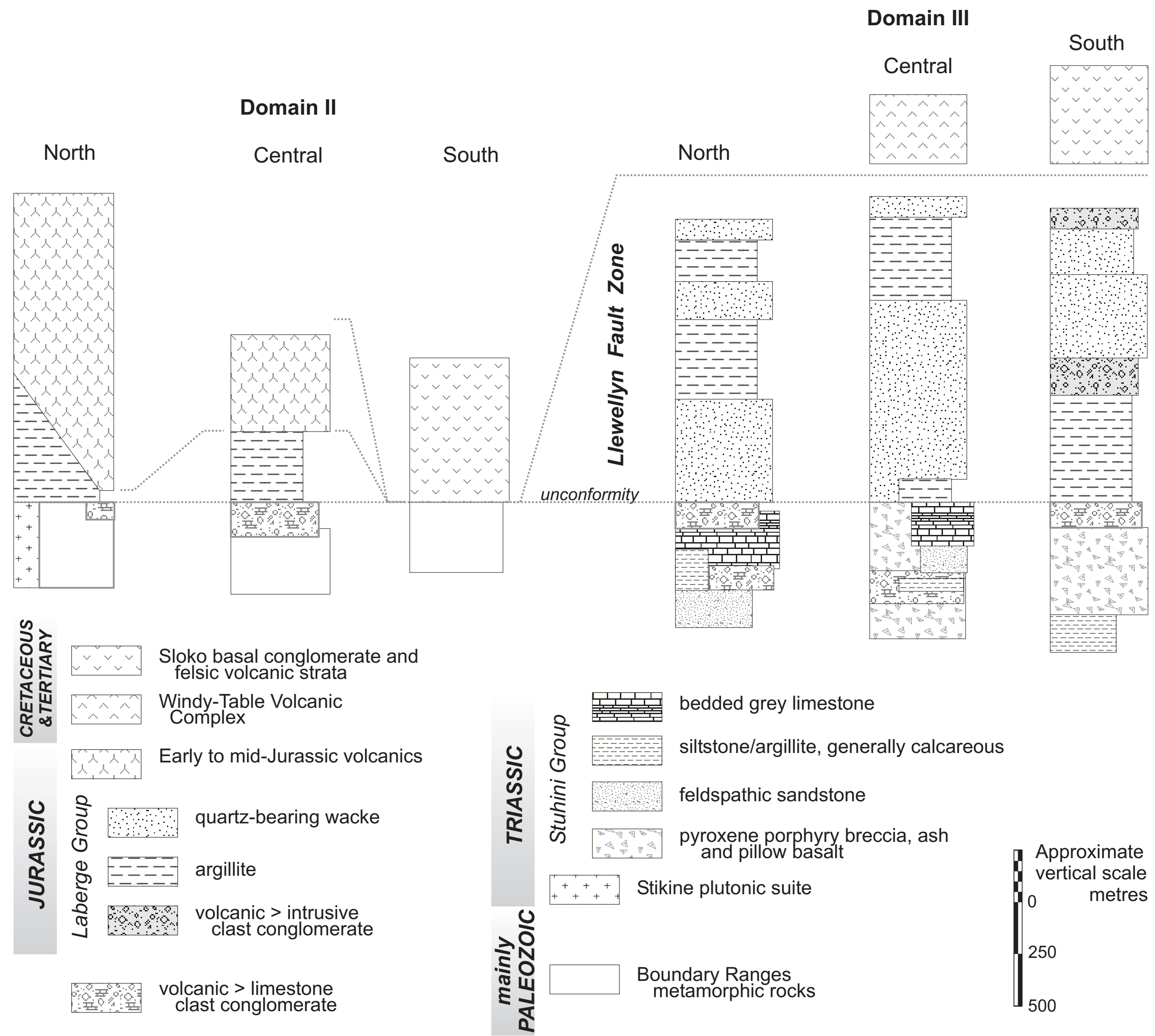


Figure 9-2. Stylized stratigraphic columns from across the map area showing an east to west thinning of the Laberge Group. Unit thicknesses are mainly determined from map distribution and bedding orientation information. In all cases the stratigraphic columns represent areas where Laberge Group stratigraphy is incompletely preserved.

Table 9-2 Interpretations from lower contacts of the Laberge Group

Laberge area, Bostock and Lees, 1938	conformably overlies Lewes River (Stuhini) Group; may be disconformable
Whitehorse area, Wheeler, 1961	at least two locations display a disconformable contact with underlying Lewes River (Stuhini) Group.
Tulsequah, Souther, 1971	Inklin: structurally conformable (disconformity) with underlying Sinwa Formation Takwahoni: disconformably or unconformably overlies Stuhini; Sinwa[1] has been removed by erosion at most localities
Bennett-Atlin, Bultman, 1979	mainly in fault contact with older rocks, may conformably overly Peninsula Mountain suite

1 Significance of the Sinwa Formation in terms of the terrane concept is currently in dispute. Terrane maps such as that of Monger *et al*. (1991) indicate that the Sinwa Formation mapped by Souther (1971) belongs to the Cache Creek Terrane. Mapping conducted as part of this study and mapping by Bultman (1979) both demonstrated a persistent carbonate horizon between the Stuhini and Laberge strata which is on trend with carbonates at the same horizon in the Tulsequah area where it was named by Kerr (1948) and later mapped by Souther (1971). Intercalation of Sinwa carbonate with volcanic strata of the Stuhini Group is in agreement with stratigraphic ties between the western Sinwa facies and the Stuhini Group strata as originally suggested by Souther. In this latter case the Sinwa more clearly belongs to the Stikine Terrane.

west of Windy Arm (near the bend of Tutshi Lake) where it is believed to be disconformable. Almost continuous outcrop exposed in a large syncline-anticline pair west of southern Racine Lake probably contains the contact between the Laberge and Stuhini groups, but it has not been clearly identified. Huge blocks of Norian carbonate may be olistoliths which, together with the enclosing coarse conglomerate, mark the contact between Upper Triassic and Lower Jurassic rocks. Rocks of clear Laberge aspect that sit structurally above the conglomerate yielded Jurassic fossils (Table AB1).

Photo 9-1. Laberge Group conglomerate that contains clasts of fine-grained felsic volcanic (V), medium-grained mica schist (M), and marble derived from the immediately underlying metamorphic strata. Although fossil fauna including corallites and belemnites (B) also occur in the conglomerate they are not sufficiently well preserved to be diagnostic.

Near the bend of Tutshi Lake, strata of the Laberge Group are in contact with limestone (possible Sinwa Formation; Bultman, 1979) that apparently caps the Stuhini succession. This contact has been mapped as a thrust fault by Bultman, mainly due to evidence of deformation at the carbonate contacts. Other evidence argues equally strongly that this is an essentially conformable (or disconformable) succession with relatively minor motion on bedding-parallel faults. Consistently the section dips about 45° northeast. Beds directly beneath the carbonate become increasingly less limy down section away from the massive carbonate unit. Conglomerate east of the carbonate contains limestone clasts, indicating a disconformable relationship. In a roadcut on the south side of the Klondike Highway[1] the carbonate displays a sharp eastern contact with argillite. Scattered carbonate clasts within the argillite, again point to a disconformity. Thus, although the contact between the Laberge Group and underlying Stuhini Group is commonly disrupted, locally its fundamental character is that of a disconformity as noted by several authors in adjacent map areas (Table 9-2).

South of Racine Lake, where the Stuhini surface expression narrows along the Llewellyn fault, its contact with Laberge strata is not exposed. However, like areas to the north, it may be represented by a conglomerate (unit uTSc) which is locally mapped at the top of the Stuhini succession. Where the contact zone is coincident with or within a couple of kilometres of the fault, there is a broad covered interval between the Stuhini and Laberge Group

1 Unfortunately, road construction obscured these relationships during a widening of the highway in 1990.

rocks. In rare outcrops within this interval, lithologies are fine grained, typically argillite ±wacke, and are similar to the Upper Triassic - Lower Jurassic transition mapped at the Klondike Highway exposure.

Apparently disconformably overlying the Laberge Group are Lower to Middle Jurassic volcanic strata (Figure 9-2). Younger still are Eocene Sloko Group epiclastic and felsic volcanic rocks that overlie deformed Laberge strata. In many instances contacts are clearly displayed, with the Eocene strata above a deeply incised paleosurface. Contact relationships with these younger units are described in more detail in Chapters 10 and 13.

Laberge Lithologies

Typical Laberge Group lithologies include conglomerate, greywacke, diamictite, immature sandstone and siltstone, and both noncalcareous and lesser calcareous argillite. The dominant lithology is brown to green weathering, medium-grained, thick-bedded lithic wacke with thin shale and sand interlayers. Conglomerates and greywackes generally occur as massive beds while argillites and siltstones are normally thinly bedded and may be laminated. Conglomerates commonly form tabular or lensoid bodies reflecting deposition in channels. Rapid lateral facies changes within the Laberge Group are well portrayed by Wheeler (1961, see his Figure 7). Facing indicators are relatively uncommon, but include grading, scour marks, flute casts, and rare cross laminations.

Argillites (lJLa)

Laberge Group argillites are of two major types: a rhythmically bedded type with 2 to 5-centimetre beds, showing good internal normal grading; and an irregularly and thinly bedded type.

Rhythmically bedded argillites form successions 10 to 100 metres or more thick. A typical graded bed consists of basal, light grey or tan, fine-grained wacke to siliceous argillite. This grades upwards to a dark grey or brown to black argillite. Other than grading, individual beds lack internal sedimentary structures (Photos 9-2, 9-3). Bedding tops may display bioturbation and feeding trails are preserved locally; these are especially prominent in calcareous beds, which may attain a thickness of 10 centimetres. The beds generally have slightly irregular tops and bottoms. Very sparse cobbles of a variety of protoliths comprise less than 1% of the rock. Commonly a pervasive platy parting is developed. Where the parting is strongly developed, the rock cleaves into paper-thin

Photo 9-2. A view to the northeast of well exposed rhythmically bedded Laberge argillite on the shore of Tagish Lake.

Photo 9-3. An intraformational unconformity that probably resulted from seismically induced slumping during deposition of rhythmically bedded Laberge argillite.

Photo 9-4. Irregularly bedded argillite between massive wacke beds. Numerous growth faults apparent in the lower wacke unit (arrows) decrease in abundance upwards. None appear to have affected the lower contact of the upper wacke bed (upper large arrow)

sheets. Scattered clasts within these deformed rocks display simple shear, like a deck of cards (*see* Chapter 13).

Irregularly and thinly bedded argillites are typically found as sets between massive wacke beds (Photo 9-4). They are dark brown to black and have thicknesses ranging from a few millimetres to several centimetres. Some individual layers display good normal grading, but this is not typical. They range from siltstone to argillite, and have common interbeds of lithic wacke. Light grey to tan limy mud or siltstone beds, 0.5 to 2 centimetres thick, are locally present and contrast with the enclosing darker strata. Intraformational pebbles and cobbles of argillite are common in these layers. Irregularly and thinly bedded argillite are typically recessive and rusty weathering. In places, they are highly disrupted by closely spaced (centimetre-scale) growth faults (Photo 9-4). They can also be disharmonically folded (Photo 9-5), or ripped up and redeposited as pebble to boulder-sized intraclasts, generally in a wacke matrix (Photo 9-7).

Along the western margin of the Whitehorse Trough argillite of this character is generally early Sinemurian in age (H.W. Tipper, unpublished report, 1988; personal communication, 1992). North of The Cathedral mountain, similar black argillite hosts limestone olistoliths(?). As these deformed strata are structurally underlain by quartz-bearing tuff and epiclastics of the Stuhini Group, they may represent some of the oldest preserved onlap Laberge strata in the map area. Samples collected for microfossil determination were barren.

Greywackes (lJLg)

As used here, the term greywacke denotes a rock dominated by poorly rounded, sand-sized grains in a 15 to 75% mud matrix. Greywackes are by far the dominant rock type within the Laberge Group. Feldspathic and lithic types predominate; grain sizes vary from very fine sand to granules, with medium to coarse sand the normal modal grain size. Typical textural and compositional variations are: subround to subangular quartz grains comprise 1 to 15% of the rock, angular plagioclase grains comprise less than 10 to about 50%, and altered muscovite and biotite total 1%. Chloritized lithic grains and matrix generally comprise the remaining rock volume; these are often difficult to distinguish except in coarse-grained wackes.

Other mafic minerals, particularly hornblende, and to a lesser degree, epidote, may comprise up to 5% of the rock. Locally, greywackes grade into lithic arenites, but

Photo 9-5. Disharmonic folding in soft-sediment deformed argillite intraclast conglomerate of the Laberge Group.

these are rarely laterally persistent. Neither quartz arenites nor quartz wackes have been observed. Detrital epidote may be very difficult to distinguish from coarse, equant, authigenic epidote except where the latter replaces another mineral, such as plagioclase, and also extends into the surrounding matrix. Authigenic epidote can also be identified where it forms granular masses with delicate extremities that occlude the matrix. Such forms are unlikely to survive transport.

Wackes are invariably calcareous and may display elongate, bulbous concretions up to several metres long and half a metre thick. Beds are massive or graded and vary from a few centimetres to 10 metres or more in thickness. Massive beds or sets of massive beds are typically interlayered with sets of graded siltstone and argillite beds that are generally less than 2 metres thick. Greywackes are grey to green or orangish weathering and resistant compared to adjacent argillites. In several isolated localities, they occur as discordant dikes, probably related to dewatering (Photo 9-6). Individual components of coarse wackes and pebble conglomerates are discussed in more detail below under "Laberge Provenance and Paleoflow".

Greywacke occurs throughout the Laberge stratigraphy and, therefore, ages range generally from Sinemurian to Pliensbachian (Figure 9-3).

Conglomerate (lJLc)

Polymictic conglomerate is common as local thin tabular to lensoid units within a stratigraphic succession dominated by argillites and wackes. Conglomerate units may exceed 200 metres in thickness, but such thicknesses appear to be restricted to the lower part of the Laberge stratigraphy. In the Yukon, Hart and Radloff (1990) report that a conglomerate unit with interbedded greywacke and argillite is at least 1700 metres thick in the Fish Lake syncline.

Photo 9-6. Greywacke dikes are relatively common within the Laberge Group. They are probably caused by rapid dewatering, possibly induced by seismic shock.

Photo 9-7. Intraclast-rich Laberge Group conglomerate with coarse wacke to granule conglomerate matrix.

Both clast and matrix compositions vary. Clasts are well rounded and include volcanic, sedimentary and intrusive lithologies. Volcanic clasts range in composition from pyroxene and hornblende feldspar porphyries to feldspar porphyries, to aphanitic mafic and felsic rocks. Intrusives vary from syenite through to leucogranite. Generally plutonic clasts are medium grained, altered and rarely foliated. Sedimentary clasts are dominated by light and dark grey, rarely fossiliferous, carbonates (probably equivalent to the upper Norian Sinwa Formation) with lesser wacke and argillite. Higher in the Laberge section there appears to be a gross change from volcanic-clast dominated to intrusive/carbonate-clast dominated conglomerates. However, some horizons may consist of more than 90% intraclasts (Photo 9-7). Typically the conglomerates are clast supported with a coarse wacke matrix, but matrix-supported types with generally 1 to 2%, rarely up to 30%, of clasts floating in irregularly bedded argillite are also common. Foliated quartzite and quartz-mica schist clasts comprise up to 15% of exposures near Fish Lake (Hart and Radloff, 1990), but are relatively rare in the map area except for isolated Laberge-like strata west of the Llewellyn fault.

Conglomerates are conspicuous in outcrop due to the contrast between light-coloured carbonate and intrusive clasts and the dark wacke or argillite matrix. Intrusive boulders may attain a diameter of a metre or more, however, both intrusive and limestone clasts are most commonly less than 15 centimetres in diameter.

Conglomerate provenance is most likely the Upper Triassic Stuhini Group (including the reefal Sinwa Formation). One distinct suite of potassium feldspar megacrystic granitic clasts is probably derived from Late Triassic Stikine intrusives which cut Boundary Ranges metamorphic rocks and the Stuhini Group, but the overall paucity of Boundary Ranges suite metamorphic clasts is curious. Other clasts are alaskitic or micropegmatitic and resemble pegmatite dikes that cut the Hale Mountain granodiorite (Aishihik suite; Chapter 3) or monzogranitic phases of the Long Lake plutonic suite in the Yukon. Johannson (1994) reports a U-Pb zircon age date of 186 +0.5/-1 from one of these clasts within a conglomerate along southern Atlin Lake. Clasts of hornblende granodiorite similar to the Hale Mountain body are common, but unlike the Hale Mountain granodiorite, foliation in these clasts is not striking. North of Whitehorse, intrusive boulders within the Laberge Group have been K-Ar dated at 199, 179 and 174 Ma (Tempelman-Kluit, 1976) and are believed to be derived in part from the Aishihik suite (*see* Chapter 14).

Siliciclastic strata (lJLs)

Indurated siltstone to quartz-rich lithic wacke are included within the siliciclastic subdivision. They commonly display small-scale trough cross-stratification (Photo 9-8) and well developed internal layering (unlike the massive wackes). They are rusty weathering and have a diagnostic conchoidal fracture resulting from a surprisingly high degree of induration.

Thicknesses in excess of 250 metres in the Mount Cameron area are punctuated by sets of conglomerate beds. Commonly this siliciclastic unit is 100 to 200 metres thick where it forms dip-slopes to the northwest-trending belt of high peaks west of the Whitehorse Trough axis. It sits relatively high in the stratigraphic succession and, because of its uniqueness and continuity, it may be one of the most useful markers within the Laberge Group (Figure 9-2). Sparse ammonite collections invariably indicate a Lower Pliensbachian or Pliensbachian age (Figure 9-3).

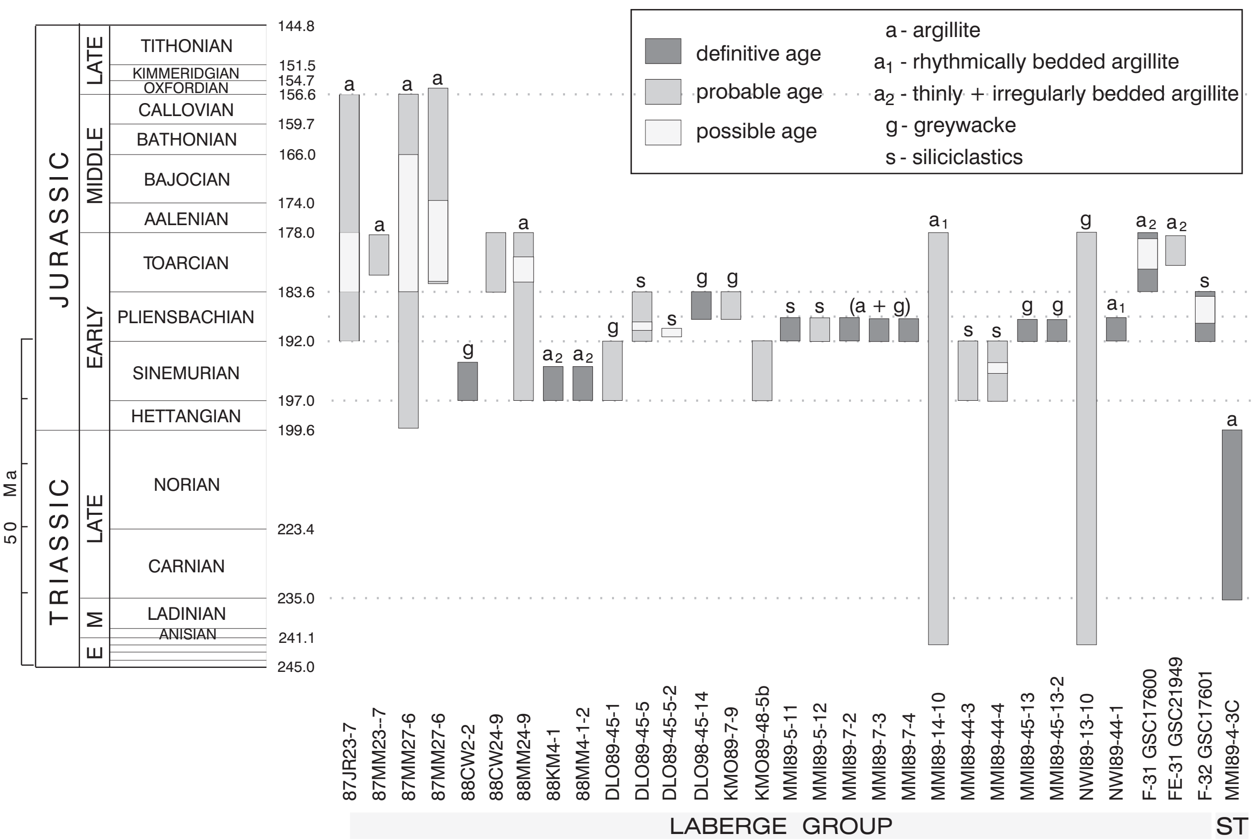


Figure 9-3. Fossil-bearing samples from the Whitehorse Trough and their apparent age ranges (Table AB1). Age ranges are from fossil identifications by H.W. Tipper (GSC, unpublished reports HWTJ1-87, J5-89-HWT) and T.P. Poulton (unpublished report J-12-1987-TPP). ST denotes Stuhini Group.

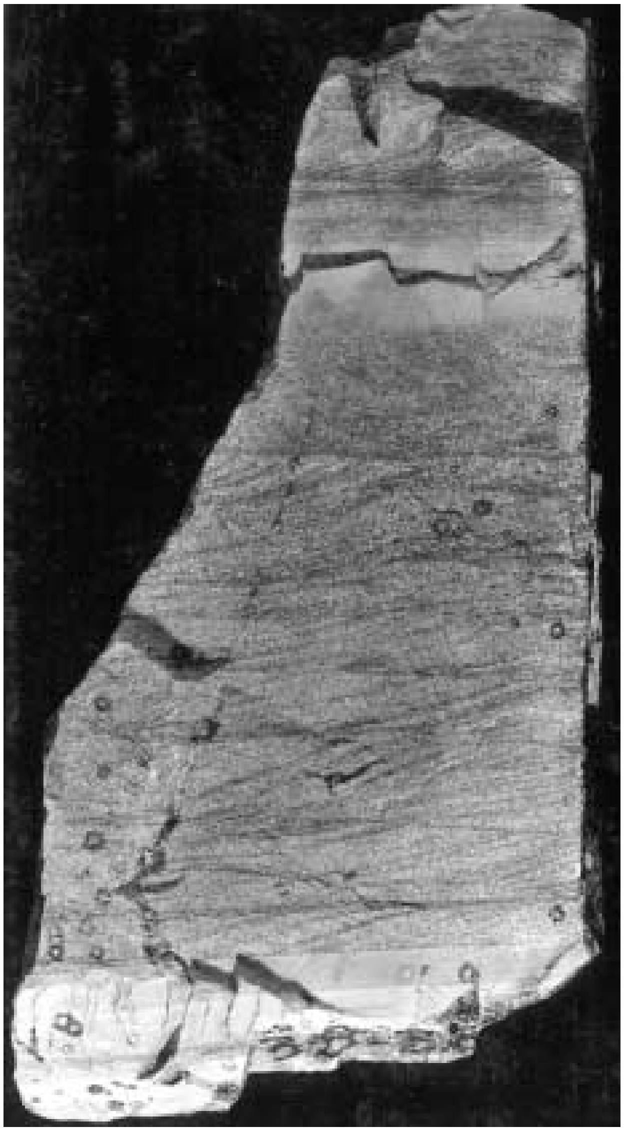


Photo 9-8. Good cross-stratification is locally well preserved in well indurated Laberge siliciclastic units of fine to medium-grained, quartz-rich wacke. Long dimension of the photo represents 16cm.

Hornblende-Feldspar-Porphyry Conglomerate (lJLh)

Rocks of the hornblende-feldspar-porphyry unit occur both above and below the siliciclastics. Superficially they look like coarse lithic and feldspathic wackes, except for the abundance of hornblende feldspar porphyry pebbles, granules, and crystals derived from the porphyritic source (Photo 9-9). A large lobate conglomerate body occurs south of Mount Clive where it appears to undergo a rapid lateral facies change into feldspathic wackes. Moderately fresh hornblende may comprise several percent of the rock. Clasts are subangular to rounded, rarely attain cobble size, and are supported within a quartz-feldsparrich wacke matrix. Much less commonly, the conglomerate is clast supported and almost monomict, except for minor intraclasts.

This unit, together with the associated siliciclastics (probably Pliensbachian), is very similar lithologically to the section exposed on the peaks southeast of Moon Lake, where they are interbedded with rocks containing fossil fauna of Toarcian age (Figure 9-3).

Age of Laberge Group within the map area

Most fossil age data in the map area have come from the western half of the Whitehorse Trough where Sinemurian to Toarcian sediments probably rest disconformably on rocks as young as late Norian (although evidence of the original contact relationship is commonly masked by later folding and faulting; Tables

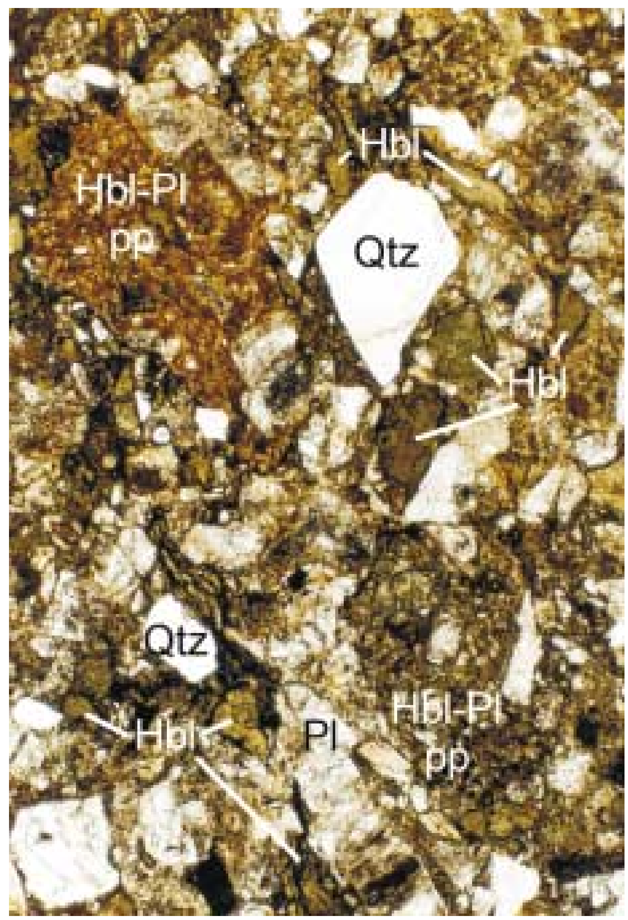


Photo 9-9. Tuffaceous wacke shows typical habit of quartz (Qtz) and feldspar grains (mainly plagioclase, Pl). However, this example is wacke matrix from the hornblende-feldspar porphyry (Hbl-Pl pp) conglomerate, and like other samples from the unit, is unusually rich in hornblende (Hbl). Long dimension of photo represents 2.5 mm of sample MMI89-46-2.

AB1 and AB2, Figure 9-3). Only one fossil has been recovered from Laberge strata of the eastern trough in the map area. An angular block of conglomerate resting on bedrock was collected from a new road cut along the Alaska highway near where it crosses the "Sinwa Formation" limestone because it contains an ammonite fossil. Block and outcrop are comprised of the same lithology. A preliminary ammonite identification by H.W. Tipper (personal communication, 1998) suggests an lower to middle Sinemurian age.

Laberge Provenance and Paleoflow

The focused accumulation of Laberge Group sediment in the Whitehorse Trough poses several questions. What controlled the formation of the Whitehorse Trough? Where were the source areas for the Laberge Group? How far were the sediments transported? What was the geological setting of the source areas? What mechanism caused them to be uplifted and exposed? What can be said about the paleoclimate, and how might it have affected erosion or alteration of the source areas? How extensive was the Whitehorse Trough and when did the structural shortening recorded by its deformed sediments occur? To what extent, if any, did deformation accompany sedimentation within the trough?

Provenance and paleoflow analyses are relatively simple, but effective in helping to constrain answers to such questions. Interpretation of plate tectonic-depositional basin interactions in the geologic record can be guided by relative proportions of sand and sandstone framework components as the relationship between provenance and depositional setting is ultimately governed by plate tectonic events.

Sandstone compositions are influenced by the sediment source, sedimentary processes during transportation and within the depositional basin, and the type of dispersal paths that connect provenance to basin. Unfortunately, unstable minerals and lithic fragments that tend to be most characteristic of a source terrain are quickly reduced by physical and chemical weathering processes that take place during sediment transport and reworking in the depositional environment.

In many regards the Laberge Group sediments are an ideal subject of provenance studies: they are restricted to the elongate Whitehorse Trough and they have and high percentage of unstable elements which indicate minimal transport and chemical weathering of the materials. Thus, previously adjacent terranes are the most likely dominant sediment sources.

Paleocurrents

Most of the paleoflow indicators such as ripple and trough cross stratification (Photos 9-8, 9), tool marks on

Photo 9-10. Linear scour marks can indicate unidirectional paleoflow direction. However, the scours shown in the photo are bidirectional and do not record a unique paleoflow direction.

Photo 9-11. Imbrication of platy micrite cobbles indicate a flow direction from left to right.

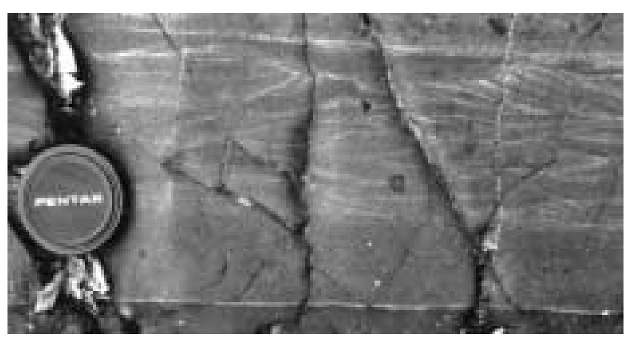


Photo 9-12. Trough cross-stratification in a turbiditic greywacke bed that directly overlies the argillaceous top of another cross-stratified bed. Note the small scours at the argillite - greywacke interface; these yield way-up data consistent with normal grading within the beds.

bed soles (Photo 9-10) and clast imbrication (Photo 9-11) show an overall easterly paleocurrent direction (Figure 9-4), but paleoflow varies from slightly west of north to southeast. Vergence and trend of syndepositional slump faults and folds also indicate an overall northeast paleoslope to the depositional basin.

There are two paleoflow populations. One group, near the western margin of the trough, shows eastern paleoflows. Closer to the axis of the trough, paleoflow directions appear to be parallel to the trough axis and flow directions are southeast (*see also* Johannson, 1994).

The conclusions of Wheeler (1961), Bultman (1979), Dickie (1989), Johannson (1994) and the limited data analyzed here, are essentially consistent. Bultman (1979) concluded that paleocurrents were dominantly northeast directed although there is considerable dispersion of the data about the mean (based on evaluation of 399 crossbedding measurements, 92 unidirectional current indicators and 59 bidirectional current indicators). Slump folds that he observed indicated a northeast paleoslope. Wheeler (1961) concluded that conglomerates of the "western belt" were derived from the west and he estimated a transport distance of about 30 kilometres or less. Dickie (1989) noted that although depositional bedforms show regional paleocurrent variability, individual sections display little variability but both northeast and southeast paleocurrents are indicated. No Yukon data indicate transport toward the west. Johannson (1994) combined detailed paleoflow and biogeochronologic data to show temporal variations in paleocurrent patterns. Sinemurian paleoflow was dominantly parallel to the basin axis. Early Pliensbachian paleoflow was perpendicular to the basin axis and bidirectional, possibly sourced in an eastern (present coordinates) outer arc ridge or reflected by an eastern paleotopographic feature. Late Pliensbachian paleoflow was basin axis normal and dominantly from the southwest.

Provenance

With the exception of specific diagnostic lithologies, such as coarse pyroxene porphyries of the Stuhini Group, it is very difficult to correlate lithic grain types in Laberge strata and probable provenance sources on the basis of petrographic criteria alone. For example, andesitic to basaltic volcanic fragments within Laberge clastics could be derived from the Stuhini Group, the Cache Creek Complex or the Peninsula Mountain Volcanic Suite. Lithologies restricted within the Tagish area to the Cache Creek terrane, like Paleozoic radiolarian chert, ultramafite, and limestone with Tethyan fusulinids, are not seen as clasts within the Laberge Group. Johannson (1994), likewise found no evidence for Cache Creek provenance in Laberge Group sediments from southern Atlin Lake.

Petrographic studies combined with paleoflow determinations make provenance more certain. For example, a western source of western Laberge clastics in the map area is based not only on the match between Stuhini Group lithologies and those in Laberge clasts, but also on paleoflow indicators that are dominantly easterly.

Determining a source for the eastern Laberge clastics is more problematic. There is no obvious lithologic difference between Laberge wackes and those mapped as probable Laberge (lJLg) in the far east side of the trough. Yet this eastern package in part sits east of the Nahlin fault zone, and similar wacke occurs as interbeds with chert yielding Middle to Upper Triassic radiolarians (F. Cordey, unpublished report, 1990). The eastern package apparently differs from most Laberge wackes in that it is slightly lighter grey in colour, a little less calcareous, and generally more massive, but as unique properties were specifically sought out during mapping of these rocks, it is not known to what extent these same features occur elsewhere in the Laberge Group. It is possible that the western facies of the Whitehorse Trough forms an onlap with rocks as young as late Norian while older, basinward Laberge components are interlayered with Triassic sediments of Cache Creek Terrane character. If it is older, the eastern wacke package should probably be included with the Middle to Late Triassic Teenah Lake assemblage of Jackson (1992) with which they share many characteristics, thus avoiding the confusion introduced by a redefined and highly diachronous Laberge Group. Contemporaneous StuhiniLewes River volcanism might provide an explanation for the high tuffaceous component of some wacke within the eastern package, but cannot readily account for the oldest wackes since Middle Triassic volcanism in Stuhini and Lewes River Groups is not common. Peninsula Mountain suite volcanics and possible Kutcho formation correlatives provide a source terrane of appropriate age (*see* Chapter 7 and Mihalynuk *et al*., 1997), but lthologic comparisons with detritus are not certain. Further mapping and discovery of fossils within the wackes will be required to determine whether the eastern wacke package should be included with the Laberge Group. Identification of unique lithologies in volcanic source terrains and detrital components of the Whitehorse Trough is needed before provenance ties can be made with certainty. As a first step to pinpointing provenance sources it is necessary to evaluate the post-Lower Jurassic translational motion on the Llewellyn fault that forms much of the western trough margin today (translational motion along the Llewellyn fault is discussed in Chapter 13). In order to more boadly understand the evolution of the Whitehorse Trough, theTriassic to Jurassic paleogeographic setting of the trough needs to be deciphered (for example, *see* Chapter 15).

Mineral Potential

Coarse, immature, arc-derived sediments dominate the Laberge Group. These were rapidly deposited in a marine basin at a destructive plate margin. As such, the Laberge Group does not provide fertile ground for the search of syngenetic ore deposits. An exception may be submarine vents related to centers of Toarcian (187 Ma) Nordenskiold volcanism, but none of these have been clearly identified. Rheological properties of the Laberge Group strata, however, make it a suitable host for the formation of dilatent precious metal veins (*e.g.* Engineer mine). Thus, where Laberge strata occur together with high-level magmatic rocks (a hydrothermal system), particularly where adjacent to large structures such as the Llewellyn fault (focused fluid pathways), the potential for precious metal vein formation is moderate to high.

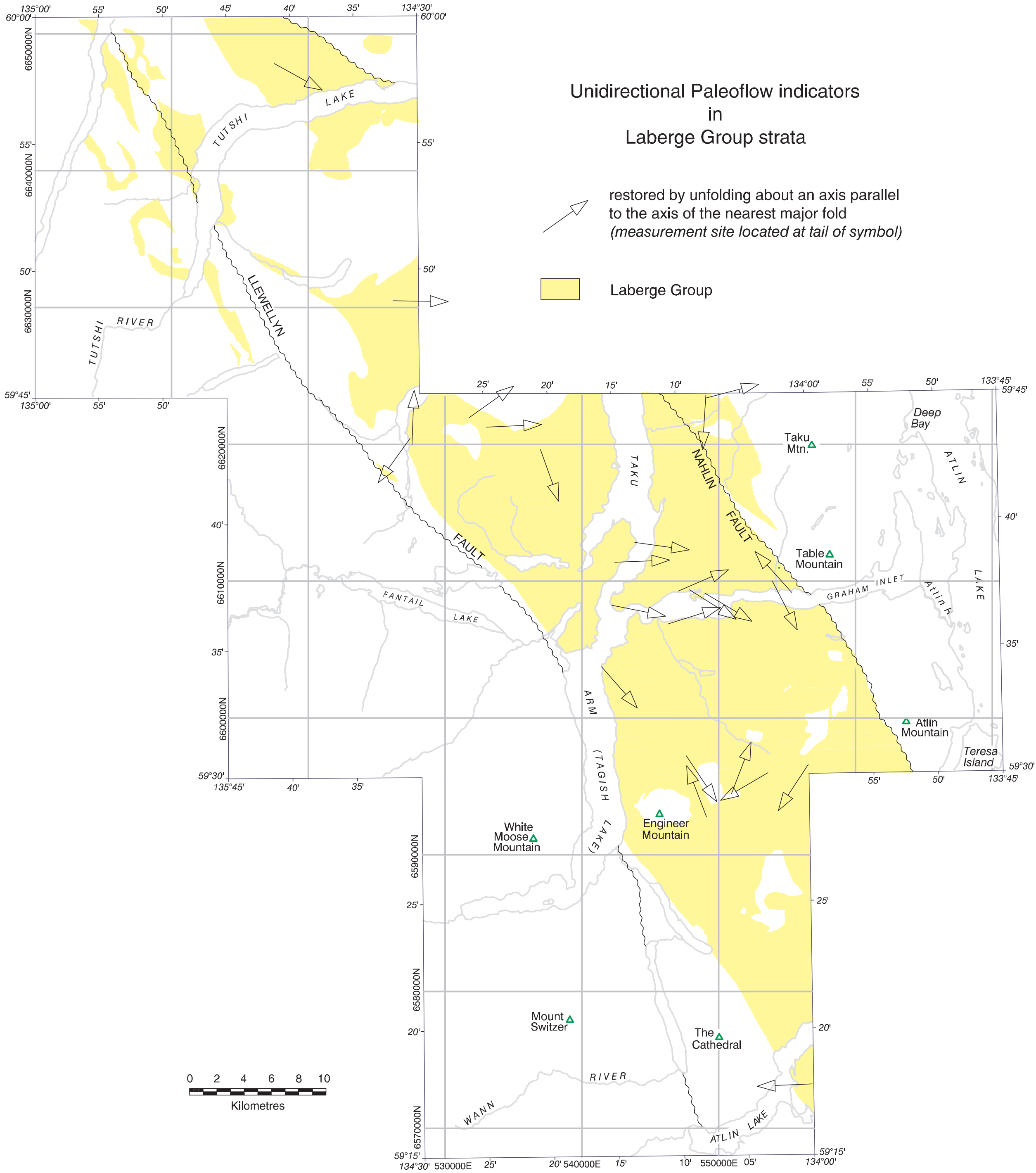


Figure 9-4. Paleoflow results from the Whitehorse Trough in the Tagish area.

Oil and Gas Potential

Oil and gas potential of the Whitehorse Trough, as in all sedimentary basins, is controlled primarily by the hydrocarbon generating capacity of source rocks, the level of organic metamorphism and reservoir quality. Favourable conditions must exist for each of these controlling factors before oil or gas accumulations can occur. While no analysis of source rock potential was conducted during the Tagish project, estimates of the level of organic maturation and qualitative conclusions about reservoir quality can be made.

Thermal data for the Tagish area are available from a variety of sources including: fission track studies, investigations of authigenic mineralogy, descriptions of thermal metamorphic aureoles around plutons, discordant emplacement and cooling ages from K-Ar and ^{40}Ar-^{39}Ar isotopic studies, and estimates of crustal thickening. Metamorphic grade of the Whitehorse Trough between 59°30' and 60°N is shown on the isograd map of Figure 3-5. Metamorphic grade of Whitehorse Trough rocks is prehnite-pumpellyite or lower greenschist. Zeolites as authigenic minerals are conspicuously absent. Thus, the zeolite metamorphic facies assignment made by Reed *et al.* (1991) to this part of the Whitehorse Trough is not correct. Conodont colour alteration indices (CAIs), known for the Triassic and Jurassic parts of the Trough, support the metamorphic grade estimate based on petrographic analyses. CAIs from Stuhini rocks in the Atlin area are typically in the 5-6 range (Appendix B) approximately chlorite to biotite zone (Epstein *et al*., 1977; Rejebian *et al*., 1987). CAIs from Laberge rocks are determined from conodonts extracted from Norian limestone cobbles. These fall in the 4.5 to 5 range (Appendix B) equivalent to the upper prehnite-pumpellyite facies to chlorite zone.

K-Ar ages from volcanic rocks of the Triassic Whitehorse Trough near Southern Atlin Lake yield ages of 80, 72 from whole rocks and 175 and 188Ma from hornblende and pyroxene respectively (Bultman, 1979). These have been reset from depositional ages of 210 to 220Ma (Mihalynuk *et al*., 1997). Cooling ages of 72 and 80Ma are consistent with the fission track data of Donelick and Dickie (1991). Closure temperature for amphibole is 500-550°C (Harland *et al*., 1990). If argon loss in the hornblende was due to thermal resetting, it may indicate temperatures in excess of 500°C. Adjacent basalts contain the authigenic assemblage: actinolite-epidote-plagioclase, but lack almandine garnet; indicating that transitional greenschist-amphibolite facies had not been attained. Thus, temperatures likely did not exceed 450°C. K-Ar isotopic data from plutonic boulders within the Jurassic Whitehorse Trough also show evidence of thermal resetting (Hart, 1995). In many instances K-Ar ages for the boulders are younger than the rock that they occur in and must have been reset, most likely following their deposition.

Fission track studies conducted by Donelick (1988, 1988; Donelick and Dickie, 1991) indicate that the northern part of the Whitehorse Trough in British Columbia cooled through 200°C at around 80 Ma. Geological relationships constrain the major deformational pulse in the Whitehorse Trough to Aalenian or Early Bajocian (Mihalynuk *et al.*, 1995a). During this brief interval, the Whitehorse Trough was shortened by at least 50% (see Chapter 15). Earliest post-kinematic plutons have been dated at circa 172 Ma (Mihalynuk *et al.,* 1992a). Thus, a tectonically thickened Whitehorse Trough was probably subjected to an elevated thermal regime (based on geothermal gradient) from around 170Ma to 80Ma, and may have been at greater than 200°C for several tens of millions of years. If this is the case, then the level of organic maturation would exceed the limits for dry gas generation (*e.g.* Waples, 1980; Gretener, 1981).

Metamorphic grade may decrease to the southeast as Johannson (1994) reports laumontite in sandstones from southern Atlin Lake. Farther southeast in the Tulsequah map area, where the Whitehorse Trough is at its widest, metamorphic grade may be at a minimum. One series of argillaceous outcrops mapped during a reconnaissance survey of the King Salmon Creek headwaters was notable for its abundance of ammonites and lack of induration (unpublished, 1995). However, no thermal data is available, and elsewhere in the Tulsequah area authigenic epidote is common (*e.g.* Mihalynuk *et al.*, 1995a).

Dynamothermal metamorphism of the Whitehorse Trough has produced pronounced joint sets in massive wackes and a strong slatey cleavage, or a phyllitic parting in argillites that are incompatible with hydrocarbon trapping. East of eastern Dease Lake area fabrics are even more intense than in the Tagish area. Descriptions of these rocks indicate the development of a strong NNE-dipping planar fabric, probably imparted during early Mid Jurassic deformation (Thorstad and Gabrielse, 1986). In the Cry Lake area, these rocks are phyllitic with incipient development of quartz segregations (Mihalynuk *et al*., unpublished, 1997).

In summary, the level of organic maturation in Whitehorse Trough strata of the Tagish area exceed the limits for the survival of gas and the intensity of structural deformation and fabric development probably precludes the survival of reservoirs. These same deleterious factors may not persist to the Tulsequah area, but the data needed to help guide oil and gas potential estimates there are not available.

Chapter 10 Jurassic to Cretaceous volcanics

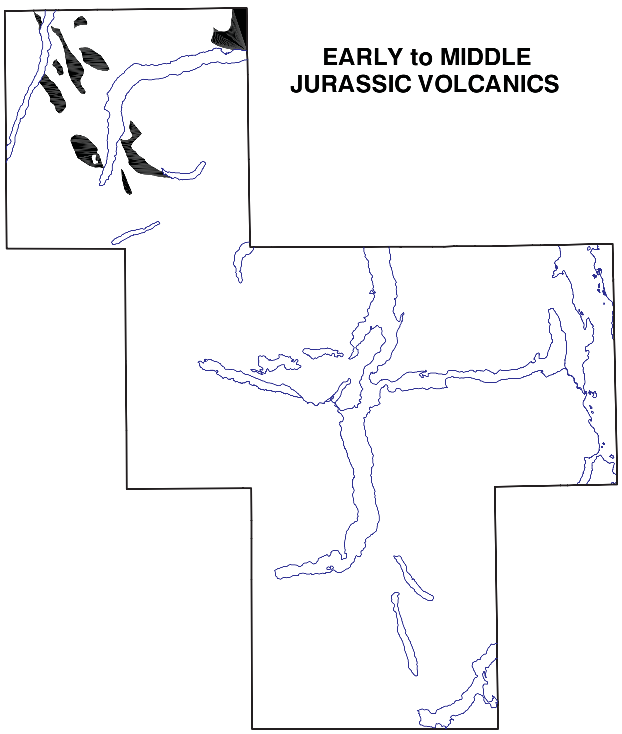


Figure 10-1. Distribution of Early to Middle Jurassic volcanic rocks.

Volcanic rocks ranging from probable Lower Jurassic to Tertiary age occur sporadically throughout the map area. Past investigators have been disadvantaged by a paucity of isotopic age data for these rocks. This has impeded correlation, or due to the similarity of many non-coeval volcanic units, has led to incorrect correlations. Relative ages assigned by lithologic and geochemical similarity as well as stratigraphic relations involving rocks of known age has been moderately successful. However, in many instances such correlations are ambiguous and have led to nomenclatural problems. New isotopic age dating of rocks in the map area considerably aids in the correlation of distinct volcanic successions. Products of this study include five new U-Pb and two new K-Ar age determinations on Cretaceous and younger volcanics. An additional four U-Pb and two K-Ar dates from probable synvolcanic intrusions are reported in "Intrusions" (section 14). Most of these dates are reported here for the first time. Detailed analytical techniques and tabulated data are presented in Mihalynuk *et al.* (1992). Numerous new isotopic age determinations are also presented in Hart (1995) for coeval rocks immediately north of the map area in southern Yukon.

Young volcanic strata occur as numerous widespread, isolated remnants of originally much more extensive blankets. In many instances volcanism appears to have been focused along major structural breaks, such as the Nahlin and Llewellyn faults. As many as five separate volcanic episodes may be represented, each composed of several lesser volcanic pulses. An undated episode includes folded, mafic to felsic tuff and distinctive coarse, bladed feldspar porphyry flows and tuff; it is presumed to be Lower to middle Jurassic. A Middle Cretaceous episode, *circa* 90 Ma, is dominated by the intermediate to felsic Montana Mountain volcanics. An early Late Cretaceous episode, *circa* 82 Ma, includes the extensively block faulted and tilted Windy-Table volcanics. An isolated episode of Paleocene age is indicated by *circa* 59 Ma age date from rhyolite near Skelly Lake, but the age is suspect (*see* Chapter 4). Sloko Group volcanism spanned 56 - 54 Ma and produced the intermediate to felsic pyroclastic and epiclastic rocks that were relatively flat or gently warped as they infilled paleotopography developed on deformed Boundary Ranges and Laberge Group strata (*see* next Chapter).

Lower to Middle Jurassic Volcanic Suite (lmJv)

Intermediate pyroclastic and flow units of probable Lower to Middle Jurassic age crop out both northwest and southeast of Tutshi Lake within 104M/15 (Figures 10-1 and GM97-1). Prior to this study they were included as part of a Pennsylvanian to Triassic suite (Christie, 1957) now known to be primarily composed of Upper Triassic Stuhini Group strata (Mihalynuk and Rouse, 1988b). However, these volcanics are distinguished from Stuhini Group volcanic rocks because they lack both voluminous augite-phyric basalt flows and granite boulder conglomerate interlayers. Further, they are interlayered with conglomerates most likely derived from the Laberge Group (Figure 10-2).

A variety of lithologies are common within this rock package. These include bladed feldspar porphyry flows and tuffs, dacitic lapilli ash tuff, dark angular lapilli tuff, rhyolite flows and ash flows, variegated feldspar-phyric flows or coarse pyroclastics, and polymictic felsic lapilli tuffs. An average composition for the suite is probably

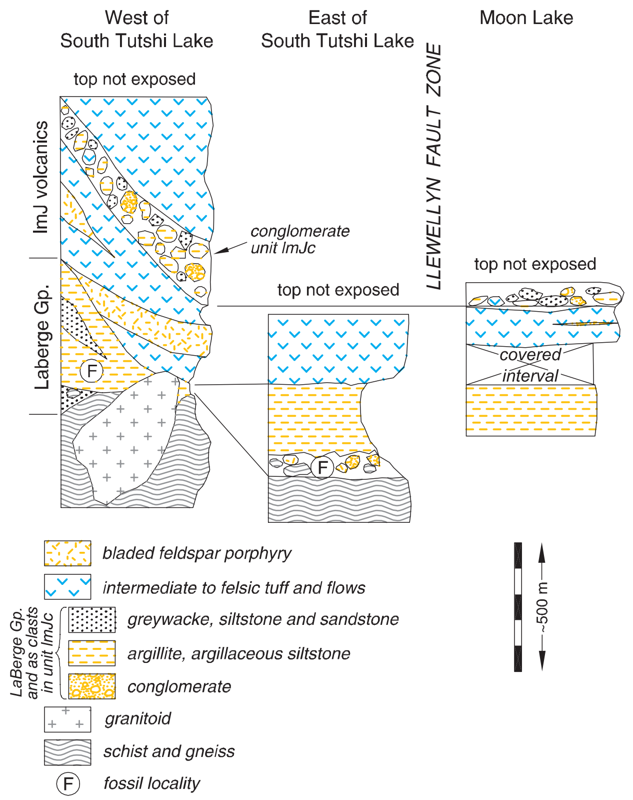


Figure 10-2. Correlation of Early to Middle Jurassic volcanic rocks within the Tagish Lake area. Basement rocks include Boundary Ranges metamorphic suite, Late Triassic granodiorite, and Laberge Group west of the Llewellyn fault.

andesite to dacite, albeit small amounts of rhyolite to basalt are common.

Bladed Feldspar porphyry

Bladed feldspar porphyry flows are the most conspicuous rocks of the lower to middle Jurassic volcanic suite and are probably of basaltic andesite composition. White plagioclase crystals 2 to 3 cm long are commonly trachytically aligned and crowded within an amygdaloidal dark brown to olive green quartz-calcite-epidote-chlorite altered matrix. Plagioclase can comprise up to 40% of the rock, although sparsely porphyritic and even aphanitic flows occur. Within one relatively thick succession (approximately 120m), individual flow thicknesses are less than 5m and typically 0.75m - 2m. Flow-top breccias are common, as are interflow bladed crystal or ash tuffs. This lithology, while characteristic, cannot be considered diagnostic of the suite since similar lithologies occur within both older and younger volcanic packages. For example, both Upper Triassic rocks of the Stuhini and Takla Groups (Monger, 1977b) and Lower Jurassic rocks of the Hazelton Group (Mihalynuk, 1987) contain units that are lithologically identical. Hart (1995) describes similar units as being characteristic of the *circa* 80 Ma Wheaton River volcanics to the immediate north in the Yukon. In the absence of age data to the contrary, the Wheaton River volcanics are the favoured lithologic correlative of the Lower to Middle Jurassic volcanic suite. However, the basal contact shows bladed feldspar crystals in a mixed ash and argillite matrix above Laberge Group argillites. Thus, a depositional continuity and therefore a Lower to Middle Jurassic age is indicated (*see* "Contact Relationships" below). In general, bladed feldspar porphyry flows are most abundant in the lower to middle portions of the suite.

Dacitic tuffs and rhyolite

Felsic tuffaceous rocks are more typical of lower and upper stratigraphic intervals. The lower stratigraphy is dominated by lapilli tuffs of a composition that probably ranges mainly from rhyolite to andesite. They are pink, brown and dark grey matrix-rich tuffs with light grey, green or white subangular to flattened lapilli. Commonly the lapilli contain up to 20% epidote-chlorite altered feldspar crystals. Less commonly they are sparsely quartz-phyric. Intense epidote-chlorite alteration locally affects entire outcrops.

On the flanks of the tallest mountain in the area (unnamed, 7245 feet), vesicular bladed feldspar porphyry flows and interflow pyroclastics give way up section to well layered lithic ash and lapilli tuff in 1 to 50 centimetre thick beds at the mountain peak. Beds are normally massive, but can display normal and reverse grading. Bedding sags resulting from balistic lapilli are common. On average these tuffs are probably of dacitic composition. They are well indurated, light grey to buff-weathering and black on fresh surfaces. Fragments are commonly more resistant than the fine ash matrix. Lapilli are variegated, mainly red, black or white. Accretionary lapilli are rare.

One distinctive vitrophyric ash tuff crops out on both sides of Tutshi Lake. It contains 10-20 percent white or pink-weathering, elongate, subangular lapilli in a glassy black matrix. Flow or compaction foliation aligned the lapilli with the internal fabric of the eruption units.

Pink, tan or grey rhyolite flows and flow breccias are common but aerially restricted. Rhyolite lapilli and bombs occur in strata having a wider distribution. Welded rhyolite ash flows display a strong flow lamination and abundant fiammé having length to width ratios of 10 or more.

Lithologic variability in the dacite - rhyolite package precludes its subdivision at the scale of mapping.

Conglomerate of Laberge Derivation

West of southern Tutshi Lake, an interval of conglomerate up to 250 metres thick occurs near the middle

Photo 10-1. Conglomerate within the Lower to Middle Jurassic volcanic package. Cobbles are comprised mainly of Laberge-like lithologies.

of the Jurassic volcanic suite stratigraphy (Photos 10-1, 10-2). It is composed mainly of well-rounded cobbles of finely bedded sandstone, siltstone, wacke and arkose (60%). Black, laminated argillite clasts comprise a further 20% (Photo 10-2). Possible rhyolitic comprise up to 2% of clasts. Other dark-coloured clasts of possible volcanic origin are difficult to distinguish from cherty mudstone in outcrop, although their volcanic origin is apparent in thin section. Hornblende feldspar porphyry and other intermediate to mafic volcanics comprise about 1%. Granules and pebbles of vein quartz are a minor but conspicuous component. Arkosic matrix accounts for about 15% of the rock. Proportions of different clasts change from south to north. Argillite clasts decrease while quartz and igneous clasts increase in numbers. Sandstone clasts remain constant in number. A sandy matrix gives way to wacke. Locally, clast imbrication suggests south-directed paleoflow.

Similar and possibly correlative conglomerate is exposed 2 kilometres northeast of the mouth of Moon Creek. Sedimentary clasts are most likely derived from the Laberge Group since clast lithologies are identical to a variety of Laberge units. Carbonized tree trunks, branches and fronds up to a metre or more in length are common, and accumulations of plant debris have produced thin, irregular and sandy coal seams (less than 10 cm thick) within the conglomerate.

Contact Relationships

Early to Middle Jurassic volcanic rocks are deposited on a variety of substrata. Most nearly coeval are argillites of the Lower Jurassic Laberge Group. Near contemporaneity is based on the ash-rich nature of argillites near their contact with the volcanics west of southern Tutshi Lake. Here, hyaloclastite and pillow breccia overly lithic arkose and wacke probably belonging to the Laberge Group. Also at this locality, argillite olistoliths up to a few metres long occur within the lowest volcanic units. Such olistoliths appear to be soft-sediment deformed, suggesting they were not lithified when incorporated into the volcanics. Although the argillite olistoliths are thought to have been derived from the Laberge Group, this is by no means proven. Much of this interpretation relies upon lithologic similarity of the olistoliths to sediments yielding sparse ammonites of Early Jurassic age (Tipper, 1987; north of the Llewellyn fault; Fossil locality C-153903, Table AB1) that are correlated with the Laberge Group.

On the peaks east of southern Tutshi Lake, exposure is imperfect but fine-grained black lapilli tuff appears interbedded with argillite, siltstone and wacke at the con-

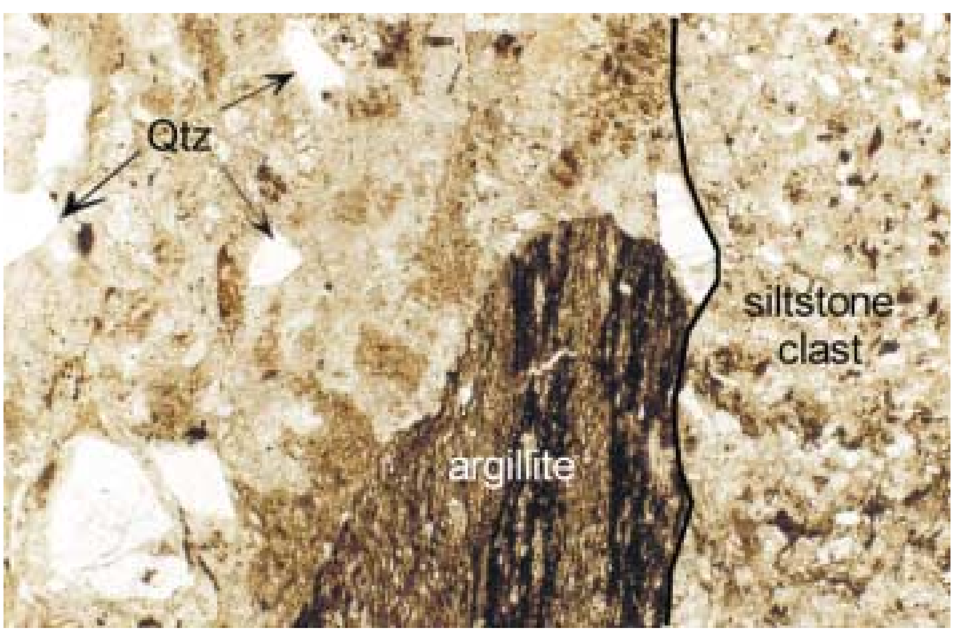


Photo 10-2. Photomicrograph of a representative sample of the conglomerate shown in Photo 10-1. Scale: width represents approximately 2.5 mm of sample.

tact between marine sedimentary rocks and dominantly subaerial volcanic rocks. Here too, the sediments most closely resemble Laberge Group strata. Macrofossils collected from these sediments include belemnites and coralites, but none of the collections are diagnostic (Photo 9-1).

A knife-sharp contact is exposed between these volcanic strata and altered rocks of the Late Triassic Bennett granodiorite (*cf.* Hart and Radloff, 1990). At one locality these volcanics were deposited on conglomerate derived from both Bennett granite and highly strained quartz-mica schist (Photo 8-3). Rocks of this age probably also sit directly on schists of the Boundary Ranges Metamorphic Suite, although good exposures only extend to within a few metres of the contact, which was not observed.

About 500 metres west of the southern end of Tutshi Lake, argillite mapped as Laberge Group (Figure GM97-1) is intercalated with basaltic rocks. The basalt appears to form a small, 2 metre thick pillowed lens below the contact with the main exposures of Lower to Middle Jurassic volcanic rocks.

Between Paddy Pass and Bennett Lake Early to Middle Jurassic volcanics are in contact with Laberge-like strata at several localities. In some cases the two are juxtaposed across high angle faults, in others the contact appears disconformable if not gradational. In general, however, an unambiguous conformable relationship cannot be demonstrated at any locality.

Geochemistry, age & tectonic setting

One mafic sample of unit lmJv was analyzed for rare earth elements. A normal MORB-normalized plot is shown in Figure 10-3. The pattern shows light REE enrichment with no appreciable europium anomaly. Positive Gd and Yb anomalies cannot be accounted for given the limited data set. This REE pattern is most like those displayed in supra-subduction zone settings.

Lower to middle Jurassic volcanics appear to paraconformably overly Laberge Group strata (as discussed above) and must be Lower Jurassic or younger in age. Isotopic age constraints on the youngest age is limited by granitoid plutons that cut deformed volcanics and have been dated by the K-Ar method at 78 and 92 Ma (new decay constants after Bultman, 1979; Table AA5). The age of deformation is unknown, but it may be related to emplacement of the Cache Creek terrane prior to about 172 Ma (*cf.* Mihalynuk *et al.*, 1992a), when the Fourth of July batholith was emplaced (*see* Chapter 12).

Deposition of these rocks appears to span a period of tectonism accompanied by differential uplift. Two depositional series are represented; they are separated by the significant interval of cobble conglomerates composed almost exclusively of Laberge-like argillites and wackes. The predominance of sedimentary clasts is surprising. Apparently, volcanic deposition was briefly overwhelmed by sediment supplied from a denuded basin containing only Laberge Group or identical lithologies. In the Yukon, the Tantalus conglomerate may be Upper Jurassic age in part, but it contains primarily chert clasts. Possibly, the volcanics above the conglomerate are significantly younger than that those below. Isotopic dating is needed to firmly establish the age of these volcanics, and the range in age of deposition within the succession.

If, as is interpreted here, these volcanics are deposited paraconformably on Laberge strata, and the youngest dated Laberge strata in the map area are of Toarcian age, then Toarcian is the maximum age of the volcanics. One possible magmatic correlative is the regionally extensive *circa* 185 Ma Nordenskiold dacite (*see* Chapter 9; *cf.* Johannson, 1994), although the dacite is slightly older thanthe youngest dated Laberge Group in the area (Toarcian is 183.6 +1.6/-1.1 to 178 +1/-1.5Ma according to Pálfy, 1998) and there is no evidence of basin uplift during Nordenskiold time. Another is the Bennett Plutonic suite of about 179 to 176Ma (Chapter 12) although no volcanics of this age are known elsewhere.

Mineral potential

No significant mineral occurrences are known within the Early to Middle Jurassic volcanic succession and lack of age control precludes serious speculations based on correlation with mineralizing events elsewhere. However, it is worthwhile to note that the shallow marine setting, felsic volcanic composition and potential age range have potential equivalents at the shallow hydrothermal,

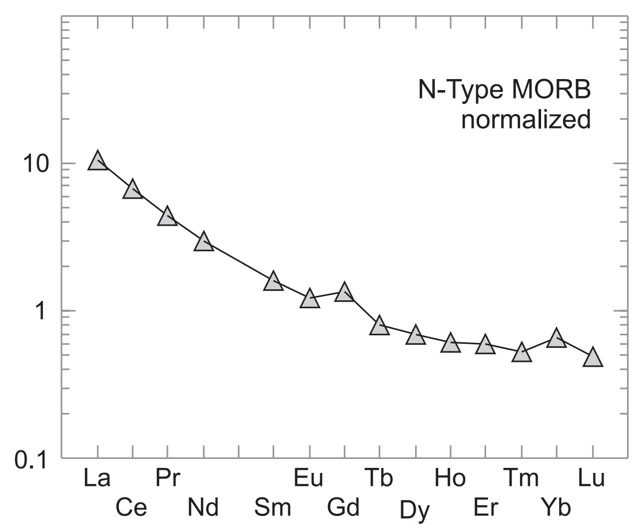


Figure 10-3. N-type MORB normalized plot of REE concentrations in a Lower to Middle Jurassic volcanic sample analyzed by inductively coupled plasma mass spectroscopy technique. The plot shows light element enrichment like that observed in subduction zone environments.

gold-rich Eskay Creek deposit in the northern Bowser Basin.

Cretaceous Volcanic Suites

Volcanic rocks of known Cretaceous age are mainly exposed in northeastern Tutshi Lake map area and north of Graham Inlet (Figure 10-4). As discussed above, they have historically been subjected to a plethora of names, but here are grouped into either the Montana Mountain or Windy-Table volcanic suites. Most of the known exposures probably belong to the latter suite; Montana Mountain volcanics are probably restricted to within a kilometre east of the shore of Windy Arm (Figures 10-4 and 10-5).

Montana Mountain volcanic complex (Kmv 95 Ma)

Immediately north of the British Columbia border, altered volcanic rocks of the mid-Cretaceous Montana Mountain volcanic complex host about 20 polymetallic mesothermal gold-bearing base metal sulphide veins, including those at the historically important Venus Mine (Figure 1-1). The complex also hosts several other polymetallic gold veins within southernmost Yukon.

Rocks comprising the complex have been mapped in detail by Roots (1982) and, most recently, as part of a 1:50 000 scale study by Hart and Pelletier (1990). Although details of the distribution and origin of units differ between the two studies, three major compositional units are recognized. From oldest to youngest, these are: a lower unit of dark green and maroon, massive to poorly bedded andesite and more restriced mafic flows and tuffs; a middle unit of rhyolitic flows, breccia and tuff characterized by its rust to yellow colour; and an upper unit comprised of dark green, aphanitic and feldspar-hornblende-phyric hypabyssal andesite. Roots (1982) considered the volcanic units to be products of a continuum of successive eruptive episodes. Isotopic data presented by Hart (1995) points to a magmatic hiatus of about 10 Ma between the lower mafic-intermediate (95 ±1 Ma) and middle rhyolite successions (84 ±1 Ma). Thus, the two are separated in this report. The lower unit is included in the Montana Mountain volcanic complex, while the middle and upper, felsic volcanics and intrusive equivalents are included with the Windy-Table suite (*see* following section).

At its southern limits, the Montana Mountain volcanic complex extends into British Columbia (Figure 10-4). It is shown on Figure GM97-1 to cover about 10 km^2 east of Windy Arm; however, a large portion of this unit, and unit lmJv to the east, probably are more appropriately included with the Windy-Table suite. In an extreme view, Mihalynuk *et al.* (1996) show both of these units as belonging to the Windy-Table suite. In actual fact, probably one or two square kilometres are underlain by Montana Mountain complex (lower unit) as shown in Figure 10-5, but detailed mapping and isotopic dating will be required before the limits of Montana Mountain volcanics and similar units can be accurately delineated.

Grey-green intermediate lapilli tuff and breccia are lithologically similar to rocks on the west (Yukon) side of Windy Arm (Photo 10-5). This unit extends about 200 vertical metres up the valley wall where it gives way to rhyolitic rocks that are now correlated with the Windy-Table suite. Unfortunately, this contact was crossed only once and its nature was not determined.

Windy-Table suite (lKW 82 Ma)

Rocks included in the Windy-Table suite occur in a belt that is coincident with the Nahlin fault, although a genetic connection cannot be proven. The belt extends from Windy Arm southeast to at least Table Mountain and perhaps farther to include steeply dipping volcanic strata on the north flank of Atlin Mountain (Figure 10-4). Rock exposures are best near the north and south ends of the belt. The belt encompasses rocks in southernmost Yukon that are mapped as part of the Montana Mountain volcanic complex (Roots, 1980; Hart and Radloff, 1990). In British Columbia, they have been mapped as “volcanic rocks of uncertain age” (Christie, 1957; Aitken, 1959), as

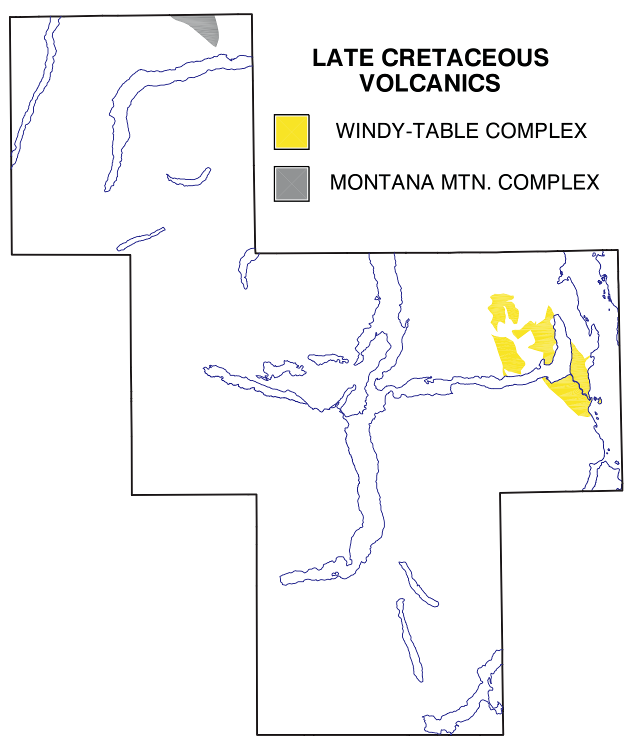


Figure 10-4. Distribution of Montana Mountain and Windy-Table suite volcanic rocks within the Tagish Lake area.

Photo 10-3. Photo of Montana Mountain complex volcanic breccia.

Late Cretaceous to Early Tertiary volcanic rocks (Monger, 1975), as Triassic Peninsula Mountain volcanics (Bultman, 1979), as Late Cretaceous Hutshi Group (Bultman, 1979; Grond *et al.*, 1984), and as equal parts of Middle to Upper Jurassic volcanics and Late Cretaceous Montana Mountain volcanics (Mihalynuk and Rouse, 1988a; Figure GM97-1). Mihalynuk *et al.* (1991) adopted the nomenclature of Bultman (1979) and included all of the volcanic strata on Table Mountain with the Peninsula Mountain volcanics, despite a reported Rb-Sr whole rock isochron of 72.4 ±2.1 Ma (Grond *et al.*, 1984) arising from analysis of these and other volcanic rocks in northwestern British Columbia. However, a U-Pb zircon age of 81.3 ± 0.3 (Mihalynuk *et al.*, 1992a) from the upper volcanic stratigraphy within the Table Mountain volcanic complex confirmed the Late Cretaceous age assignment of Grond and others (Mihalynuk and Smith, 1992a; *see also* Chapter 7).

Volcanic divisions followed here are essentially those of Mihalynuk and Smith (1992b) where intermediate to felsic volcanics of the Late Cretaceous Table Mountain volcanic complex are believed to rest above possible Triassic strata of the Peninsula Mountain suite. However, the name Windy-Table volcanic suite is used here in recognition of the more widespread distribution of these volcanics and to conform to a standardized nomenclature for magmatic rocks in southern Yukon and northern BC that is currently under development (*cf*. Hart, 1995).

Windy-Table volcanics are dominantly felsic in composition and are characterized by quartz-phyric ash flow units (Figure 6-2). Altered, orange-weathering, quartz-orthoclase-plagioclase-biotite (± hornblende) porphyry stocks up to 5 square kilometres in size, partly crosscut the succession, but are believed to be comagmatic (Chapter 12).

Windy Arm to Eastern Tutshi Lake

Andesite to rhyodacite flows, ash flows, tuff and related volcanic strata occur at both Windy Arm and eastern Tutshi Lake. Many units can be followed at least intermittently between these areas, although they are not specifi-

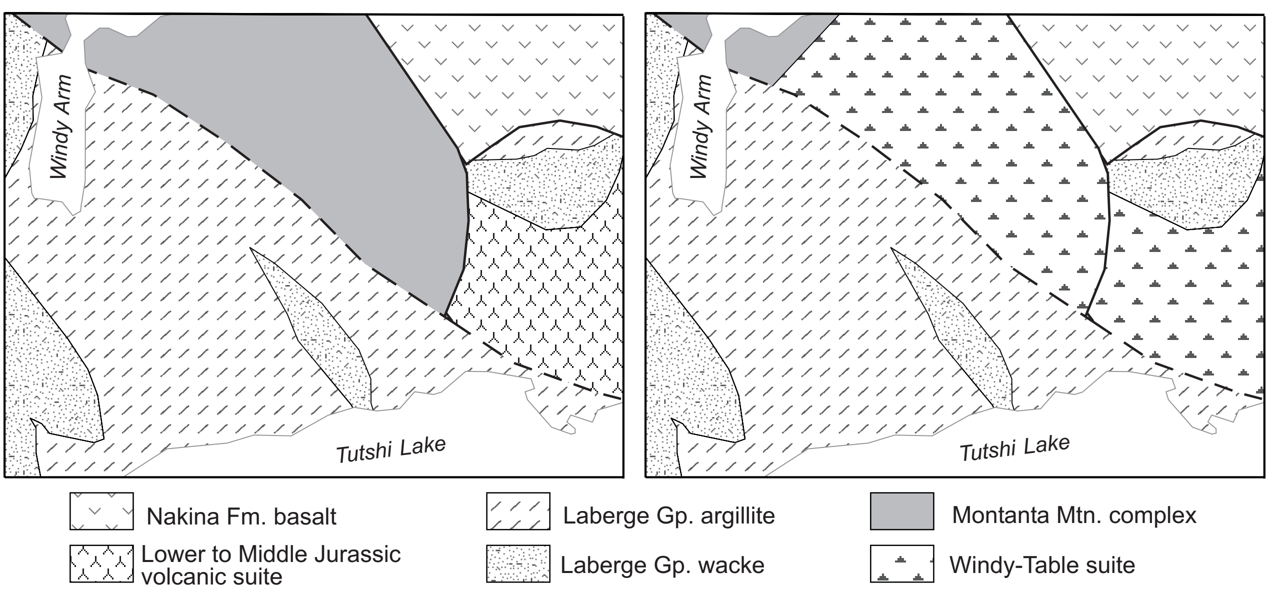


Figure 10-5. A comparison of the interpreted extents of Montana Mountain volcanic rocks. (a) as shown in GM97-1 (b) an alternative, equally plausible, and preferred interpretation.

cally shown on Figure GM97-1. Rocks at Mount Conrad comprise the western part of the area. They correlate with the upper, felsic flows and pyroclastics of the Montana Mountain volcanic complex as mapped by Hart and Radloff (1990). However, new isotopic data (Hart, 1994) indicate that the upper felsic volcanics belong mainly to the middle unit of Hart and Radloff (1990) and are coeval and correlative with the Windy Table suite.

Windy-Table suite volcanic rocks underlying Mount Conrad are typically flaggy weathering, argillically altered (clay, calcite, remnant pyrite) and quartz feldspar-phyric. Chlorite locally replaces both matrix and clasts and is pseudomorphous after mafic minerals, particularly in an aerially restricted unit of green to maroon andesitic lapilli tuffs. Rhyodacite flows are banded, and probable ash flows display elongate, flattened fragments.

Closer to Tutshi Lake, relatively flat-lying flows are an important part of the succession (Photo 10-4). They range in composition from probable andesite to rhyolite. Andesitic flows are 2 to 7 metres-thick, brown weathering and sparsely feldspar-phyric. Feldspar as glomerocrysts or as subtrachytic laths up to 1 centimetre long comprises up to 10% of the rock. Amygdules of quartz-calcite and prehnite? are common. Good flow tops and rubbly flow bottoms commonly grade into interflow polymictic lapilli tuff and/or laharic units. Interflow tuffs include autobrecciated blocks of the flows and aphanitic brown, cream, green and reddish fragments in a fine crystal-ash matrix.

Rhyolite flows and ash flows have the same general phenocryst composition: quartz (5%), plagioclase (5-10%), sanidine? (5-10%) and biotite (2-3%). The flows have steep margins and are commonly flow banded and spherulitic.

Felsic tuffs are generally green, less commonly maroon, grey or brown, with cream, buff, green and pink fragments in a siliceous and chloritic lapilli-crystal matrix. Feldspar is ubiquitous (5 - 10%) and biotite, though less abundant, is widespread. Quartz phenocrysts are not common, but where present, comprise approximately 2% of the rock. Flattened lapilli may be totally replaced by prehnite to form waxy, green flattened globules. Flow or compaction layering is common. Compositionally similar green tuffite may occur where tuffs are water lain or slightly reworked.

These volcanic strata are probably correlative with the youngest unit of Hart and Radloff (1990). They are extensively cross-cut by a series of grey-green, feldspar- and sparsely hornblende-phyric andesite dikes that consistently trend 030°, and may have been emplaced during a late pulse of Montana Mountain magmatism.

Table Mountain and vicinity

Most mapping within Windy-Table volcanic suite during this study focused on the dissected plateau around Table Mountain. Here widespread eruptive units, particularly quartz-phyric ash flow marker horizons, aid in the development of a tentative stratigraphy. Offset of these marker horizons points to block faulting or deposition on a highly irregular paleosurface. As expected, facies vary greatly across this volcanic terrain.

Conglomerate and Tuffite (lKWc)

Conglomerate is developed at the base of the Windy-Table volcanic suite at several localities where it is underlain by various phases of the Fourth of July batholith. Northeast of Table Mountain, near the west shore of Graham inlet, the contact between a red tuffite containing clasts of the nonconformably underlying hornblende-biotite monzogabbro and the intrusion is well exposed. The unit grades upwards into a coarse dacite block breccia.

The northern flank of a small mountain (elevation 3000 feet) between Graham Inlet and Safety Cove is underlain by conglomerate and tuffite containing fragments of mainly aphanitic andesitic(?) but also flow-banded rhyolite clasts as well as sparse pebbles of siliceous argillite and rare serpentinite clasts of the Cache Creek complex. Locally, clasts up to cobble size of quartz monzodiorite of the Fourth of July body predominate. Nonconformable relationships are perhaps best exposed at Safety Cove. There a polymictic cobble conglomerate containing clasts of biotite quartz diorite as well as a variety of white rhyolite and andesite clasts (Windy-Table volcanics) directly overlies altered Fourth of July biotite diorite. Alteration in the intrusive rock below the conglomerate probably represents a weakly developed paleoregolith.

Photo 10-4. A view to the northeast of relatively flat-lying Windy-Table volcanic suite strata above the north shore of eastern Tutshi Lake. Light weathering rocks in the distance are dominantly carbonates of the Cache Creek Terrane.

Rhyolite (lKWr)

Volumetrically minor, but distinctive white- to reddish-weathering, flow-banded rhyolite occurs at the base of the Windy-Table succession in many areas. Rocks are very fine grained, and have a marked linear and planar flow fabric. A platey parting commonly parallels the flow foliation. Flows were probably quite viscous, as evidenced by near-vertical flow-foliation at the flow margins and strongly brecciated flow tops. Some rhyolite units are entirely brecciated or tuffaceous.

Lahar (included in lKWa)

Near the mouth of the Atlin River, volcanic strata dip moderately to the east, but otherwise display little deformation and only minor alteration. Four lithologies are represented: coarse laharic breccias, monolithologic pyroclastics, minor epiclastic units and green to ochre flows. The most widespread of these units are coarse, predominantly clast-supported laharic breccias. Blocks are typically round, less commonly subangular, and generally of decimetre size, although they range up to several metres in diameter. They are generally either andesite or rhyolite. Andesitic blocks composed of about 35% fine to medium-grained, trachytically aligned feldspar (± hornblende) are most common. They are rounded and vary in colour; most are, red, purple, orange or green. Slightly more angular and less abundant are rhyolitic blocks that are white, grey or light green. These display flow layering, planar fractures and a waxy fresh surface. This unit is massive with little clast sorting, imbrication or alignment. Felsic clasts within the unit may in part be derived from the ash flow units described in the following section.

Apparently overlying the laharic breccia are coarse monolithologic pyroclastic and interbedded epiclastic rocks. These units dip moderately westward. The pyroclastics are grey to mauve and contain abundant rounded, 10 to 30 centimetre trachytic blocks. They are very fine to medium-grained with feldspar and hornblende as the most common identifiable minerals. Epiclastic interlayers are coarse lithic volcanic sandstones to mudstones. Some epiclastic layers may be water-lain ash tuffs.

Dark green to black pyroclastics on the north shore of the mouth of the Atlin River form beds ranging in thickness from 1 to more than 5 metres. One lapilli tuff contains abundant carbonized wood fragments, locally comprising up to 5 percent of the rock. Intercalated flows are dark green to ochre and very fine grained with rare feldspar crystals up to 3 millimetres long. Locally they contain 5 to 10 percent elongated calcite amygdales.

Ash flows (lKWaf)

Ash flows are mauve, tan, grey and light green and display a flow layering due to lapilli elongation that varies from distinct to indistinct. They locally display good welding textures. Ash flow matrix consists dominantly of altered volcanic glass (Photo 10-5), feldspar (plagioclase and sparse K-feldspar?), quartz and biotite. Atop flow units are crystal vitric tuffs consisting of feldspar (35% plagioclase) and biotite (4%). These interflow units may include non-welded flow tops of ash flow units, but are mainly pyroclastic debris that accumulated between ash flow eruptions.

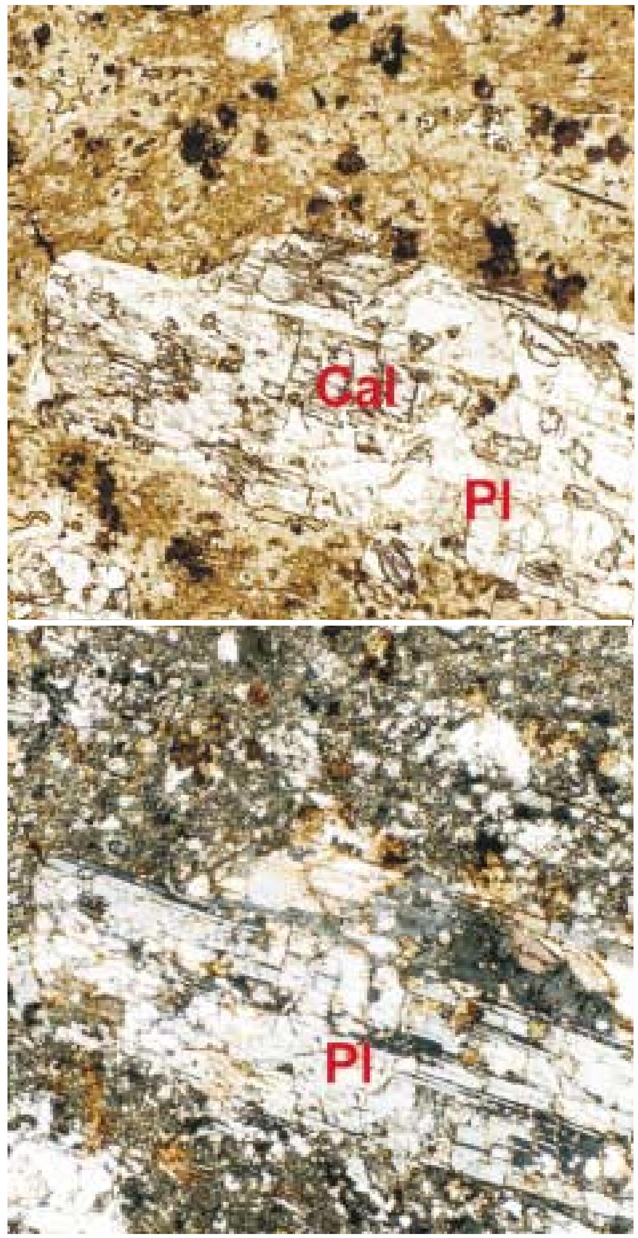


Photo 10-5. Photomicrograph of devitrified matrix within ash flow unit of the Windy-Table suite in plane polarized light (top) and cross polarized light (bottom). High relief and birefringence domains in the plagioclase phenocryst (Pl) are calcite (Cal). Scale: width represents approximately 1 mm of sample.

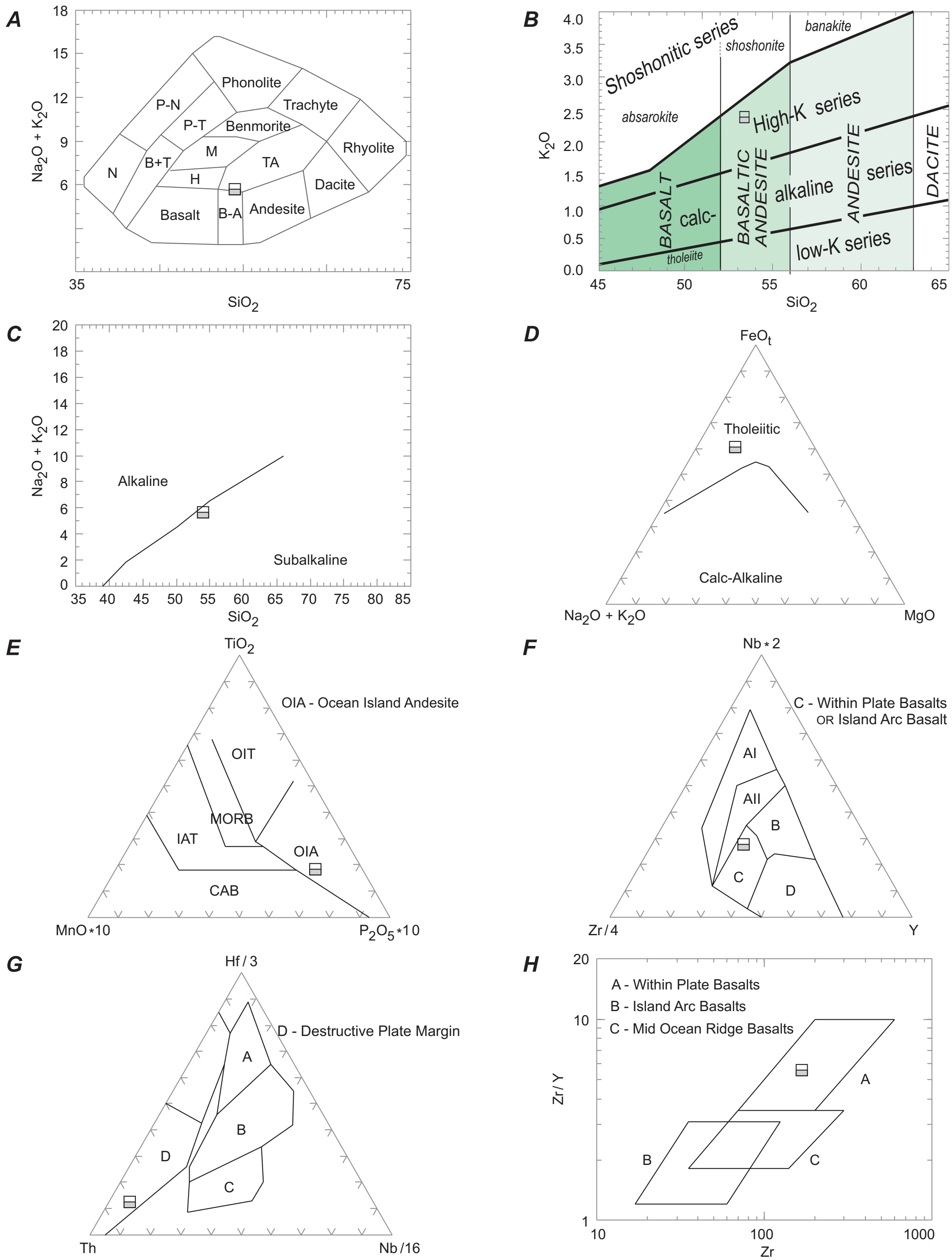


Figure 10-6. Geochemistry of one basaltic sample from the Windy-Table volcanic suite: (a) alkalis versus silica classification diagram shows the basaltic andesite composition of the sample (fields of Cox *et al.*, 1979); (b) K_2O-SiO_2 potassic index of Ewart (1982) shows that the sample is a high-K basaltic andesite; (c) alkalis-silica and (d) AFM diagrams of Irvine and Barager (1971) show that the sample plots in the subalkaline and tholeiitic series fields; (e) (f) Nb*2-Zr/4-Y following the method of Meschede (1986) and (g) Hf/3-Th-Nb/16 after the method of Wood (1980) both indicate that the basalt was formed at a destructive plate margin. (h) Zr-Zr/Y discrimination plot following the method of Pearce and Norry (1979) shows that the sample plots in the within plate basalt field.

Individual ash flow cooling units are generally homogeneous, monolithologic and 3 to 5 metres thick. Some units are more than 10 metres thick and probably record either local ponding or, where distinctive epiclastic or airfall interbeds are absent, multiple eruptive units.

Maroon to grey ash flows comprise another aerially extensive unit. Rocks are fine-grained, and strongly flow banded, with squashed lapilli. Aligned feldspar and biotite crystals further define flow foliation. They are locally quartz-phyric.

Basalt (lKWb)

Distinctive black basalt flows and blue-green, well-bedded interflow tuffs form a conspicuous unit that underlies about 1 to 2 km^2 of the northeast flank of Table Mountain. Flows are generally 0.5 to 5 metres thick and have either planar or irregular contacts displaying both flow-top and bottom breccias. Acicular to tabular vitreous feldspar phenocrysts form up to 15% of the rock and are up to 5 millimetres long. This unit may be the youngest preserved within the Windy-Table suite; it overlies a possible paleosol developed in unit lKWa.

REE and whole rock data

Examples of homogeneous, non-porphyritic and relatively unaltered basalt units that are unequivocally part of the Windy Table suite are uncommon. As a result, only a single basalt sample was collected for analysis of major oxides and trace elements (Table AD1). The volcanic package cannot be characterized by a one sample, but it does provide an indication of the geochemical orientation of the succession. It is a basaltic andesite (Figure 10-6a) that displays high-K chemistry (Figure 10-6b) it is apparently subalkaline and tholeiitic (Figures 10-6c, d). On discrimination diagrams the sample plots as either within plate (Figures 10-6e, f, h) or as island arc basalt formed at a destructive plate margin (Figure 10-6f, g).

Rare earth element analysis results from this sample are shown in Table AD2 and plotted in Figure 10-7. On the N-MORB normalized plot, the sample shows strong light rare earth element enrichment. The plot displays a negative europium anomaly, consistent with the strongly plagioclase porphyritic nature of the succession. This type of REE pattern is like that of subduction zone related mafic volcanics.

Alteration, age & initial strontium ratios

Alteration of the Windy-Table volcanics is less intense than that in the underlying Peninsula Mountain volcanic strata, but is generally more intense than alteration affecting Eocene volcanics of the Sloko Group (compare Photos 10-5, 7-5 and 11-1 respectively). Alteration assemblages include epidote-prehnite-calcite and white mica.

Ash flows at Table Mountain that are part of the Windy-Table suite have been dated by determination of U-Pb isotopic composition of zircon populations as 81.3±0.3 Ma (Mihalynuk *et al.*, 1992a). This age corroborates a Rb-Sr whole rock age determination by Grond *et al.* (1984). Rb-Sr analyses by Mihalynuk *et al.* (1992a), when combined with the Table Mountain data point of Grond *et al.* (1984), produce a three point isochron of 75.3±2.7Ma. Initial strontium ratios back-calculated using the U-Pb age range determinations are 0.7039 to 0.7042. Such initial strontium ratios are consistent with a magmatic source region that lacks a significant old, radiogenic component.

Coeval magmatic rocks within the region comprise the Surprise Lake batholith east of Atlin. The batholith has yielded an equivalent U-Pb zircon age, within error limits, of 83.8±5 Ma (Mihalynuk *et al.*, 1992a). Back calculation of initial Sr ratios based upon the U-Pb age data and Rb-Sr isotope analyses of Mihalynuk *et al.* (1992a) yield geologically unreasonable values of 0.6999 and 0.6552 for the Surprise Lake batholith. These ratios indicate open system behavior and cannot be compared with those for the Windy-Table suite.

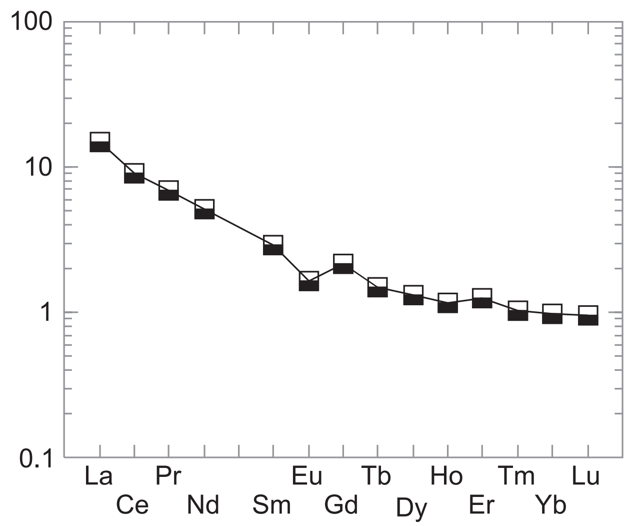


Figure 10-7. REE spidergram for a sample of the Windy-Table volcanic suite.

Mineral potential

No major mineral occurrences are known in association with Windy-Table volcanic rocks in the Tagish area. However, gold mineralization in the Graham Creek area could be associated with a magmatic hydrothermal system of this age (for example *see* Ballantyne *in* Mihalynuk *et al.*, 1990). In contrast, Montana Mountain volcanic rocks host numerous showings in the Yukon, including the former Venus mine. Past recorded production at Venus is in excess of 1.17 million grams of gold and 38 million grams of silver recovered from 154 000 tonnes of ore. Reserves stand at 200 000 tonnes (Hart and Radloff, 1990). Past efforts to increase reserves at the Venus mine have included the evaluation of Montana Mountain volcanic strata in British Columbia; so far, these have met with little success.

Chapter 11 Tertiary Volcanic rocks

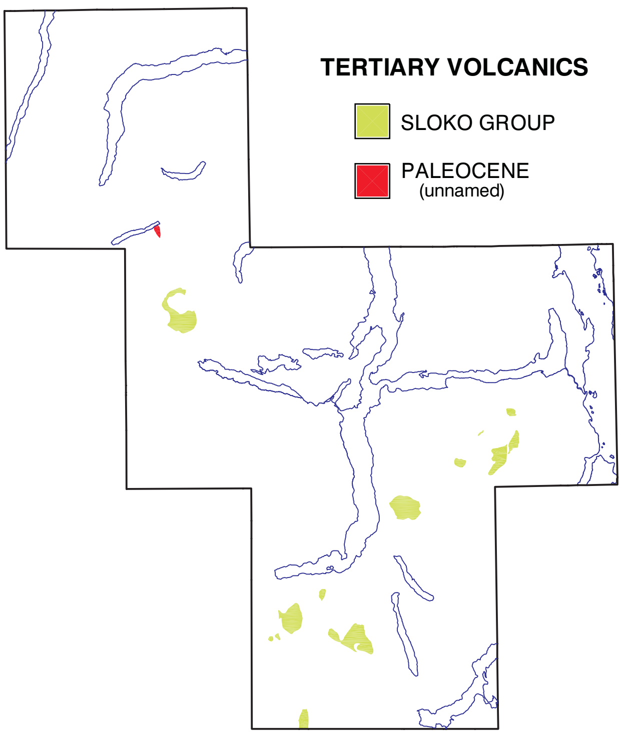


Figure 11-1. Distribution of Sloko Group and Paleocene volcanic rocks.

Early Eocene Sloko Group strata are the dominant Tertiary volcanic rocks in the Tagish area. They occur as erosional remnants which underlie many of the highest peaks in the Tagish region including Teepee Peak, Engineer Mountain, Mount Fetterly and Mount Switzer (Figure 11-1). At several of these localities the volcanic pile is cut by small, subequant, coeval plutons that are, in some cases, clearly comagmatic.

A few square kilometres of mountainside near Skelly Lake are underlain by locally foliated volcanic strata, which are apparently only about 4 million years older than the main pulse of Sloko volcanism. However, these Paleocene volcanic rocks are not included with the Sloko Group, because it is possible that the sample dated is not representative of the entire unit which could be much older.

Paleocene Volcanics at Skelly Lake (59 Ma)

Foliated volcanic rocks underlies the ridge that extends southward from the east end of Skelly Lake to an elevation of about 300 metres above the lake (about 2 square kilometres, Figure 11-1, not shown on Figure GM97-1). They comprise pyritic rhyolite flow and tuffaceous rocks with well preserved clastic textures and flow foliation. They are well indurated, locally foliated and phyllitic. Cross-cutting flow-banded dikes in the area are lithologically very similar to the banded rhyolite flows, requiring that contacts be exposed to distinguish them in the field.

These volcanic rocks appear to rest unconformably on the Boundary Ranges suite. However, Mihalynuk *et al.* (1988b) included these with the Boundary Ranges suite due to their locally foliated habit and limited extent and the absence of correlatable lithologies within the map area. On the basis of the new U-Pb zircon age determination of 58.5 ±1.5 Ma for a massive rhyolite (Figure 11-2; Tables AA1, AA2) they are apparently a much younger package of rocks and unrelated to the Boundary Ranges Metamorphic suite. However, the sample dated could unknowingly have been collected from a rhyolite cupola or dike that is much younger than the volcanics that enclose it.

On the nearby Crine property east of Teepee Peak deformed intermediate to basic volcanic rocks were mapped in detail by Cuttle (1989). They may be correlative with the foliated rhyolites. Regionally, the foliated rhyolites at Skelly Lake most closely resemble pyritic rhyolites of the Peninsula Mountain suite. However, age and lithology considered, the Skelly rhyolite is most likely a precursor to the widespread early Eocene Sloko volcanic episode. Deformational fabrics can be attributed to movement on the Llewellyn fault which is located within 1 kilometre to the northeast.

Early Eocene Sloko Group (eES 55 Ma)

The Sloko Group is the youngest layered rock unit in the map area (see “Age and Interpretation” below). Sloko Group strata are mainly flat-lying and infill paleotopographic lows incised into deformed Laberge Group strata and older rocks. Isolated occurrences of these strata in the

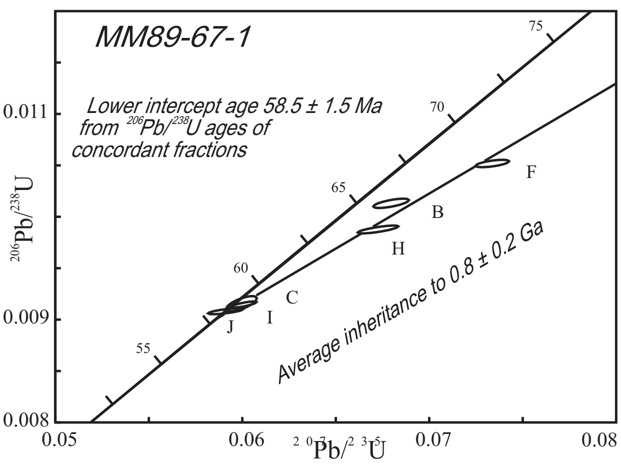


Figure 11-2. U-Pb isochron diagram for sample MMI89-67-1 from near the eastern end of Skelly Lake.

Tagish Lake area are relicts of a much more extensive blanket. Perhaps the most intact relict is preserved at Sloko Lake to the south, where the name was originally applied by Aitken (1959) to a well-bedded succession that is more than 1100 metres thick. During Quaternary glaciation, erosion of the former relatively continuous sheet of Sloko volcanics in the Tagish area left only erosional remnants atop many of the highest mountaintops.

Several erosional remnants were previously mapped as "volcanic rocks of uncertain age" or as "Cretaceous or later" by Christie (1957). Sloko volcanic rocks at Teepee Prior were formerly correlated with the Upper Triassic Stuhini Group (*i.e.* Lhotka and Olsen, 1983; Wheeler and McFeely, 1991). The considerable accumulation of volcanic rocks underlying Mount Switzer had not been documented prior to this study. Mihalynuk *et al.* (1990) correlated these rocks and adjacent volcanic outliers with volcanic strata at Engineer Mountain, based upon strong lithologic and stratigraphic similarities between them. This stratigraphic sequence varies locally as a result of onlapping paleotopographic affects, variations in magmatism and facies changes. All of these outliers are now known to belong to the Sloko Group on the basis of new isotopic age data (Mihalynuk *et al.*, 1999).

Because Sloko Group strata are only preserved in isolated outliers within the map area, it is not possible to construct a complete stratigraphic picture. However, a composite stratigraphy is shown in Figure 11-3. The most complete stratigraphic section is at Teepee Peak where Sloko Group strata attain a thickness of about 800 metres. This thickness is a minimum as the top of the succession was removed during glaciation.

Basal conglomerate and epiclastics (eESs)

At most localities the basal Sloko units are comprised of well developed conglomerate derived mainly from immediately underlying lithologies, generally either the Laberge Group or the Boundary Ranges Metamorphic suite. Pebble to boulder-sized clasts dominate the conglomerates which fill paleotopographic lows. Conglomerates are generally poorly indurated, with cobbles weathering easily from the volcanic sand matrix, which comprises 30 to 70 percent of the rock. Colour varies from green grey to dark brown or rust. Conglomerate lenses and laterally continuous beds up to 30 metres thick also occur at horizons tens to hundreds of metres above the basal conglomerate. These typically host a greater diversity of clast types, including granitoid (especially leucogranite), dark green hornblende feldspar porphyries and tan chert, but are still dominated by locally-derived lithologies.

Well bedded white to dark grey rhyolitic sandstones comprise most of the basal succession. However, grain size varies considerably so rock types range from rusty,

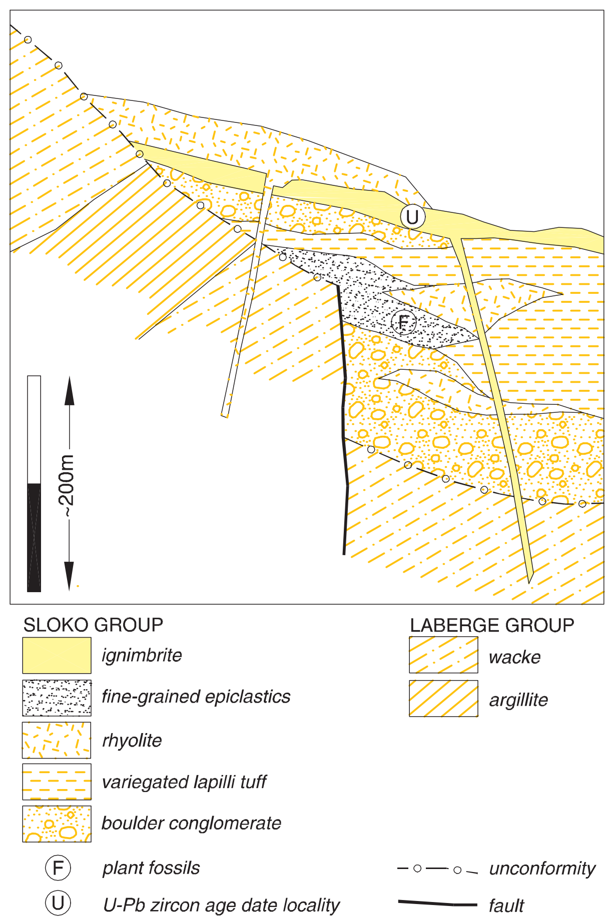


Figure 11-3. Generalized Sloko Group stratigraphy as seen in western Atlin (104N/12W) and eastern Fantail Lake (104M/9E) mapsheets.

black volcanic mudstone to grey granule and sparse pebble conglomerate. Beds are mainly planar with little evidence of cross-stratification. Minor slump folds are common, especially in fine grained, thinly laminated strata. Lithic grains and quartz granules everywhere point to quartz-phyric rhyolites of the Sloko Suite as the dominant source.

At Engineer Mountain, the basal "conglomerate" rarely exceeds two metres in thickness and is composed primarily of angular fragments of siliciclastic Laberge Group strata. Rather than a well-worked conglomerate, this basal unit is more likely a talus or an alluvial fan deposit. A similar-looking lithology occurs with steeply faulted contacts on the north side of Engineer Mountain, but at this locality it could be fault breccia.

One of the best developed basal conglomerates is a red-bed succession on the northeast flank of Mount Switzer. Thicknesses vary considerably from nearly absent to over 30 metres. The basal conglomerate clasts consist primarily of cobbles of paragneiss, pegmatite, metamorphic quartz and other resistant underlying lithologies. The conglomerate matrix is poorly sorted red sand. This conglomerate mainly formed without any volcanic influence and therefore might be significantly older than, and best not included with, the Sloko Group. However, higher in the section the conglomerate is cut by volcanic-rich clastic dikes or fissure infillings. Variegated, mainly feldspar-phyric volcaniclastic rocks form lensoid bodies within the conglomerate that are up to about 100 metres thick. Upper parts of the conglomerate contain abundant volcanic clasts and may be interdigitated with steep-sided rhyolite flows. This sequence gives way to a chaotic breccia containing blocks several to 10 metres across. One gneiss olistolith is large enough to be easily mapped at 1:50 000 scale (500m longest dimension). These breccias, probably formed due to seismically-induced collapse of a synvolcanic fault scarp.

Rhyolite flows, dikes & ignimbrite (eESr)

Rhyolite commonly occurs as flow domes and pyroclastic breccias which occur in sections less than a metre to over 100 metres thick. Where a basal conglomerate is not developed, rhyolite may occur at the very base of the Sloko succession. It is typically white to yellow and chalky or pink to grey and vitreous, and may be rusty-weathering. Spectacularly banded or spherulitic varieties are common. They are normally sparsely porphyritic, but may contain up to 15% feldspar as medium-grained euhedral crystals and smaller amounts of medium to fine-grained quartz eyes.

Light grey-green ignimbrite containing monomictic, flattened grey pumice fragments (flattening ratios of 10 to 20) are conspicuous within the Sloko strata. Some of the fragments contain white anhedral altered plagioclase phenocrysts up to 5 mm in diameter. Moderate to dense welding is apparent in thin sections which show that pumice has totally collapsed (Photo 11-1).

Numerous flow-banded, aphanitic and quartz - feldspar porphyritic rhyolite dikes that cut Laberge Group strata are believed to be feeders to the Sloko Group. Most have the same mineral assemblages as the subaerial flows. Two notable exceptions are: between Mount Fetterly and Graham Inlet, where a dike 100 metres thick contains zones of up to 10% euhedral pyroxene (5 mm in diameter); and between Mount Fetterly and Mount Cameron, where a dark grey rhyolite dike is strongly perlitic.

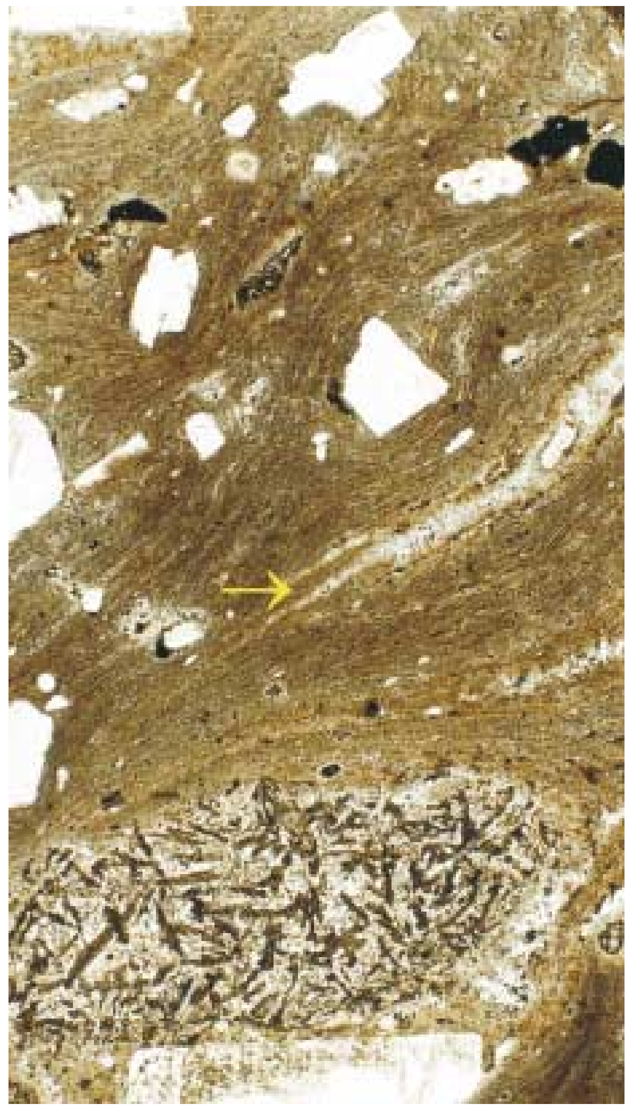


Photo 11-1. Photomicrograph of Sloko Group ignimbrite displaying strong welding. Clear crystal fragments are plagioclase and quartz. Some semiopaque clots can be identified as altered hornblende crystals. Good preservation of glass textures is common in the Sloko Group, but is uncommon in older volcanic suites. Compare with Photos 7-5 and 10-5. Scale: width represents approximately 1 mm of sample.

Mainly dacitic to andesitic pyroclastics and lesser flows (eESv)

Thick pyroclastic deposits of mainly dacitic to andesitic composition dominate the Sloko Group in the Tagish area. One of the most distinctive and widespread units is a powder green, heterolithic lapilli tuff. It contains up to 15% conspicuous white rhyolite fragments and variegated aphyric to medium-grained feldspar porphyry fragments. It is generally platey weathering and recessive, although some outcrops have an irregular rubbly surface. On Engineer Mountain, this unit encloses basalt "blocks" 10 to 30 metres in diameter which may represent flow channels in cross section.

Basalt (eESb)

Basalt is subordinate to more felsic volcanics within the Sloko Group. True basalt probably comprises less than 5% of Sloko Group strata. Basalt flows and monolithic breccia are generally well indurated and blue-black to green-black in colour. They typically contain between 5 and 35% percent idiomorphic feldspar phenocrysts. Fresh plagioclase commonly displays oscilliatory zoning, but average composition is andesine. Phenocrysts other than plagioclase are not common. Clinopyroxene and iddingsite that is pseudomorphous after sparse olivine are observed locally. In one sample, hornblende that is pleochroic from green-yellow to pink forms alteration rims on, and cores in, possible orthopyroxene. Alteration intensity is variable. Vitreous black basalt with a conchoidal fracture and only incipient devitrification of matrix can occur immediately adjacent to basalt containing feldspars that are strongly altered to calcite, prehnite and white mica, in a matrix that is largely devitrified or replaced by authigenic minerals.

Vitrophyric tuff and breccia (eESo)

Distinct vitrophyric lapilli tuff and breccia both appear to occur as caldera infill facies that are 300 to 500 metres or more thick. As such they locally dominate Sloko Group stratigraphy. On average, the composition of vitrophyric tuff is probably dacitic whereas breccias are more andesitic. Both form black cliffs.

At Teepee Peak vitrophyric tuff predominates. It is well indurated and forms tan-red or brown-black weathering cliffs. It contains variable proportions of lithic fragments (up to about 35%) in a black vitric matrix that displays eutaxitic textures. Fragments are multicoloured: green, brown and grey. Feldspar comprises up to 15% of the rock as medium-grained euhedral and broken crystals.

Breccias are well developed at Mount Switzer where their thickness probably exceeds 600m. They have a dark grey-green matrix with 15% plagioclase and 2% altered pyroxene phenocrysts. Plagioclase phenocrysts display striking zonation with the outer zones rich in fluid and opaque inclusions (Photo 11-2). Feldspars also display *in situ* cataclasis. In some areas the breccia is epidote-altered. In other areas, amygdales are filled with pumpellyite, celadonite? and chlorite (Photo 11-3) and prehnite occurs as an alteration product of plagioclase. Locally, fault scarp facies can be recognized.

About 2 kilometres northwest of the Mount Switzer summit, a thick section of Sloko Group volcanics on a hornblende-biotite-plagioclase-quartz gneiss basement is exposed. The basal 100 m is grey, amygdaloidal feldspar porphyry breccia containing abundant fragments of rhyolite and basement lithologies. This is overlain by flow-banded grey rhyolite of unknown thickness which is juxtaposed across a caldera fault scarp complex with an accumulation of more than 600 metres of dark grey weathering, coarse feldspar porphyry breccia . This thick accumulation may be the remnant of a more extensive caldera infill facies.

Photo 11-2. Plagioclase phenocryst within andesitic breccias at Mount Switzer display striking zoning outlined by opaques and fluid inclusions near the crystal margins. Scale: width represents approximately 1 mm of sample.

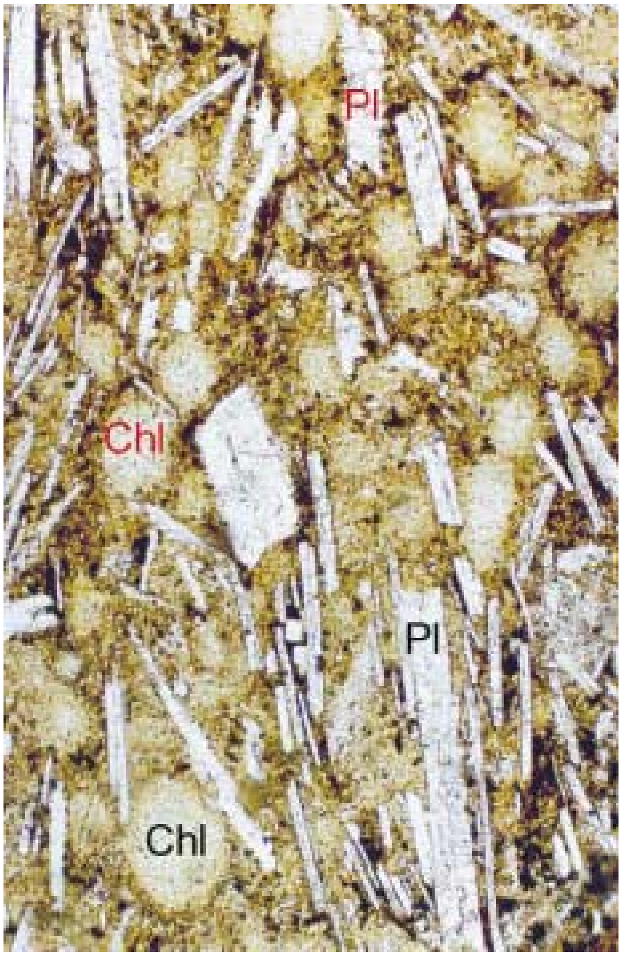


Photo 11-3. Fine ash tuff of the Sloko Group is crowded with amygdales and plagioclase microphenocrysts. Amygdale fillings and matrix show the development of low grade authigenic minerals: pumpellyite celadonite and chlorite (Chl). Prehnite replaces plagioclase (Pl) as high birefringence, angular clots. Scale: width represents approximately 1 mm of sample.

Age and Interpretation

New Sloko Group age determinations from U-Pb isotope analyses of zircons are reported for the first time here (Table AA1). Isotopic data are reported in Mihalynuk *et al.* (1999). These data yield consistent results of about 55 Ma and are concordant with K-Ar cooling ages (Table AA1, AA5). Sloko volcanics from the Tulsequah area to the south, yield similar ages within error (Mihalynuk *et al*., unpublished, and Panteleyev, unpublished) as do related intrusive rocks (53.5 ± 0.7Ma; Mihalynuk *et al.*, 1995a).

High-level, cannibalistic plutons which are coeval (within error) with the enclosing volcanic strata appear to be a hallmark of all well-dated Sloko Group volcanic piles. At Teepee Peak, a U-Pb zircon age determination of 55.5 ± 0.14 Ma is identical to an independently determined K-Ar cooling age from a cross-cutting pluton (55.5 ± 0.14 Ma, Table AA1). Coeval or slightly younger cooling ages are recorded by batholithic intrusions within the Coast Plutonic Complex to the west (see Chapter 12).

Two small plutons dated by Currie (1994) at 55.7 ±0.2 and 55.9 ±0.2 Ma (U-Pb zircon; Table AA5) are part of a suite that intrudes both basement as well as Sloko volcanic rocks at Mount Switzer. This relationship indicates that the volcanics at Mount Switzer are 55.5 Ma or older. A U-Pb age determination from the Mount Switzer succession returned 55.3 ± 0.2 Ma (Table AA1), coeval with the intrusions within the outer limits of error.

Previous age determinations, such as those from the Bennett Caldera complex immediately northwest of the map area, are younger than those in the Tagish area (Table AA5), but direct comparisons may not be appropriate due to differences in analytical procedures. The Bennett complex, straddling the BC-Yukon border at longitude 135° 15’W, is correlated with the Sloko Group, even though two K-Ar cooling ages from the complex reported by Lambert (1974) are younger by 3 to 4 million years (or 1 Ma outside of the limits of maximum error) than those reported here. Recalculated using new decay constants, these K-Ar ages are 51.2 ±3 and 51.9 ±3 Ma (Table AA5).

Sloko Group strata appear to have been deposited on an upland plateau of relatively uniform elevation. West of the Llewellyn Fault zone Sloko strata rest on metamorphic rocks; whereas, to the east, they are underlain by Laberge Group strata. The base of the volcanics at all localities is at an elevation between 1400 and 1460 metres (4600 and 4800 feet). Paleotopographic effects or later high angle faulting are responsible for the juxtaposition of the volcanic strata against older rocks at elevations up to 1830 to 1980 metres (6000 and 6500 feet). This similarity of contact elevations across the Llewellyn Fault suggests that there has been little vertical displacement since the Eocene. Unfortunately, no unit of Sloko age that pins the Llewellyn Fault has yet been discovered, so possible offset since Sloko time is uncertain. Nevertheless, correlative units of unknown lateral extent occur on either side of the Llewellyn Fault zone. This configuration of units could have accommodated limited (kilometres), but not extreme strike-slip displacements (hundreds of kilometres) across the fault since their deposition. Variations in the basement on which the Sloko strata are deposited points to a period of west-side-up displacement across the Llewellyn Fault prior to deposition of the volcanics.

Preserved Sloko successions are thickest within the subcircular, partly fault-bounded complexes that are intruded by coeval plutons at Teepee Peak, Engineer Mountain and Mount Switzer. These are interpreted as having been volcanic centres and subsidence features. Curvilinear diorite intrusions around a succession of

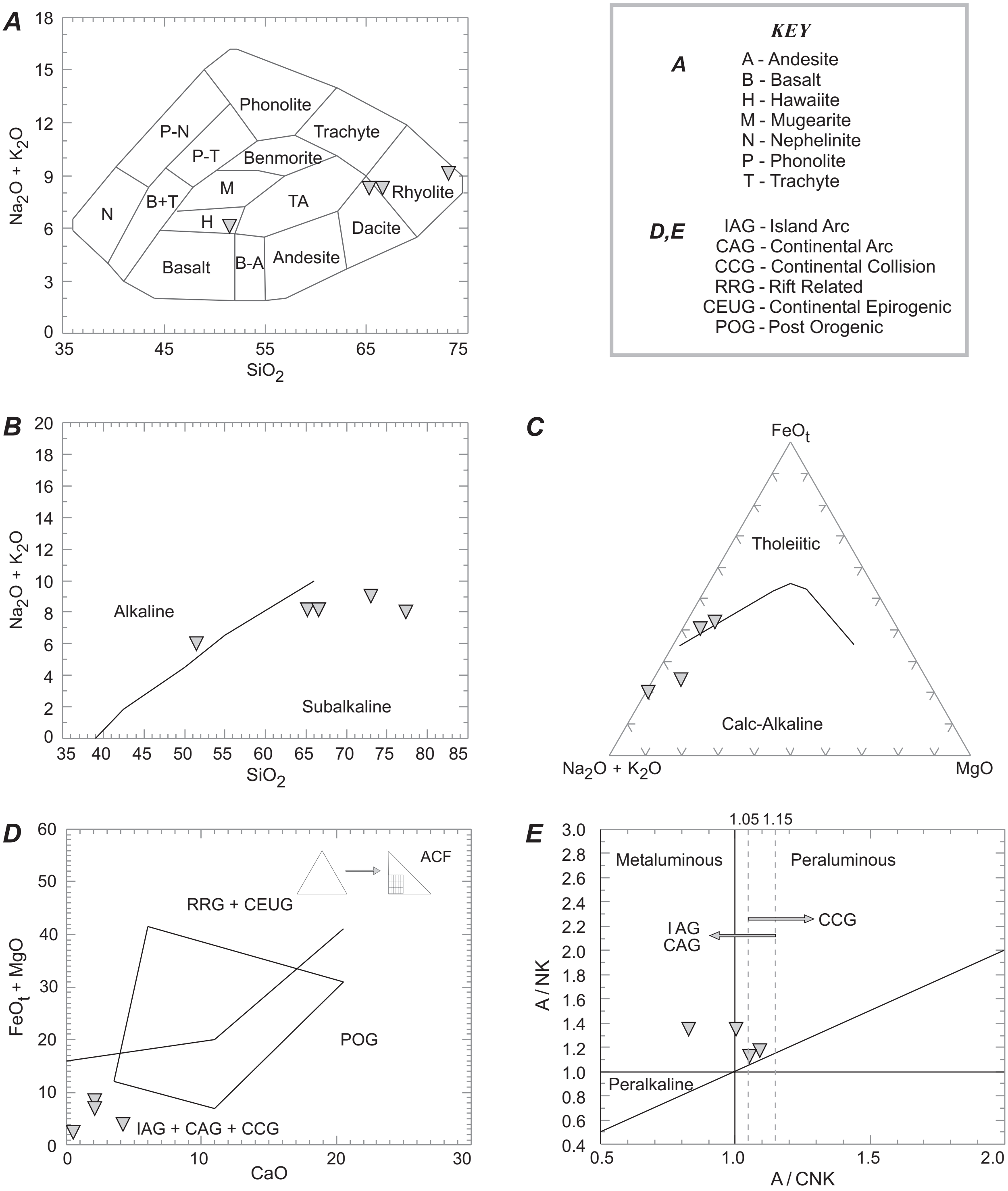


Figure 11-4. Geochemistry of Sloko Group volcanics: (a) alkalis versus silica classification diagram shows hawaiite to rhyolite compositional range (fields of Cox *et al.*, 1979); (b) alkalis-silica and Peacock's index, and (c) AFM diagrams of Irvine and Barager (1971) show that felsic members are subalkaline and calcic, but neither a tholeiitic nor calcalkaline trend is clearly displayed, principally due to low MgO contents; (d) tectonic discrimination plots of FeO+MgO vs. CaO following the method of Maniar and Piccoli (1989) show that the samples are arc-related; and (e) Shand's index shows that the suite is weakly aluminous (IAG = island arc granite, CAG = continental arc granite, CCG = continental collision granite.

Sloko volcanics a few kilometres northwest of Mount Switzer peak may represent a deep level cross-section through ring dikes.

Geochemistry

Sloko Group volcanic outliers are remnants of a continental arc built mainly of rhyolitic to andesitic flows, breccia, tuff and ignimbrite (eESv) and derived epiclastic rocks (eESs). Samples of Sloko Group analyzed for major and trace elements are shown in Tables AD1 and AD2 respectively. They span the compositional range of hawaiite to rhyolite (Figure 11-4a). Because many of the volcanic rocks have subvolcanic equivalents and dating indicates that they are coeval with plutons that cut the volcanic pile, the analyses have also been used to help classify the intrusives (Figures 11-4d, e; *see* Chapter 12).

Alkalis-silica (b) and AFM diagrams (c) show that felsic members are subalkaline. However, due to the small size of the sample population and lack of intermediate compositions, neither a tholeiitic nor a calcalkaline trend can be distinguished. The intrusive equivalents of these rocks would be calcic (b). On Shand's index (e) they are weakly aluminous and fall within a part of the diagram occupied mainly by continental arc granitoids. According to Maniar and Piccoli (1989), a plot of FeOt + MgO versus CaO (d) when combined with the Shand index (e) should enable discrimination between arc granites (IAG, CAG) and continental collision granites (CCG) for samples with more than 2% modal quartz and greater than 60% SiO_2. Clearly, the discrimination plots confirm field relationships indicating that these are arc volcanics, and according to their geological setting, probably continental arc volcanics.

Mineral Potential

There is a clear association of gold mineralization with Sloko volcanic centres. One of the best known gold deposits in Sloko volcanics is the Skukum mine, southern Yukon. At the Skukum mine, adularia-sericite alteration envelopes on the epithermal gold veins yield K-Ar ages that are apparently 2 million years younger than the enclosing volcanics (Hart and Radloff, 1990; McDonald, 1987). The veins display textures indicative of very shallow levels with open spaces and intergrowths of bladed calcite and quartz. Low Ag/Au ratios of 1:1.2 persist throughout the deposit.

In the Tagish area, gold mineralization is related to Sloko volcanic centres at two widely separated localities. At Teepee Peak, mineralization formed during development of a Sloko Group volcanic centre. It includes visible gold in Sloko volcanics adjacent to iron skarn developed in basement carbonates. At the old Engineer mine, auriferous veins are believed to have formed as part of the hydrothermal system created during development of the volcanic centre at Engineer Mountain.

Gold veins at the Engineer mine are hosted by Laberge Group argillite, wacke and siliciclastic rocks about 800 metres below the lowest volcanic rocks on Engineer Mountain. Fluid inclusion homogenization temperatures are around 195°C, hot enough to anneal fission tracks in apatite in the immediately adjacent wall rocks (*see* Table 14-4). Samples have been collected by R. Donelick in order to date the deposit by fission track techniques, but the analyses are not yet complete. The veins clearly cut folded strata and are therefore younger than Jurassic deformation. Although age control is lacking, the clear spatial association with Sloko volcanics suggests cogenesis. The Engineer Mine is classified as a deep epithermal deposit, and like the Skukum deposit, displays low Ag/Au ratios for a deposit of this type.

A third centre of Sloko volcanism in the Tagish area occurs at Mount Switzer. No gold showings are known from near Mt. Switzer, although, prior to the Tagish project this Sloko volcanic centre was unmapped and the mineral potential remains untested. Potential for gold mineralization related to Sloko magmatism also exists within and peripheral to coeval intrusive bodies like those at Teepee Peak, Engineer Mountain and Mount Switzer. Other small bodies of this age may occur within the Whitehorse Trough; although all those shown on Figure GM97-1 are grouped as Late Cretaceous in age based upon sparse K-Ar age dating.

Deep seated faults are believed to have been key in formation of the Skukum deposit (Hart and Radloff, 1990) and third-order fault structures connected to the deep seated Llewellyn Fault are an important control on mineralization at the Engineer Mine. Such faults focus hydrothermal circulation. Similar structures occur as the westernmost strands of the Nahlin fault system near Sloko-capped Mount Fetterly where they may have focused hydrothermal fluids driven by the intrusion of rhyolite sills up to 150 metres thick that also occur in the area.

The search for gold mineralization in quartz veins has dominated historic exploration in the Tagish area. However, few exploration efforts have targeted Sloko volcanic rocks in regional exploration for epithermal gold deposits. Part of the problem is that the distribution of Sloko volcanics was not well known in northwestern British Columbia prior to the Tagish project. An exploration program designed to discover deposits like the Skukum Mine might first look at gold, mercury and fluorine levels in regional stream sediment surveys (*e.g.* Jackaman and Matysek, 1993). At the property scale, exploration would focus on evidence of veining along late faults. At the scale of individual showings, peripheral alunite-kaolinite (acid sulphate) alteration and proximal adularia-sericite alteration with manganese mineralization are indicators of fertile hydrothermal systems.

Considering that two past producing gold deposits occur where only the scrappiest bits of Sloko Group are preserved, the probability for discovery of similar deposits in regions to the south, where the Sloko Group is much better preserved, should be relatively high.

Chapter 12 Intrusive Rocks

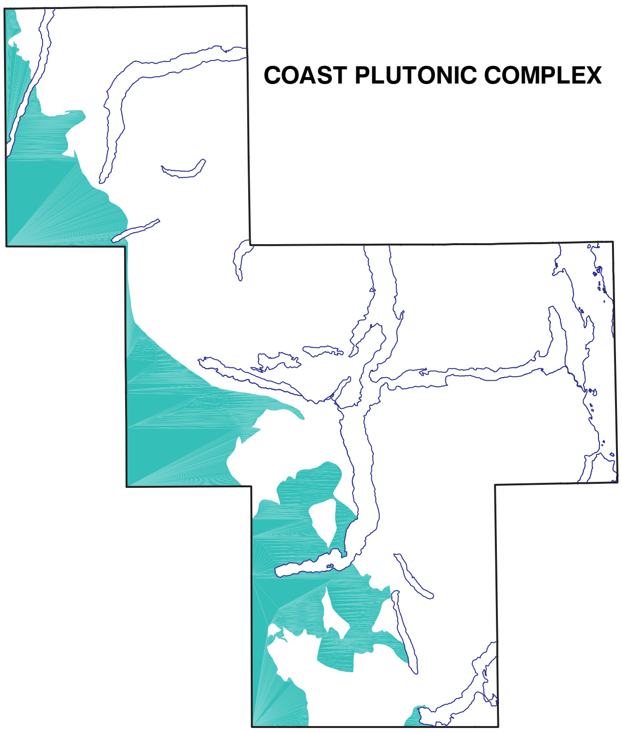


Figure 12-1. Northern Coast Plutonic Complex in the Tagish Lake area.

On a geological map of the world, the enormous mass of plutonic rocks in the western Canadian Cordillera stands out as a global magmatic anomaly. Intrusive rocks that dominate the western margin of the Tagish map area are part of the eastern and northernmost limits of this magmatic mass known as the Coast Plutonic Complex (Figure 12-1). Magmatic rocks that are genetically integral to the Coast Plutonic Complex range in age from Jurassic to Early Tertiary. Caught within this plutonic collage are scraps of older, metamorphosed intrusive and layered rocks.

Metamorphosed intrusive bodies of Jurassics and older age may be highly deformed, exhibiting a strong, pervasive fabric. Where such meta-intrusive bodies are extensively infolded with other metamorphic units, they have been described with metamorphic rocks (Chapter 3).

Previous work on subdividing the Coast Plutonic Complex has outlined a series of magmatic belts with no clear time-space distribution (Brew and Morrell, 1983; Barker *et al.,* 1986). Most plutons fall within the "Coast plutonic complex belts I and II" of Brew and Morrell (1983). These are regions underlain dominantly by (I) 45-54 Ma granodiorite and quartz monzonite and (II) mid Tertiary, Late Cretaceous and older non-migmatitic tonalite orthogneiss and weakly to nonfoliated granite.

Isolated plutons and small batholiths occur sporadically and with decreasing abundance to the far eastern limits of the Tagish map area where they intrude the Cache Creek terrane. Several intrusive episodes are recognized within each tectonostratigraphic terrane. Young intrusive episodes have affected all terranes. Some intrusions also cut associated comagmatic volcanic strata, as is well demonstrated at Teepee Peak where dating of both intrusive and extrusive rocks show them to be coeval (early Eocene) and presumably comagmatic. Similar relationships are inferred for other volcanic-intrusive associations where only the intrusive or the extrusive portion of the magmatic sequences has been dated. Close temporal ties between volcanic and plutonic events has been recognized on a Cordilleran scale (Armstrong, 1988). Likewise, the synchroneity of magmatic and metamorphic episodes is also a Cordilleran-wide phenomenon.

Magmatic Epochs and Suites

Geochronologic intervals corresponding to broad peaks of magmatic activity are herein termed *magmatic epochs*. Five major magmatic epochs encompass most plutonic and volcanic rocks of known age within the map area and adjacent parts of northwestern British Columbia and south-central Yukon (Figure 12-2). These are the Stikine (Late Triassic), Aishihik (Early to Middle Jurassic), Whitehorse (mid-Cretaceous), Carmacks (Late Cretaceous), and Sloko (Early Eocene) epochs as presented here (*cf.* Hart, 1995). Magmatic epochs within the map area can be separated into magmatic suites based upon their isotopic ages, chemistry, lithologic character and geologic setting (Figure 12-2). Discrimination of magmatic suites from age data alone is prone to error because age ranges of some protracted magmatic episodes overlap, as is demonstrated in Figure 12-3. A further complication is that isotopic ages can be skewed due to addition or removal of isotopes through post-emplacement processes (*e.g.* Ar loss in K-Ar system skews dates to younger values). Magmatic suites, both plutonic and volcanic, are distinguished within the Tagish and adjacent areas as listed in Table 12-1 and Table AA5.

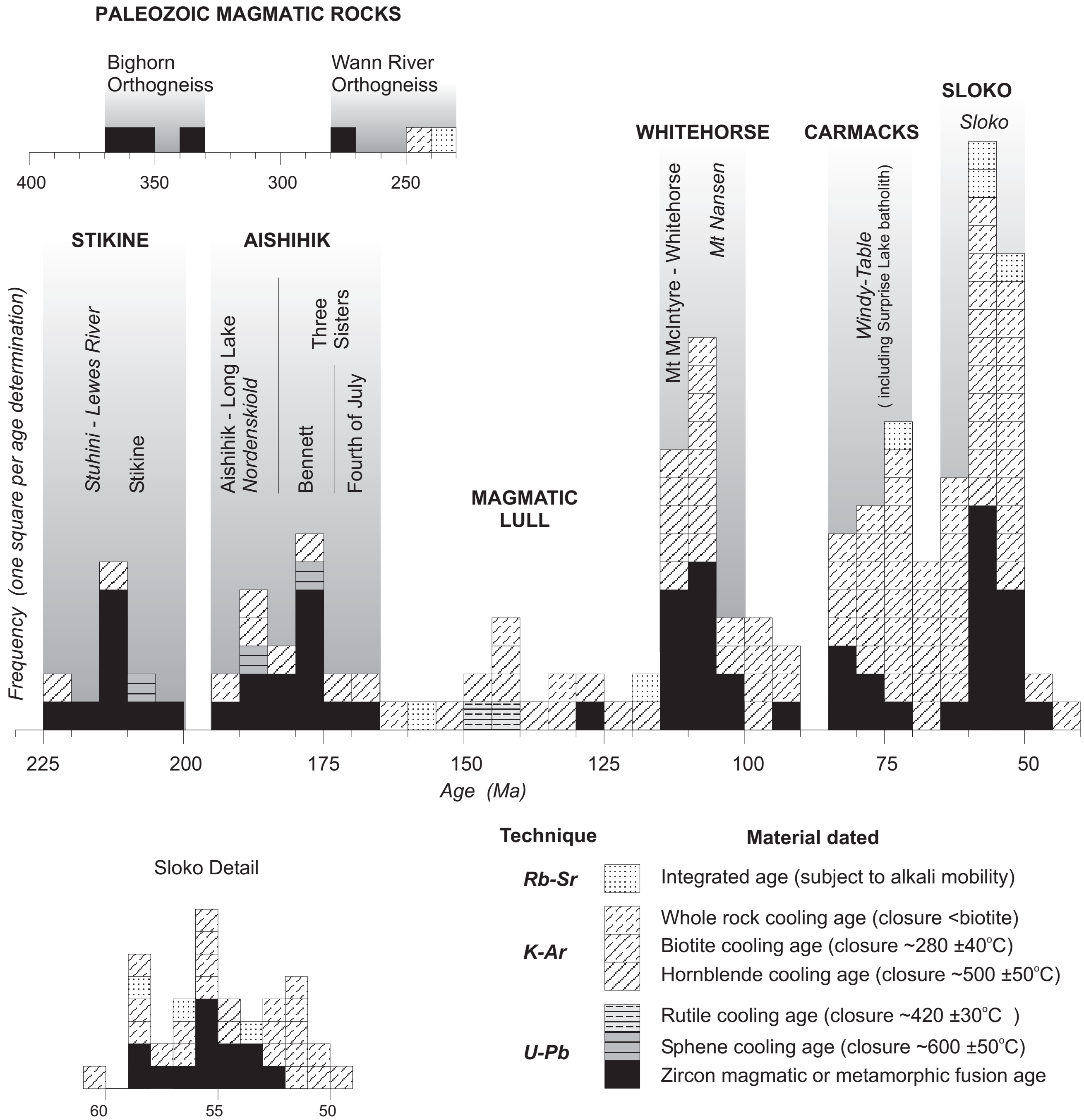


Figure 12-2. Frequency distribution of age dates from magmatic episodes in the region between Tagish Lake and Whitehorse (data from Table AA5). Each square represents one age determination that falls within a 5 m.y. interval (1 m.y. intervals are used for the expanded Sloko suite). Magmatic epochs shown by the shaded areas labeled in upper case, are subdivided into suites (volcanic suites are italicized). Closure temperatures are those recommended by Tucker *et al.* (1987) for sphene, Mezger (1989) for rutile, and Harrison *et al.* (1985) for hornblende and biotite.

Pre-existing nomenclature is applied to magmatic suites where appropriate. For example, "Carmacks Group" and "Sloko Group" are volcanic suite names that are firmly entrenched in the geological literature of the Yukon and British Columbia. They have come to imply felsic to intermediate volcanics of Late Cretaceous and Early Tertiary age ranges respectively. Current age data and field mapping in northern British Columbia and southern Yukon permits subdivision of "Carmacks Group" into suites. Nevertheless, in the broad sense these names continue to be useful field terms. Therefore, they are included in Table 12-1 as "magmatic epochs". Divi-

Table 12-1. Magmatic events within Tagish and adjacent areas.

Sloko magmatic epoch (c. 54-58 Ma, also includes Skukum Group plugs and Nisling plutonic suite in Yukon)

MAGMATIC UNIT	METHOD	AGE	OLD UNIT	NEW UNIT	REFERENCE	LOCATION
Sloko plutonic suite *(c. 54-58 Ma; comagmatic extrusives are Sloko Group, c. 55 Ma)*						
Pennington granite	K-Ar	54.9±1.9	uKg1	eESg	12	105D2
homogeneous granite	K/Ar (bt)	55.3±1.8	lKg2	eESg	1	104M8W
granodiorite-tonalite	K/Ar (bt)	55.3±1.8	KTtp	eESg	1	Teepee Pk. 104M10E
rhyolite porphyry			mlKTr	eESg		104M8W
hornblende granite			lKg1lKgh	eESg		104M8W
hornblende-biotite diorite			lKhbd	eESdi		104M8SW
granodiorite	K-Ar (bt)	56±8**	lKg2	eESg	3	Tutshi R.
biotite granite	K-Ar (bt)	58±1.1	lKR	lKgh	2	Racine Ck.
leucogranite	Rb-Sr	58.5±12	LPq		12	105D3
hornblende granodiorite			lKhgd	eESdi		Engineer Mtn.
Mt. Switzer quartz monzonite	U-Pb (zrn)	55.7±0.2	Mhs	eESy	16	104M8
Mt. Switzer hornblende diorite	U-Pb (zrn)	55.9±0.2	Ehd		16	104M8
Crozier Creek pluton	U-Pb (zrn)	60±0.6	LPqCC		12	105D3
Mount McAuley pluton	U-Pb (zrn)	53.7±0.3	eEqMM	eTqa	17	105D3, 4

Carmacks magmatic epoch (c. 64-85 Ma; includes Carcross and Wheaton River plutonic suites in Yukon)

MAGMATIC UNIT	METHOD	AGE	OLD UNIT	NEW UNIT	REFERENCE	LOCATION
Carcross plutonic suite *(c. 64-69 Ma)*						
Carcross pluton	K-Ar (bt)	64.3±2.2	PgC		8	S of Carcross -Ar loss
Carcross pluton	K-Ar (bt)	68.6±2.5	PgC		17	north end of pluton
unfoliated biotite granodiorite	K-Ar (hbl)	66±1.3	lKg		2	S Tagish Lake
granite	K-Ar (bt)	66±8**	lKg		3	WP&YRR Mile 11.9
granodiorite	K-Ar (bt)	66±8**	lKgd		3	WP&YRR mile 36.2
Windy-Table intrusive suite *(c. 70-85 Ma; includes Wheaton River plutonic suite in Yukon)*						
Surprise Lake quartz monzonite	K-Ar (bt)	71.4±2.1(ave)		lKSqm	9	Adanac showing
Surprise Lake quartz monzonite	U-Pb(zrn)	83.8±5		lKSlg	4e	104N/11
Log Cabin granite	U-Pb(zrn)	72±2[a]	lKg2	lKg2	14	Log Cabin 104M/10?
Wheaton valley pluton	U-Pb	77.1±0.7	lKgWV1		13	105D/3
Folle Mountain pluton	U-Pb	77.5±0.3	lKqF			105D2, 7
granite	K-Ar (bt)	62±8*			3	White Pass
quartz monzonite	Rb-Sr (wr)	75.9±prelim	eTqm	lKqm	4e	Atlin Mountain
rhyolite ash flow (& subvolcanic equivalents)	U/Pb (zrn)	81.3±0.3	muTPaf	lKWaf	4e	Graham Ck.,104M9E
also dated by:	Rb-Sr (wr)	72.4±2.1	muTPaf	lKWaf	7	Graham Ck.,104M9E
quartz syenite			TEqs	lKWqs		Ear and Table Mtns.
biotite-quartz-feldspar porphyryK-feldspar dacite porphyries			mJFJglTkd	lKWp		Nahlin Fault/Ear Mtn.
hornblende-feldspar porphyry			muThfp	lKWp		Graham Creek
dioritic stocks	K-Ar (hbl)	83±3	lKd	lKWd	2	Bee Peak/Sunday Peak
flow-banded rhyolite	U-Pb (zrn)	83.7±0.4	lKM2	lKWr	12	east of Windy Arm
granodiorite-tonalite			lKgdt	lKgdt		Cathedral Mountain

Whitehorse magmatic epoch (c. 90-115)

MAGMATIC UNIT	METHOD	AGE	OLD UNIT	NEW UNIT	REFERENCE	LOCATION
Late to Middle Cretaceous plutons of the Coast Plutonic Complex *(unnamed, and possible Whitehorse plutonic suite equivalents)*						
concordant granite, granodiorite	K-Ar (bt)	80.0±1.6	uKg, g2, lKg, gd	lKg2	2	S Tutshi Lk. 104M/15
biotite granite	K-Ar (bt)	84±2	uKR	lKgh	2	Racine Lk. 104M/16
biotite granite	K-Ar (bt)	92±2	uKg1	lKg1	2	Jack Pk. 104M/15
moderately altered granite	U-Pb (zrn)					104M/1
biotite-hornblende granodio.	U-Pb (zrn)					104M/1
pyroxene-hornblende diorite	K-Ar (hbl)	106±4	mKdMH?		12	Mount Hodnett
Montana Mountain pluton	U-Pb (zrn)	106.8±1.0	mKqM		12	Montana Mountain

Middle Cretaceous plutons of the Coast Plutonic Complex *(unnamed c. 120-127, 133, 145?Ma)*

hornblende-quartz diorite	K-Ar (hbl)	120±3	lKg1	lKg1	2	Ben-My-Chree 104M/8
hornblende-quartz diorite	K-Ar (bt)	123±2	lKg1b	lKg1b	2	SW of Wann R. 104M/8
muscovite-biotite granite	U-Pb (zrn)	127±0.6	lKgp	eKg	16	South Tagish
hornblende-biotite granodiorite	K-Ar (hbl)	145±4	lKgh	eKg	2	N flank Mt. Switzer
Mount Lawson tonalite *(c. 133 Ma, possibly reset)*						
hbl-rich tonalite	K-Ar (hbl)	133±3	eKt1	eKt1	2	Lawson Mtn.

Aishihik magmatic epoch (c. 165-178Ma)

MAGMATIC UNIT	METHOD	AGE	OLD UNIT	NEW UNIT	REFERENCE	LOCATION
Fourth of July plutonic suite *(c. 165.5-172 Ma, intrudes outboard edge of Cache Creek Terrane and adjacent Whitehorse Trough)*						
granodiorite	K-Ar (hbl)	110±4 reset			9	NE of Molly Lake
biotite granite	K-Ar (bt)	167±3			5	7.8 km SE of Atlin
diorite dike	U-Pb (zrn)	167		mJTg	4	104N12
quartz diorite	U-Pb (zrn)	170.4±5.1		mJTd	4e	104N13
quartz syenite	U-Pb (zrn)	171.5±3.4		mJTg	4e	104N12
Bennett plutonic suite *(c. 144-150 Ma reset? from c. 178-175, intrudes Nisling Assemblage and western Stikinia)*						
granodiorite boulder	K-Ar (hbl)	144±5 reset	in lJL		17	near Takhini
hornblendite	K-Ar (hbl)	150±6	PPM	DTBp	4a	W of Bennett Lk. 104M15
altered granodiorite	U-Pb (zrn)	175.8+5-3	PTgd	MTgd	4c	104M15
Aishihik suite *(181-191 Ma; includes Tagish Lake Suite of Currie, 1994; intrudes Nisling Assemblage and western Stikinia)*						
plagioclase-hornblende gneiss	K-Ar (hbl)	170±3 reset	PPMH	eJAgd	2	Holly Head
granodiorite	U-Pb (zrn)	185±1	PPMH	eJAgd	16	Hale Mountain
Hale Mountain pegmatite	U/Pb (zrn)	178.8±0.9	PPmh	eJAgd	4d	Mt. Switzer
granodiorite	K-Ar (hbl)	185±5	in lJL		2	Boulder in Inklin
hornblendite	K-Ar (hbl)	187±7	JKh	eJKh	4b	Teepee Pk. 104M10E
lamprophyre	K/Ar (bt)	183.6±3			2	south-most lTgd
quartz monzodiorite	U-Pb (zrn)	180.9±3.1	lJMCqm	eJAq	16	Mount Caplice 104M1
quartz monzodiorite	U-Pb (ti)	177.0±0.6	lJMCqm	eJAq	16	Mount Caplice 104M1
quartz syenite	U-Pb (zrn)	189.5±3	lJHqs	eJAg	16	W of Hoboe Ck. 104M1
quartz syenite	U-Pb (ti)	186.5±0.4	lJHqs	eJAg	16	W of Hoboe Ck. 104M1
folded tonalite dike	U-Pb (zrn)	191±1			16	W of Hoboe Gl. 104M1

Stikine plutonic suite (c. 208-220 Ma, roots of the Stuhini arc complex)

MAGMATIC UNIT	METHOD	AGE	OLD UNIT	NEW UNIT	REFERENCE	LOCATION
porphyritic granodiorite	K-Ar (hbl)	178±4 reset	lTgd	lTgd	2	Willison Bay (reset)
porphyritic granodiorite	K-Ar (hbl)	220±5	lTgd	lTgd	2	Willison Bay 104M8
Willison Bay leucogabbro	U-Pb (zrn)	216.7±4	lTgd	lTgd	4f	Willison Bay 104M1
leucogabbro	U-Pb (zrn)	214±1	Tb		17	Tally Ho Mtn. 105D3

Cache Creek veritextured gabbro (c. 340?Ma, not dated within map area)

METHOD Mineral abbreviations: act = actinolite; amph = amphibole; bt = biotite; hbl = hornblende; pyx = pyroxene; ser = sericite; wr = whole rock, zrn = zircon.

OLD UNIT: in Tagish map area: Open File maps of Mihalynuk and Rouse, 1988; Mihalynuk *et al*., 1989; Mihalynuk *et al*., 1990; Mihalynuk *et al*., 1992; and Currie, 1994. In Yukon: Hart and Radloff, 1990.

NEW UNIT: in Tagish map area on Figure GM97-1, adjacent to Tagish area in Mihalynuk *et al*., 1996.

REFERENCE for age data: 1 = J.E.Harakal, University of British Columbia ; 2 = T. Bultman and D. Seidmann, Yale University; 3 = GSC ; 4 = University of British Columbia [4a J. Harakal, Table AA3; 4b J. Harakal and D. Runkle, Table AA3; 4c D.C. Murphy and J.E. Gabites, Table AA2; 4d J.E. Gabites, Table AA2; 4e J.E. Gabites *in* Mihalynuk *et al*., 1992; 4f J.E. Gabites *in* Mihalynuk *et al*., 1997; 4g J.E. Gabites *in* Mihalynuk *et al*., 1999; 4h J. Harakal *in* Mihalynuk *et al*., 1999]; 5 =Geological Survey of Canada, Paper 88-2; 6 = M. Lambert and M. Safiquillah, Carleton; 7 = H. Grond *et al*., 1982, UBC; 8 = Morrison *et al*., 1979; 9 = Christopher and Pinsent, 1982; 10 = Doherty and Hart, 1988; 11 = Pride and Clark, 1985; 12 = Hart and Pelletier, 1989; 13 = Hart and Radloff, 1990; 14 = Barker *et al*., 1986; 15 = Anderson, 1989; 16 = Currie, 1994; 17 = Hart, 1995; 18 = Mihalynuk *et al*., 1999.

** = low K and Ar content, analyses may be unreliable.

[a] =age is average of reported $^{206}Pb/^{238}U$ and $^{207}Pb/^{235}U$ ages, error estimate is reported as "precision".

sion of suites in Table 12-1 relies heavily upon published and unpublished data of Hart and Radloff (1990) and Hart (1995).

Pre-existing nomenclature has been abandoned or redefined where new data show it to be inappropriate and/or confusing. For example, the “Bennett suite” was used by Woodsworth *et al.* (1991) to encompass all plutons of northern British Columbia and Yukon Territory believed to be of Tertiary age. More recent age dating of these plutons show that they range from Early Jurassic to Eocene age, and the name is herein restricted to plutons of 175 - 178 Ma after the recommendation of Hart (1995).

Nomenclature recommended here breaks the tradition of using distinct names for plutonic and volcanic suites when they fulfill two criteria: they are demonstrably comagmatic; and they are newly recognized or in need of significant revision. Such is the case for both the Sloko and Windy-Table volcanic and plutonic suites. This usage helps to control the expanding number of magmatic suite names. Comagmatic volcanic and plutonic suites that are well defined with names firmly entrenched are retained here. For example, Stuhini Group and the comagmatic Stikine plutonic suite.

Varitextured gabbro (MTrGg <340, >172 Ma)

Varitextured gabbro occurs at Graham Inlet (Figure 6-1) where it has been mapped as part of the Graham Creek Igneous suite (Figure GM97-1). Lithologically identical rock may occur in the interiors of adjacent massive pillows or flows, an indication that they may be comagmatic. Infilled miarolitic cavities confirm a very shallow level of intrusion. Gabbro also crops out on the west side of Atlin Lake, 5 kilometres south of the mouth of Atlin River, apparently as a tectonic lens enclosed by Cache Creek lithologies.

Petrographically, varitextured gabbro is comprised of strongly sericite and calcite-altered plagioclase (about 60%), net-texture amphibole (25%), serpentinized olivine (15%), and sparse calcite-actinolite-altered clinopyroxene relicts (less than 5%). Olivine and pyroxene are mantled by two phases of amphibole (Photo 12-1). Apatite comprises less than one percent subhedral to euhedral grains within xenomorphic feldspar and hornblende. Authigenic minerals include serpentine, clinozoisite (Photo 12-1), prehnite (Photo 12-2), white mica and calcite, indicating a sub-greenschist metamorphic grade.

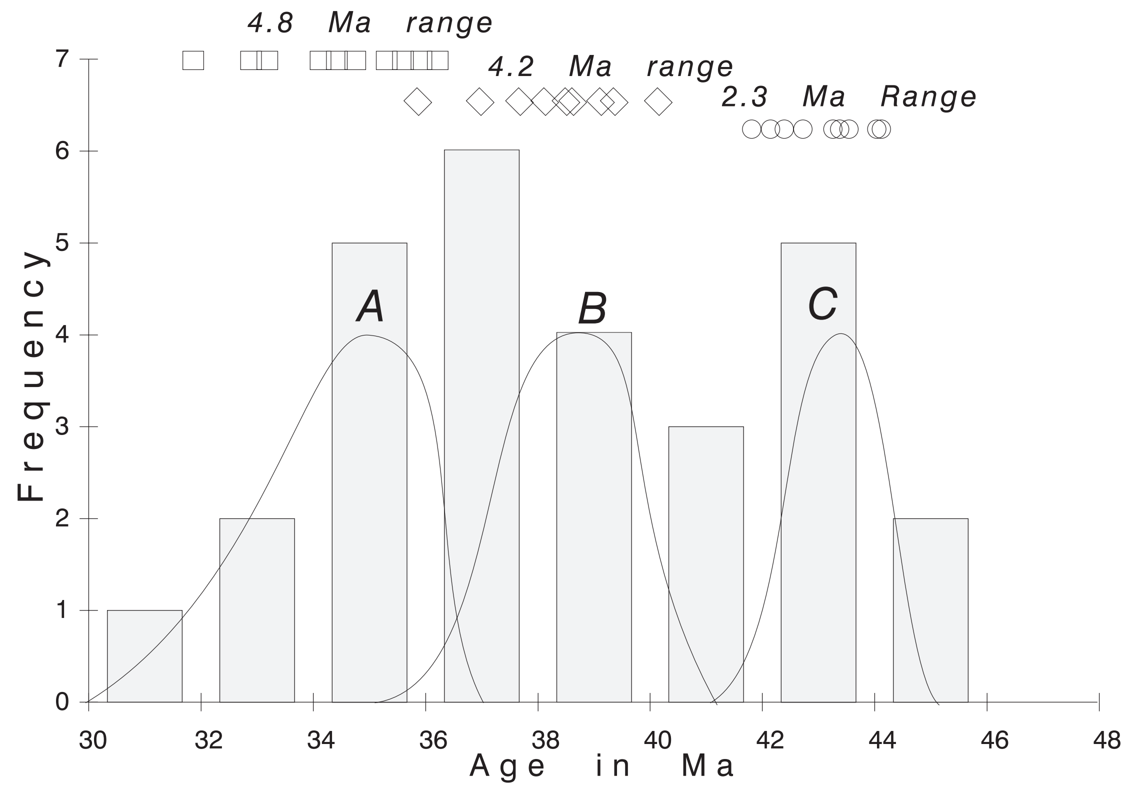


Figure 12-3. A demonstration of potentially erroneous interpretation of three magmatic episodes based upon a hypothetical age frequency distribution diagram (see text for explanation).

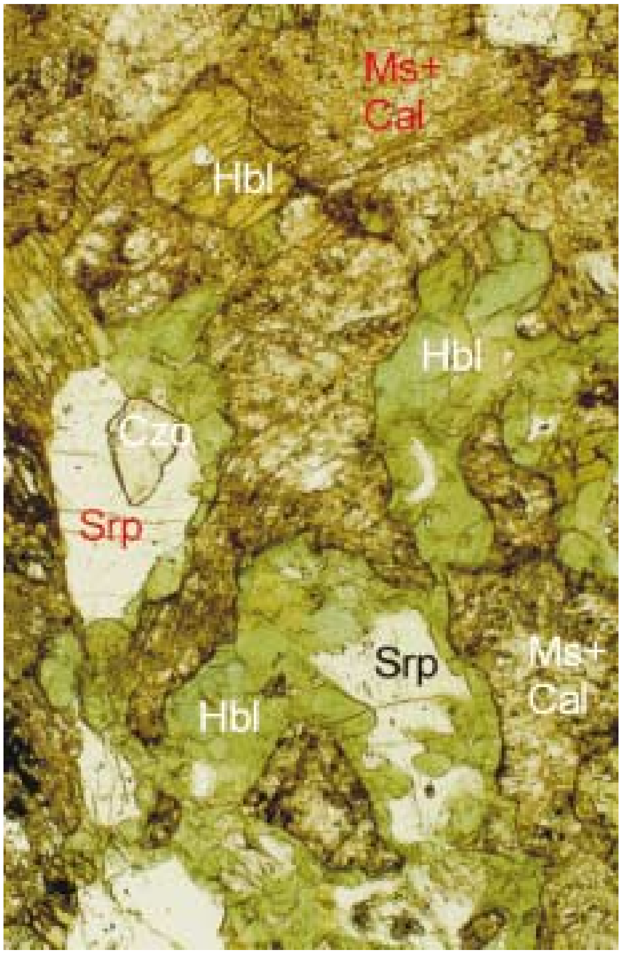


Photo 12-1. Net-texture amphibole mantling olivine, now completely replaced by serpentine (Srp) and talc (Tlc). Sparse grains of authigenic clinozoisite (Czo) are also present. Scale: height represents approximately 2.5 mm of sample MMI91-2-3, collected from the west shore of Atlin Lake.

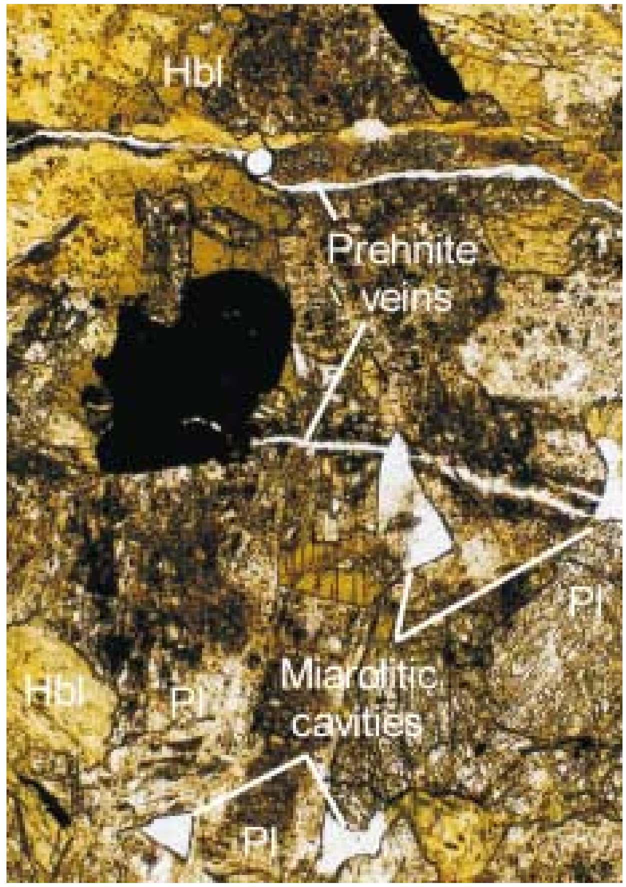


Photo 12-2. Graham Creek hornblende (Hbl) gabbro displays subidiomorphic plagioclase (Pl) crystals that border a miarolitic cavity later infilled by radiating prehnite and minor calcite. Miarolitic cavities attest to the very shallow level of intrusion. Scale: height represents approximately 2.5 mm of the sample.

Aitken (1959) originally mapped the varitextured gabbro lens on Atlin Lake as part of the Fourth of July suite. However, it can be distinguished from Fourth of July mafic phases petrographically: the latter are quartz dioritic in composition and display a different petrogenesis. Fourth of July batholith is not known to contain olivine, and hornblende growth does not appear to be episodic. Also, apatite in Fourth of July intrusive phases occurs as abundant euhedral prisms which may also contain other euhedral minerals such as feldspar; it is sparse in varitextured gabbro samples.

Varitextured gabbro appears to be part of an oceanic crustal package. Pillow basalts with rare earth element abundances indicative of formation in a mid-ocean ridge setting (Mihalynuk *et al.*, 1991; Figure 6-3) are most reasonably interpreted as comagmatic. If these indications are correct, then the gabbro presents an opportunity to date the oceanic crustal package, particularly since zircon, petrographically visible as inclusions in hornblende

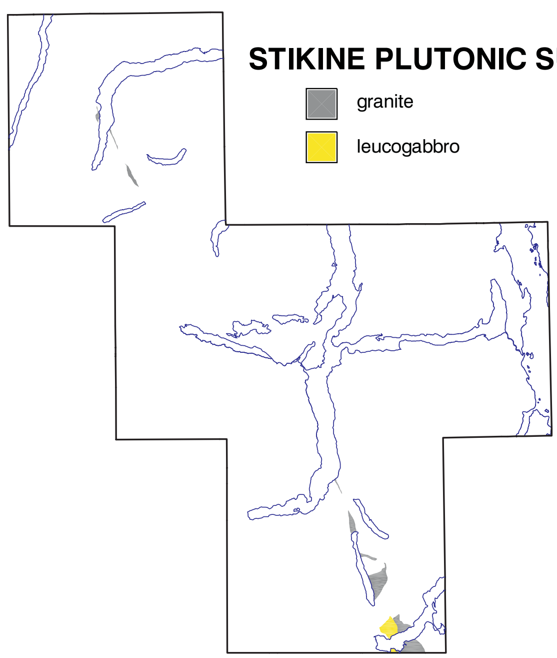


Figure 12-4. Distribution of Stikine plutonic suite plutons and potentially coeval bodies in the Tagish Lake area.

crystals, could be yield a magmatic U-Pb isotopic age determination. However, at this point the age can only be loosely constrained if it is assumed that the vetritextured gabbro on Atlin Lake correlates with the Graham Creek gabbro. If this is the case, then the age must be younger than the Carboniferous age of similarly metamorphosed host rocks, and older than the Middle Jurassic Fourth of July batholith which cuts and thermally overprints the host rocks. It is equally possible that the Graham Creek gabbro is not part of the Cache Creek terrane but rather forearc basement related to Stikine terrane - as discussed in Chapters 6 and 15.

Stikine Magmatic Epoch (200 - 225 Ma)

Late Triassic to Early Jurassic plutons that intrude Stikine and Yukon-Tanana Terranes in southwest Yukon were collectively known as the Klotassin suite (Wheeler, 1987) after the Klotassin batholith in the Snag area (Tempelman-Kluit, 1974). However, the Klotassin batholith is now known to be partly, if not entirely, of Cretaceous age (Godwin, 1975; Hart, personal communication, 1998). Because this is a potentially confusing situation, use of the term "Klotassin suite" should be discontinued. Instead, Stikine magmatic epoch is recommended because of the broad distribution of Stikine suite plutons and association of these magmatic rocks with the Stikine assemblage. As used here, it encompasses plutons emplaced during pulses of magmatism that overlap temporally and spatially within the period 200 -225 Ma.

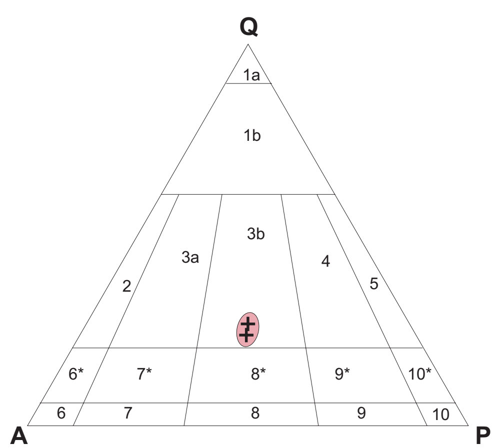


Figure 12-5. Modal mineralogy of the Willison Bay pluton shown on the quartz-alkali feldspar-plagioclase ternary plot indicates a monzogranite composition (for other fields see Table 12-2).

Table 12-2. Field label definitions of LeMaitre (1989).

1a	quartzolite
1b	quartz-rich granitoids
2	alkali feldspar granite
3a	syenogranite
3b	monzogranite
4	granodiorite
5	tonalite
6	alkali feldspar granite
6*	quartz alkali feldspar granite
7	syenite
7*	quartz syenite
8	monzonite
8*	quartz monzonite
9	monzodiorite
9*	quartz monzodiorite
10	diorite
10*	quartz diorite

Stikine Plutonic Suite (lTrgd 220-212 Ma)

Late Triassic intrusions are common in northern Stikine terrane, where they are collectively known as the Stikine plutonic suite (Anderson, 1984). They are generally cospatial with the thickest accumulations of Stuhini Group volcanic rocks, and with hornblendite and hornblende-clinopyroxenite ultramafites (Figures 12-4, GM97-1). They range from granodiorite to alkali granite (Figure 12-5, 12-6) which are weakly aluminous (Figure 12-6b) to gabbro. In the Willison Bay area they are cut by bladed plagioclase and clinopyroxene-porphyry dikes which are probable feeders to overlying Stuhini Group volcanic strata (see also Bultman, 1979). At the same locality they cut deformed pyroxene-porphyritic volcanic breccia, thought to represent an earlier (but undated) pulse of Stuhini arc construction.

Hornblende pyroxene gabbro (lTrhg >216.6 ±4 Ma)

Variably foliated gabbros occur at several localities within the Tagish map area; most are within a few kilometres east of the Llewellyn fault. Occurrences extend from the British Columbia-Yukon border to at least the southern end of Atlin Lake. Gabbros comprise portions of the Graham Creek suite and the Atlin complex in 104N/12W, but these have been affected by brittle deformation and are clearly unrelated to the Stuhini arc complex.

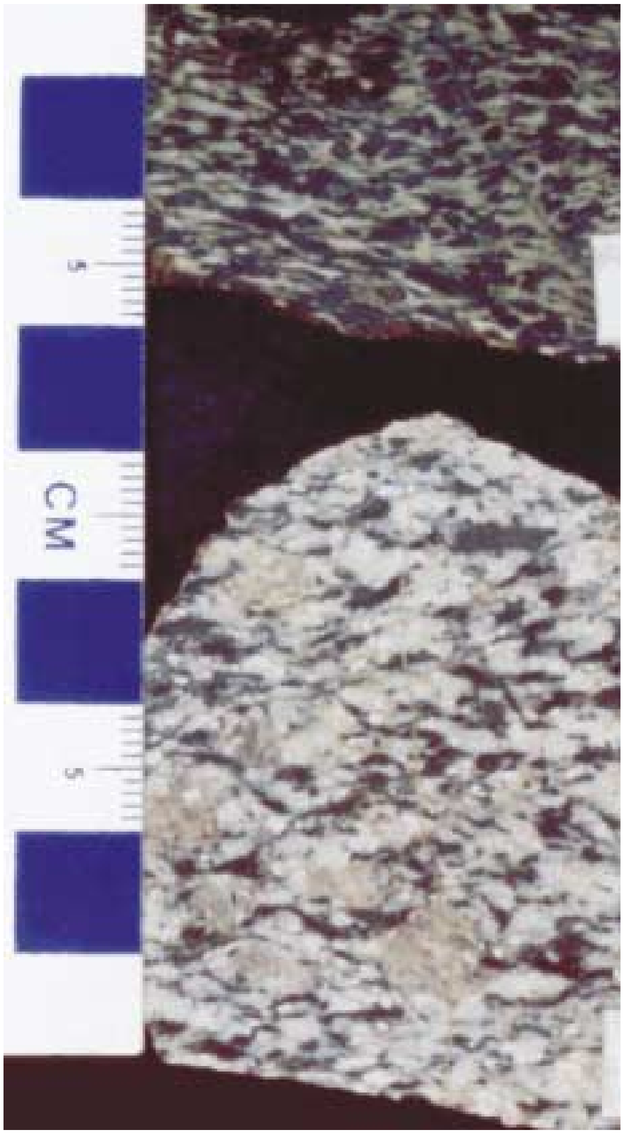


Photo 12-3. Foliated gabbro of the Late Triassic Stikine plutonic suite (top) collected from along the Llewellyn fault zone at the Yukon border. Fabrics were probably developed within the Tally-Ho shear zone, the deep ductile precursor of the Llewellyn fault. Foliated Stikine assemblage granite (bottom) cuts the gabbro where it has been isotopically dated at Willison Bay (see photos 12-4, 12-5).

Unit lTrhg rocks are red, white or green to black on the weathered surface and dark green to black on fresh surfaces. Rarely, they display primary intrusive layering with alternating chloritized pyroxene and white plagioclase-rich segregations. In some zones of strong semi-ductile shearing, the gabbro is now a medium to coarse-grained pyroxene augen gneiss with a granulated plagioclase matrix (Photos 12-3, 12-4). One of the largest gabbroic bodies varies from strongly foliated to unfoliated hornblende gabbro (pyroxene is subordinate); it underlies the southwest flank of The Cathedral. This polyphase intrusive displays a bewildering variation in grain size and degree of foliation over distances of just a few metres. Schistose zones are crosscut by less foliated material; perhaps indicating emplacement in a tectonically active zone at moderate to shallow depth. These textural and compositional variations are analogous to those displayed in border phases of the Copper Mountain (Preto, 1972), Iron Mask (Kwong, 1987) and the Hogem (Garnett, 1978) bodies within the Nicola-Takla-Stuhini belt.

Foliated hornblende gabbro must be older than 216.6 ± 4 Ma, the age of crosscutting K-feldspar megacrystic hornblende granodiorite (Willison pluton; *see* following section). In southern Yukon, U-Pb isotopic determinations from zircons of the lithologically identical Tally Ho leucogabbro yield an age of 214 ±1 Ma (Hart, 1995). Thus, unit lTrhg is considered both correlative with Tally

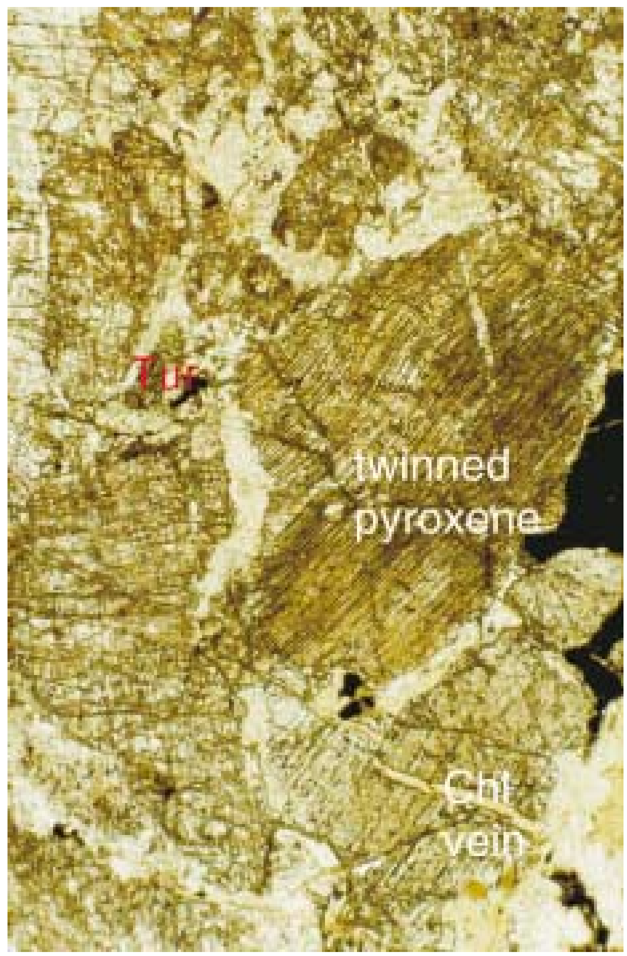


Photo 12-4. Weakly foliated leucogabbro of the Late Triassic Stikine plutonic suite. This sample occurs along the Llewellyn fault zone. Pyroxene twin lamellae are folded and the sample is cut by late prehnite - chlorite (Chl) veins with minor tourmaline (Tur). Scale: height represents approximately 2.5 mm of sample KMO89-2-3-1 collected near the north shore of Willison Bay.

Ho leucogabbro and comagmatic with the Willison pluton which cuts it (Figure 12-7).

Willison Pluton (lTrg 216.6 ±4 Ma)

Conspicuous meagacrystic granite of the Wiilson pluton and related bodies occur within, or adjacent to, the Llewellyn fault zone. The main pluton extends from 3 km north of Willison Bay to14 kilometres south of Willison Bay, where the Llewellyn Fault forms its western contact. Lenses of lithologically identical plutonic rock have been identified at five separate localities along the Llewellyn fault zone to the north (Figure 12-4; mapped as both lTgd and Mgd on Figure GM97-1).

These rocks are grey weathering, white, pink or tan on fresh surfaces, and commonly display a weak to moderate foliation (Photo 12-3). Locally foliation is intense. Potassium feldspar megacrysts up to 5 centimetres long are characteristic. Megacrysts may be weakly perthitic and commonly contain concentric zones of inclusions (Photo 12-5). In the coarsest samples, the inclusions can be identified in hand sample as plagioclase and hornblende. At its northeastern margin, near Splinter Peak, the pluton is porphyritic with 10 to 15 per cent K-feldspar megacrysts in a matrix of 60 per cent 4 millimetre tabular plagioclase phenocrysts, and 20 percent quartz eyes, all in an aphanitic grey to pink groundmass. Porphyritic clasts in volcaniclastic rocks of the Norian Stuhini Group are almost identical to this marginal phase of the Willison pluton. Presumably these clasts were eroded from the margins of the Willison Pluton when arc-related deformation caused parts of the pluton to be exhumed.

Age Data

Willison Bay pluton has yielded an isotopic K-Ar age of 220±5 Ma (hornblende, Bultman, 1979; recalculated, Table AA5) from a sample collected along the south shore of Willison Bay. U-Pb isotopic analysis of a sample collected from the ridge south of Willison Bay returns an age of 216.6 ± 4 Ma (Table 12-1; Mihalynuk *et al.*, 1997). The two ages are equivalent within the limits of error.

Just east of the age date sample localities, the granodiorite is unconformably overlain by a conglomerate that contains a large proportion of megacrystic granodiorite clasts. On the basis of fossil data (*Halobia* and conodonts) in overlying strata, these conglomerates are Carnian in age, yet geochronologic studies set the lower and upper Carnian stage boundaries at 235.0 and 223.4 Ma (Harland *et al.,* 1990). How then is the 216.6 ±4Ma Willison body emplaced, cooled, uplifted, exhumed and covered Carnian strata which are apparently at least 7 m.y. older (223.4 Ma)? One possible explanation rests in the method of creation of the 1989 Geologic Time Scale. In fact, according to Harland *et al.* (1990) there are no significant isotopic age data in the range 223 to 230.5 Ma that constrain the age of the Carnian-Norian boundary. So the interval mid point, 226 Ma, was taken to be the boundary; or, after application of chron interpolation, 223.4 Ma. Of all the Triassic stages, this boundary age estimate has the greatest error, ±8.6% or 20 Ma. Clearly, at the youngest limit of error (203.4 Ma), both the fossil and isotopic age of the Willison Bay pluton are comfortably accommodated (*cf.* Mihalynuk *et al.,* 1997, for further discussion).

Geochemistry

Modal mineralogy of the body near Willison Bay indicates a monzogranite composition when plotted on a quartz-alkali feldspar-plagioclase (QAP) diagram (Figure 12-5). Alkalis versus silica and alumina-alkali ratios indicate that the Willison pluton is calcic and weakly peraluminous (Figures 12-6a, b).

Rare earth element (REE) data obtained for four samples of the Willison- pluton(s) are shown in Appen-

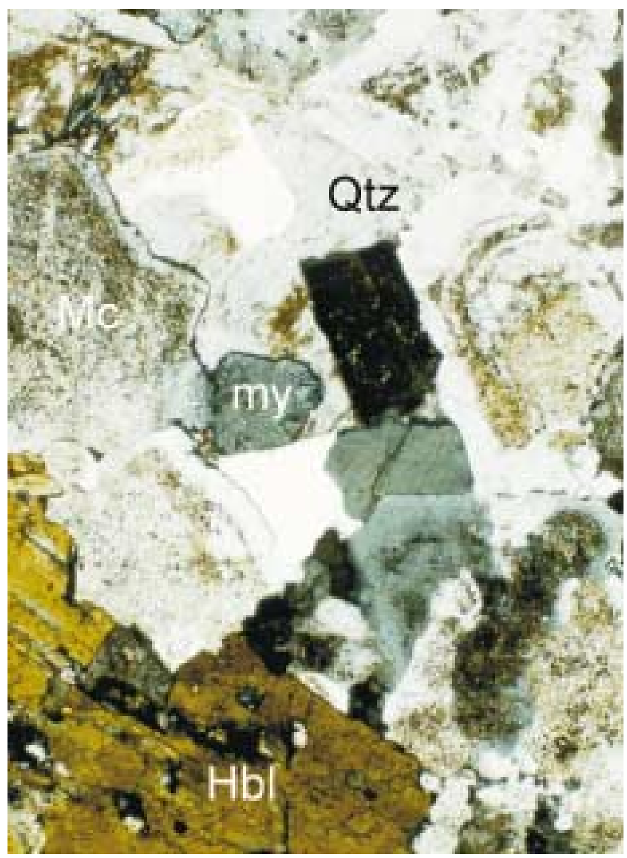


Photo 12-5. Willison Bay hornblende granodiorite typically displays well developed zoning in coarse, subidiomorphic, perthitic microcline (Mc) and myrmekitic intergrowths (my) of quartz (Qtz) and potassium feldspar. Scale: height represents approximately 2.5 mm of sample MMI89-2-2 collected near the north shore of Willison Bay.

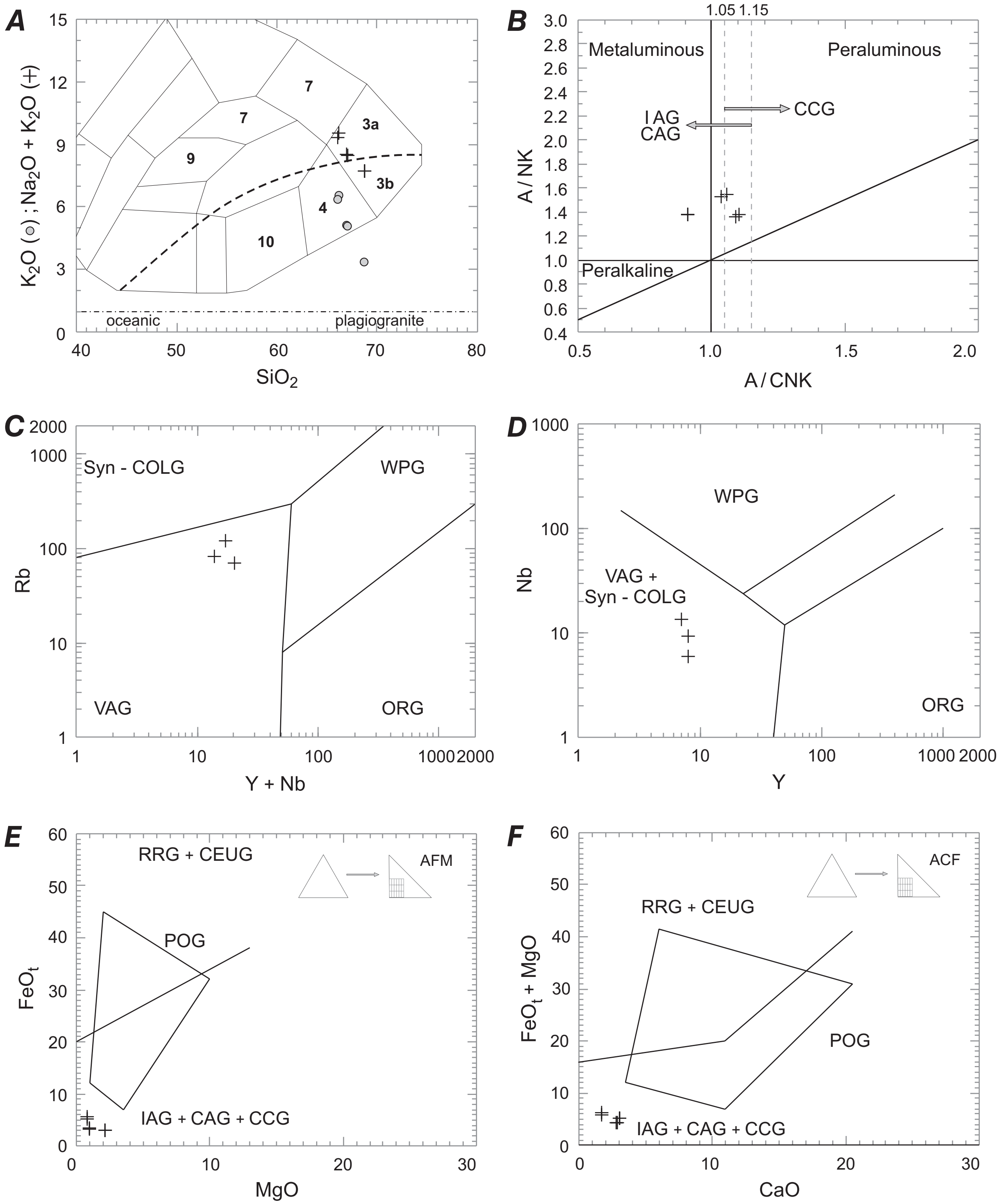


Figure 12-6. Geochemical classification of Stikine suite granitic plutons. (a) alkalis versus silica diagram with superimposed volcanic rock compositional fields of Cox *et al.* (1979) assigned compositionally equivalent plutonic names (after Wilson, 1989; field numbers correspond to those in Table 12-2) shows that the plutons fall in the granite and alkali granite fields, (b) Shand's index shows that the suite is weakly aluminous, A/NK = Al_2O_3/CaO+Na_2O+K_2O, A/CNK = Al_2O_3/CaO+Na_2O+K_2O (IAG = island arc granite, CAG = continental arc granite, CCG = continental collision granite with limits proposed by Maniar and Piccoli (1989)), (c) Rb versus Y+Nb plot after method of Pearce (1984, as is (d)) indicates a volcanic arc granite, consistent with its geological setting (WPG = within plate granite, VAG = volcanic arc granite, syn-COLG = syn-collision granite, ORG = ocean ridge granite), (d) Nb versus Y plot is consistent with plot C (indicates reliable Rb analysis), (e) and (f) are both discrimination plots where AFM and ACF space is projected into Cartesian coordinates after the method of Maniar and Piccoli (1989). The suite plots in the field of island arc (IAG), continental arc (CAG), and continental collision (CCG) granites (RRG = rift-related granite, CEUG = continental epeirogenic uplift granite, POG = post-orogenic granite).

dix Table AD2. Mid ocean ridge and ocean ridge granite-normalized plots are shown in Figure 12-7. Two of the samples overlap: MMI90-16-1 from a strongly foliated lens within the fault at Tutshi Lake, and MMI89-2-2 from east of the fault on southern Atlin Lake. A third sample, MMI89-2-5 is from a boulder of the basal conglomerate stratigraphically above sample MMI89-2-2. Both MMI90-16-1 and MMI89-2-2 were analyzed via inductively coupled plasma mass spectroscopy techniques; whereas analysis of sample MMI89-2-2 was by X-ray fluorescence (missing Pr and Gd on Figure 12-7). The XRF analysis is suspect as other samples of the analytical batch are known to have given erroneous results.

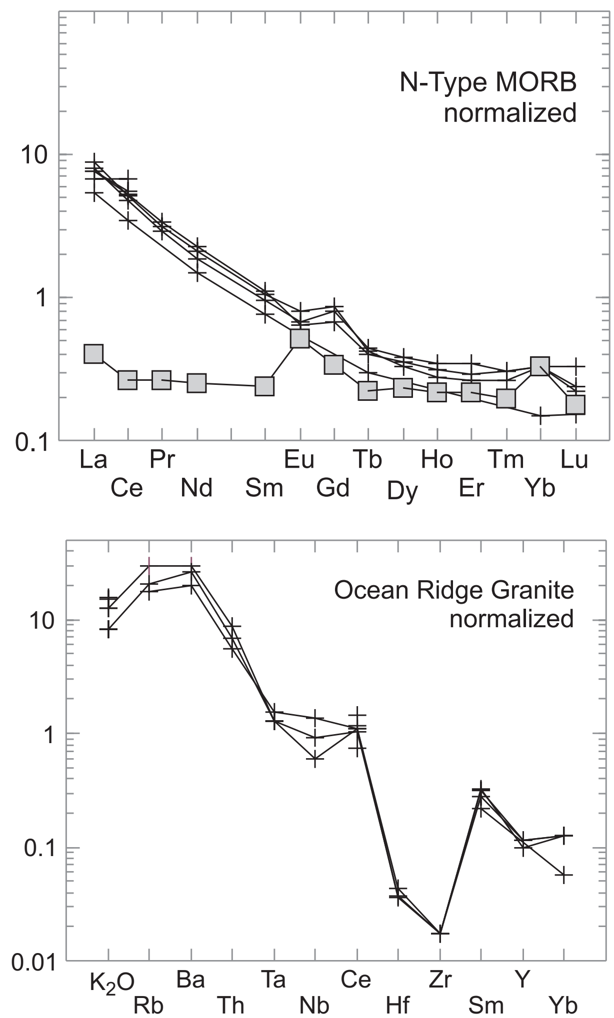


Figure 12-7. (top) Mid-ocean ridge normalized (factors of Sun and McDonough, 1989) and (bottom) ocean ridge granite normalized (factors of Pearce *et al.*, 1984) plots both show a clear arc signature for the Stikine plutonic suite, consistent with its geological setting (see text for explanation). One analysis of Stikine suite leucogabbro is shown by the shaded boxes. It is depleted in LREEs relative to Stikine granite, consistent with its origin as a pyroxene-plagioclase residual melt following extraction of the granitic magma.

Enrichment in Ba and Th, a strong overall negative slope and Hf plus Zr depletion are similar to volcanic arc and syn- or post-collisional granites (compare with Pearce *et al.*, 1984). However, geological indications of an arc environment are supported by elevated large ion lithophile elements and, in particular, a Ba/Ta of 923 to 1661 (Gill, 1981). An arc setting is also indicated by the discrimination plots of Figure 12-6 (c, d, e, f). Field observations likewise support an arc environment since the coeval Stuhini Group volcanic rocks are of arc origin and both overlie and are intruded by the pluton.

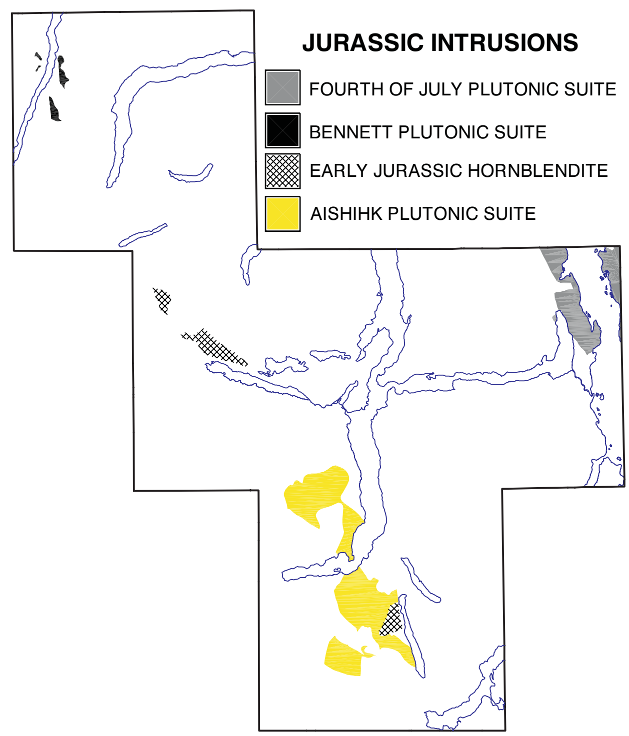


Figure 12-8. Distribution of Jurassic plutons in the Tagish area.

Aishihik Magmatic Epoch (*c.* 191 - 166 Ma)

Plutons of the Aishihik magmatic epoch were emplaced during pulses of magmatism that overlap temporally and spatially within the period 191 - 166 Ma in southwest Yukon and northwest British Columbia (Figures 12-2, 12-8). Four plutonic suites can be resolved from this broad clustering of magmatic events: Early Jurassic Aishihik - Long Lake Plutonic suites (*c.* 191 -185Ma and 186 - 178Ma); the Bennett plutonic suite (179 - 176 Ma) and the Fourth of July suite (166 - 172

Ma). Hart (1995) has shown that in the Yukon, the Aishihik and Bennett suites have the following age limits, respectively: 192 - 185 Ma, 178 - 175 Ma.

Aishihik suite (eJA 191-185 Ma)

A suite of foliated, early Jurassic hornblende-biotite granodiorite to diorite bodies are coincident with the western margin of Stikinia (*sesu lato*) in southwestern Yukon. They are interpreted as either having been structurally emplaced over the pericratonic Nisling assemblage as sheets along west verging thrusts (Wheeler and McFeely, 1991), or intrusive into the Nisling assemblage (Johnston, 1993). They are most thoroughly described in the Aishihik Lake area by Johnston (1993) and Johnston and Erdmer (1996) and are there named the Aishihik plutonic suite. This nomenclature has herein been extended to the Bennett map area to include the Hale Mountain granodiorite which is nearly identical to the well documented intrusions. These bodies were originally thought to be Late Triassic in age, but more recent higher precision isotopic dating now indicates an Early Jurassic age (Johnston, 1993; Currie, 1991). Hornblendite bodies of the Tagish area have terrane relations similar to those of coeval bodies within the suite, and are included with the suite on this basis.

Hornblendite (eJh 187 Ma)

Black, epidote-feldspar-veined hornblendite forms an elongate, structurally concordant body at Teepee Peak (Mihalynuk *et al.*, 1989b) where it intrudes and assimilates metamorphic rocks of the Boundary Ranges suite. A similar body also occurs west of Nelson Lake where it is less well defined (Mihalynuk *et al.*, 1989b) and another occurs west of Bennett Lake where it is more homogeneous, medium to coarse-grained and green in colour (actinolitic?); it might not be correlative.

Hornblendite bodies are non-homogenous, very coarse to fine-grained hornblendite to hornblende gabbro or hornblende diorite in which multiple intrusive/cannibalistic events preceded final emplacement. Thermal halos associated with these bodies are wide, in some cases hornfelsing country rocks over 1 kilometre from the main body. Intense hornfelsing produces a ‘dioritized’ country rock in which feldspar and actinolite clots produce a medium to fine-grained igneous-looking texture that is commonly crosscut by a plexus of irregular, chlorite and actinolite veinlets and clots. This recrystallization and assimilation is selective, with more refractory units, such as carbonate bands, preserved at the margins and for several hundred metres inside the body of hornfels. Where the northern contact of the largest hornblendite body (just north of Fantail Lake) cuts serpentinite, a hackley red-weathering, carbonate-altered zone results. The zone is thoroughly invaded with sub-centimetre quartz veinlets to produce a highly indurated and tough rock.

Age and Correlation

Mihalynuk and Rouse (1988b) Mihalynuk et al. (1989b) originally mapped the bodies as Jura-Cretaceous, but a sample of fresh black hornblendite collected at Teepee Peak returned a K-Ar cooling age of 187 ±7Ma (early Jurassic; Tables AA1 and AA3). A K-Ar cooling age of 150±6 Ma (Mihalynuk *et al.*, 1989a) was obtained from green hornblendite collected west of Bennett Lake near the British Columbia - Yukon border. Since this sample locality is near a large, probable Late Cretaceous intrusive mass to the west, thermally induced argon loss has probably occurred; thus this age should be regarded as a minimum protolith age.

Just west of Nelson Lake, unfoliated hornblendite crosscuts foliated Hale Mountain granodiorite. This hornblendite is very similar to the Teepee Peak body and is assumed to be coeval. If this is true, then the non-foliated nature of the body places limits on the age of the latest pervasive foliation which affects enclosing rocks. Either the deformation is older than 180 Ma (the youngest limit of error for the K-Ar age) or deformation did not affect the competent hornblendite.

Blocks of the Teepee hornblendite are included in basal portions of the volcanic strata at Teepee Peak, necessitating a post 194Ma (187 ±7Ma) age for the volcanics (isotopic data presented here for the volcanics at Teepee Peak show that it is of Eocene age, see “Sloko Group” above).

Teepee Peak pyroxenite dikes (185 Ma?)

Northwest-trending, structurally concordant pyroxenite dikes intrude rocks of the Boundary Ranges metamorphic suite near Teepee Peak (too small to show on Figure GM97-1). They pinch and swell along their length and range up to at least 25 metres thick; one intermittently exposed body may be more than 120 metres thick. An internal fabric mimics the dominant foliation of the enclosing metamorphic rocks.

A diagnostic characteristic of the dikes is their exceedingly tough, dense nature, which gives rise to a high-pitched ringing when they are struck with a hammer. They are charcoal grey, and reddish weathering. Typical dike composition is: 85% medium-grained pyroxene, about 10% magnetite and 0 to 7% phlogopite. All minerals appear unaltered.

The age of the dikes has not been directly determined, but because they crosscut the thermal aureole around the hornblendite (eJSh), they must be younger than 187 Ma. They are probable late stage intrusions related to the hornblende ultramafite event - perhaps following cooling of the hornblendite at about 185 to 181 Ma.

Hale Mountain granodiorite (eJAgd 185 Ma)

Strongly foliated Hale Mountain granodiorite forms resistant, steeply jointed exposures that are easily distinguished from adjacent schists or younger intrusions at the southern end of Tagish Lake. It is white to grey on weathered or fresh surfaces. One of its most characteristic features is the presence of fine to medium, equant epidote grains and groups of grains comprising up to 5% of the rock. Hornblende is always present and typically, although not universally, is more abundant than biotite, occurring as consistently aligned crystals up to 2.5 centimetres long, and comprising as much as 30% of the rock (Photo 3-6, also in outcrop Photos 13-8a-d). Plagioclase normally occurs as oval grains less than 1 centimetre in diameter, but may also have a pronounced augen shape. Locally K-feldspar augen up to 3.5 centimetres long are well displayed. Feldspar augen rarely have a distinct asymmetry, but when they do, it is generally consistent with a top-to-the-south sense of motion (*see* Chapter 13).

A mainly medium-grained, nematoblastic texture commonly accompanies a strong, nearly flat foliation. Melanocratic layers composed of hornblende and biotite are generally boudined or rodded with rods aligned parallel to the north northwest mineral lineation. Locally, coarse-grained leucocratic zones can be nearly devoid of mafic minerals except for sparse, coarse hornblende.

Age and isotopic geochemistry

U-Pb zircon data indicate that the granodiorite is Early Jurassic in age (185 ±1Ma; Currie, 1994). Equivalent Aishihik suite granitoid rocks in the Yukon yield a similar age (187.0 +9.7/-0.9Ma, Johnston, 1993). Clasts of Aishihik granodiorite are common within the Laberge Group of southern Atlin Lake (Johannson, 1994) and of the Yukon (Tempelman-Kluit, 1974). Similar clasts can be found in Upper Triassic conglomerates (Mihalynuk and Mountjoy, 1990), but despite their similarity, must be derived from an older source.

Hale Mountain granodiorite from the map area yields an initial strontium value of 0.7052 (Werner, 1977 *in* Currie, 1992), an indication that significant amounts of old radiogenic crust were not assimilated during intrusion of the body.

Hale Mountain pegmatite (Long Lake suite 181-179 Ma)

White pegmatitic to aplitic dikes either cut across, or are ductily deformed with, the Hale Mountain granodiorite. They are composed of variable amounts of quartz, plagioclase and alkali-feldspar. Locally, authigenic epidote comprises up to a few percent of the rock. In general, the dikes are between 2 and 40 centimetres thick, although one pegmatite-flooded breccia zone near Mount Switzer covers a zone 120 metres across.

Most pegmatite dikes are extensively cut by brittle fractures which are oriented north-northeast to northwest. The fractures are chlorite-epidote-lined and most display dextral offset in the 1 to 50 centimetre range. Locally the pegmatite intrudes along the same fractures that offset it. Such instances indicate that pegmatite injection was synchronous with late brittle deformation. Indeed, it would seem that pegmatite injection began before ductile deformation of the Hale Mountain granodiorite ceased, and continued at least until the initial stages of brittle deformation of the granodiorite. A new U-Pb isotopic age determination on zircons from a pegmatite accompanying late brittle deformation yielded 178.9 ±0.9Ma. This age is important to the structural interpretation of the area. Full implications of these structural age relations are addressed further in Chapters 13 and 15. In the Yukon, mainly non-foliated, high-level, pink quartz monzonite of the Long Lake suite cuts and locally grades into strongly foliated, deep-level, Aishihik suite quartz diorite. Both yield U-Pb ages of about 186 Ma (Johnston, 1993). Similar relationships are displayed between the Hale Mountain granodiorite and Hale Mountain pegmatite, although the Hale Mountain pegmatites clearly postdates the granodiorite. Both the pegmaitites and the 181 Ma (Currie, 1994) quartz monzodioritic Mount Caplice pluton are included with the Long Lake suite.

Three Sisters suite (179-166 Ma)

The regionally extensive Three Sisters plutonic suite of Woodsworth *et al.* (1991) generally includes calc-alkaline, felsic plutons ranging in age from 186 - 150 Ma, but most are dated by K-Ar and U-Pb methods at around 170 Ma. Because temporal limits of the Three Sisters plutonic suite overlap several suites within the Aishihik magmatic epoch, the name is not applied here as suggested by Woodsworth *et al.*, but is applied to much more temporally restricted late syn- to post-accretionary calc-alkaline intrusions that fall in the age range of 178 - 166 Ma. Used in this way in northern British Columbia and southwest Yukon, it includes two plutonic suites: the Fourth of July Plutonic suite (173 - 166 Ma) and the Bennett plutonic suite (178 - 175 Ma).

Bennett Plutonic Suite (eJgd 178 - 175 Ma)

Late synkinematic plutons of the Bennett plutonic suite are well represented in the Yukon (Hart and Radloff, 1990; Hart, 1995), but are limited to four small bodies,

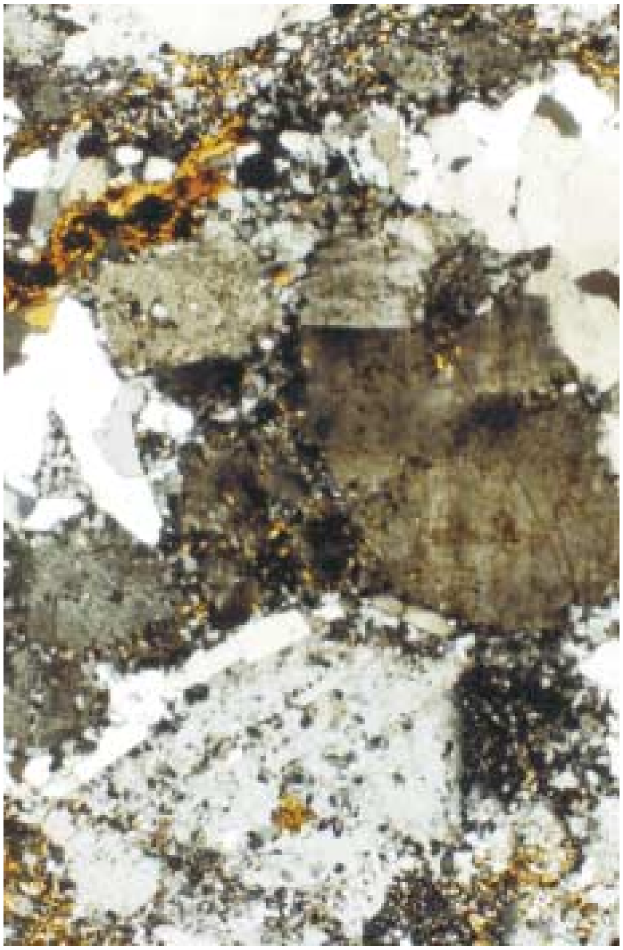


Photo 12-6. Bennett suite granite displays a pervasive cataclasis with secondary biotite developed along permeable zones of mortar texture quartz. This sample has been silicified and primary mafic minerals have been destroyed. Scale: height represents approximately 2.5 mm of sample MMI87 40-4 collected in western Paddy Pass.

all within a few kilometres of Bennett Lake in British Columbia. A characteristic of the Bennett suite in Yukon and British Columbia is compositional variability that is displayed over a few tens of metres with changes from diorite to granite, and the relationships between these phases suggests multiple intrusive pulses. Typically the bodies are comprised of less than 10% quartz; 40% plagioclase and subequal or subordinate potassium feldspar that commonly forms megacrysts 2 cm or more in diameter with diffuse borders. Mafic minerals are totally altered; relicts are chlorite-actinolite smears at the grain boundaries of felsic minerals.

The Largest and most southerly of these bodies is a 3 km by 1 km body of silicified granodiorite located in Paddy Pass. It is a cataclasite that demonstrates silica and potassium metasomatism as both quartz and fine grained biotite mend the broken fabric of the rock (Photo 12-6).

Intrusive contacts are displayed with adjacent Boundary Ranges metamorphic suite rocks. At some localities contacts appears chilled. At two localities, Laberge Group strata sit unconformably atop separate Bennett plutons and at the contact is a foliated conglomerate comprised dominantly of clasts of mylonitic plutonic rocks. Where first encountered, northeast of Pavey, the contact was mapped as a detachment fault, but this was later discounted because the pluton in Paddy Pass displays a regolith-like upper contact with the spaces between large askew blocks of intrusion infiltrated by Laberge sediment.

Isotopic Age and Implications

If the Bennett plutons are overlain by Laberge Group strata, they must be Early Jurassic or older. A sample

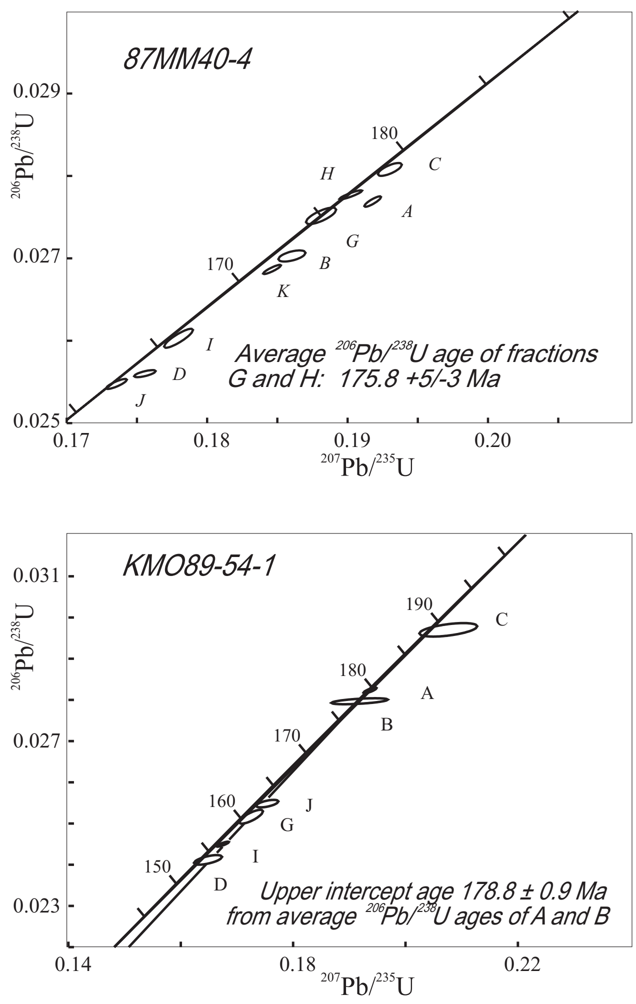


Figure 12-9. Concordia plot for U-Pb zircon age determinations of (a) K-feldspar megacrystic granodiorite at Bennett Lake, and (b) pegmatite dikes that cut Hale Mountain granodiorite near Mount Switzer. Analyses by

(MMI87-40-4) was collected from the Paddy Pass body for isotopic age dating which would test this age relationship. Zircons separated from the sample were clear, colourless, doubly terminated prisms. Two populations were present; long thin crystals, and multifaceted lozenge-shaped crystals. Clear fluid inclusions were present in some of the zircons. Nine fractions were analysed; all plot near concordia between 160 Ma and 180 Ma (Figure 12-8; Table AA2). Most of the fractions exhibit either a small amount of inherited old zircon or some lead loss, or possibly a combination. Two fractions, G and H, are essentially concordant, although even these may contain a small amount of old zircon. A best estimate of the age of the rock is 175.8 +5/-3 Ma, given by the mean of the $^{206}Pb/^{238}U$ ages of the two most concordant. The errors quoted are a conservative estimate to reflect the fact that the two fractions do not overlap each other.

This age provides constraints on the depositional age of Laberge Group strata which are interpreted to be deposited non-conformably atop the body in Paddy Pass. The isotopic age of the body corresponds with the middle of the Aalenian stage according to the Jurassic time scale of Pálfy *et al.* (1998). Assuming that the isotopic age is correct, the strata deposited atop the pluton are necessarily of Aalenian or younger age. Laberge Group strata of this age are known from the Tulsequah area (Mihalynuk *et al.*, 1995) where they range up to Bajocian in age, but strata this young have not been previously recorded in the Tagish area. Both the age of the Paddy Pass body and the age of overlying strata need to be confirmed before this relationship is considered in regional interpretations.

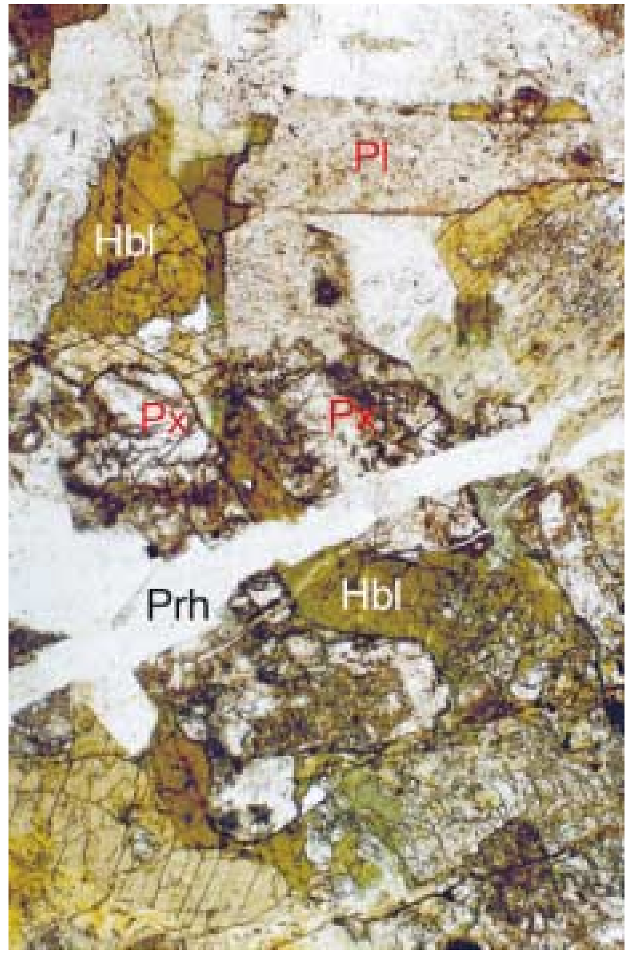


Photo 12-7. Photomicrograph of hypidiomorphic granite of the Fourth of July batholith. Note especially the characteristic pyroxene nuclei (Px) within hornblende grains (Hbl). Plagioclase (Pl) is turbid and the sample is cut by a prehnite vein (Prh). Scale: height represents approximately 2.5 mm of sample.

Fourth of July batholith (mJTg 173-165.5 Ma)

Middle Jurassic intrusions cut both the northern Cache Creek and Stikine terranes. One of the largest of these bodies is the Fourth of July batholith. The Mount McMaster stock southeast of Atlin is compositionally and texturally similar to the Fourth of July and is believed to be the same age (Mihalynuk *et al.*, 1992a). In the Dease Lake area, near Tachilta Lakes, plutons of the same age cut west-verging structures thought to be related to the emplacement of the Cache Creek terrane (*c.* 173 Ma; Stevens *et al.,* 1982). South of the northern Cache Creek Terrane, a series of coeval granitoid bodies form a diffuse zone that extends around the northern margin of the Bowser Basin (Anderson, 1984) from the Cry Lake area in the east to the Stikine River area in the west (Brown and Greig, 1990) where they appear comagmatic with recently recognized volcanic strata.

The Fourth of July Batholith is a heterogeneous, polyphase intrusive suite of middle Jurassic age (Bajocian). It underlies an area of approximately 650 square kilometres north of the townsite of Atlin; just over a tenth of this area falls inside the area mapped as part of this study (104N/12W). Originally called the Fourth of

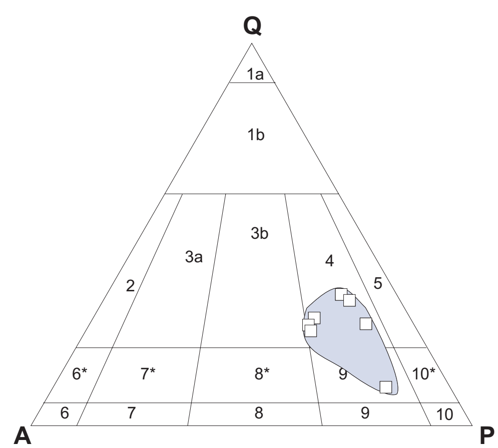


Figure 12-10. Mesonormative plot showing compositions of major intrusive phases within the Fourth of July batholith. Fields 4 and 9* are granodiorite and quartz monzonite respectively (for other fields see Table 12-2).

July Creek batholith by Aitken (1959) who described it fully, most recent workers refer to it as the Fourth of July batholith (e.g. Bloodgood and Bellefontaine, 1990). Features particular to the Atlin map area (104N12W) are discussed in Mihalynuk *et al.* (1991).

Fourth of July intrusives range from lamprophyric to granitic composition, and are distinguished by the presence of pyroxene-cored hornblende (Photo 12-7) and large, pink K feldspar megacrysts in many areas. Mineralogical and textural zoning is apparent, with varying abundances of biotite, hornblende and potassium feldspar megacrysts being most conspicuous (Photo 12-8). Pink granodiorite, granite and monzonite are the most common phases (Figures 12-10, 12-11). Zoning is particularly evident near the margins of the batholith; mimicking the type of zonation that is seen on a more regional scale (*cf.* Aitken, 1959, for a more comprehensive overview).

The batholith is generally non-foliated, and cuts accretion-related regional penetrative deformation and metamorphism of the Atlin Complex. Map units in the Fourth of July Batholith are described following, however, there is considerable compositional overlap between some units due to unit heterogeneity down to the outcrop scale. Such heterogeneity is particularly evident within the border phase (Photo 12-9).

Biotite-Hornblende Granite (mJTg1)

Equigranular, medium grained crystalline granite (locally quartz monzonite) comprises this unit. It is medium to light grey on fresh surface and commonly weathers pink. Dark brown biotite and dark green to black pyroxene-cored hornblende comprise from 5 to 15% of the rock, in roughly equal amounts.

Photo 12-8. A cumulate within the Fourth of July batholith is crowded with potassium feldspar megacrysts. Note the pronounced crystal zoning.

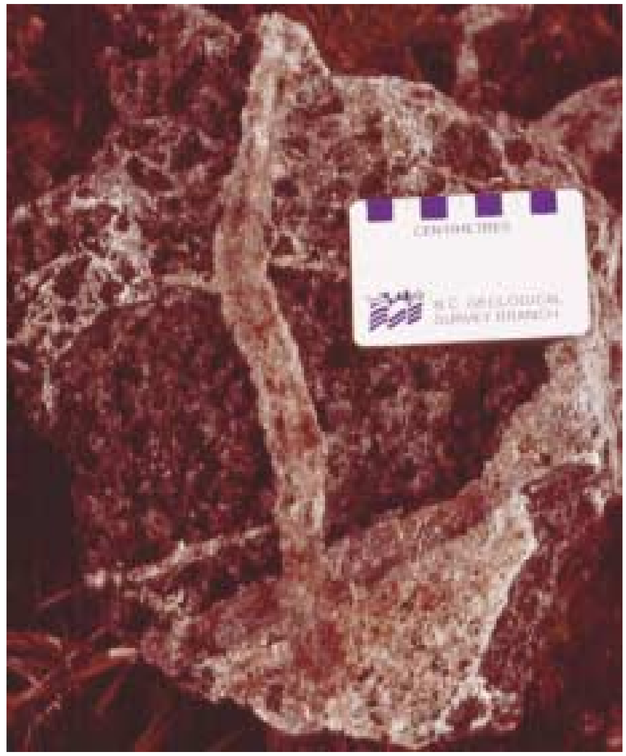


Photo 12-9. Fourth of July batholith border zone granite is cut by a lamprophyre dike which is then back-veined by a later felsic phase of the batholith.

Hornblende Granite to Quartz Monzonite (mJTg2)

Medium crystalline hornblende (5 to 25%) granite (more hornblende-rich varieties may be quartz monzonite) comprises this unit. The hornblende is dark green to black with pyroxene cores and is typically euhedral in habit.

Biotite Granite to Alaskite (mJTg3)

Rocks ranging from biotite granite to alkali feldspar granite to alaskite comprise this unit. They are medium to coarsely crystalline and biotite content ranges from about 1% (alaskite) to more than 20%. Hornblende is a common accessory mineral in more mafic varieties. Colouring varies from light grey to pink on fresh surface and it weathers pink. Potassium feldspar ranges from approximately 50% to nearly 100% of the total feldspar. Rocks of the latter composition are very leucocratic and classify as alkali feldspar granite or alaskite. Alaskite also forms dikes within other phases of the Fourth of July Batholith, and is the dominant phase over a large area south of Deep Bay.

Potassium Feldspar Megacrystic Granite (mJTg4)

A K-feldspar megacrystic zone defines a north-northwest-trending, kilometre-wide belt that extends from the north side of Deep Bay to the east side of Atlin Lake opposite Eight Mile Bay, and perhaps as far south as Como Lake in 104N/12E. It is bounded to the east by equigranular biotite hornblende granite and to the west by a dioritic border phase. Large (1-4 cm) K-feldspar megacrysts lie in a matrix of medium to coarsly crystalline granite (Photo 12-8). The matrix may be biotite or hornblende-rich, with mafic components approximately 5 to 25% of the total. Layers defined by accumulations of feldspar megacrysts occur locally within hornblende-rich rocks. Megacrysts are typically zoned, from light grey or white cores to pink rims. Sphene is a common accessory mineral.

Border Phases (Granodiorite to Gabbro, mJTgd)

As mapped, this unit is a diverse assemblage dominated by granodiorite (locally diorite) ranging to lesser alaskite. The assemblage includes: (1) fine- to medium-crystalline biotite-hornblende granodiorite; (2) medium-crystalline hornblende-biotite granodiorite; (3) medium-crystalline, pyroxene-glomeroporphyritic

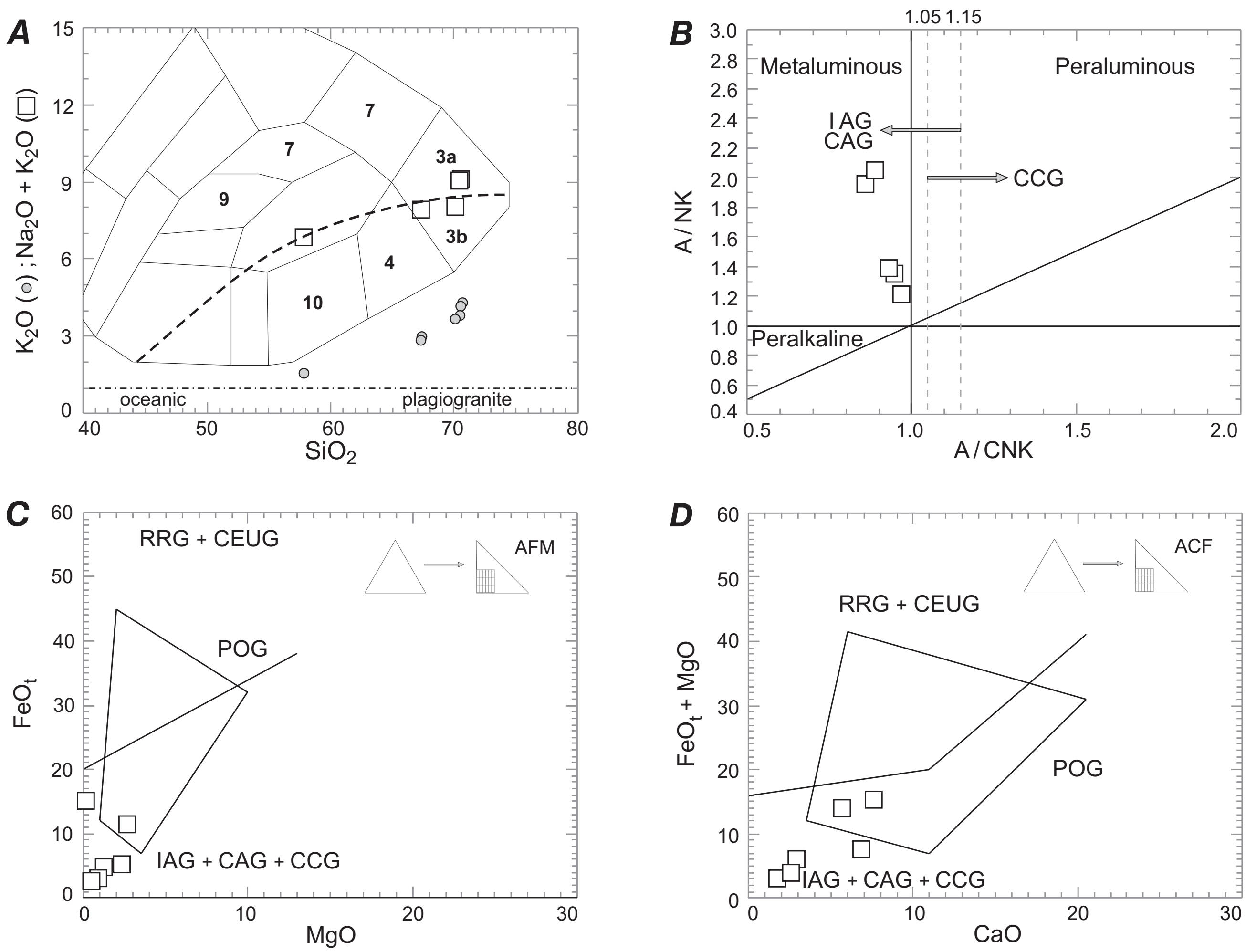


Figure 12-11. (a) alkalis versus silica diagram with superimposed volcanic rock compositional fields of Cox *et al.* (1979) assigned compositionally equivalent plutonic names (after Wilson, 1989; field numbers correspond to those in Table 12-2) shows that the major intrusive phases within the Fourth of July batholith fall in the granite and alkali granite fields with one sample falling in the syeno-diorite field, (b) ratios of A/(N+K) versus A/(C+N+K) where A= Al_2O_3, C=CaO, N=Na_2O, K=K_2O shows that the batholith is dominantly metaluminous on the Shand index, (c) and (d) are granite discrimination plots where AFM and ACF space is projected into Cartesian coordinates following the method of Maniar and Piccoli (1989). They show that the batholith to plots in the field of island arc (IAG), continental arc (CAG) and continental collision (CCG) granitoids (RRG = rift-related granitoid, CEUG = continental epeirogenic uplift granitoid). Note that CCG is eliminated on the basis of Al_2O_3 and CaO in (b).

hornblende granodiorite or diorite; (4) medium-grained granite; (5) lamprophyre; and (6) leucogranite and alaskite. Distinctive xenolith-rich areas occur where granodiorite and lamprophyre are intruded and brecciated by the late leucogranite and alaskite.

Dikes Comagmatic with mJTg (mJTl)

A swarm of northwest-trending, steeply dipping dikes crosscuts the batholith and extend with decreasing abundance into surrounding Cache Creek lithologies. They range from lamprophyre (earliest) to alaskite (latest). Texturally and mineralogically they are equivalent to border phases of the batholith.

Lamprophyre dikes intrude early phases, and are intruded by late phases, of the Fourth of July Batholith (Photo 12-9). They are volumetrically significant particularly along the margins of the batholith, where large outcrop areas (up to tens of metres in length) consist dominantly or entirely of lamprophyre. Dikes range from 1 m to greater than 10 metres thick, and are dark green and knobby weathering. Lamprophyre is fine to coarsely crystalline, and may contain up to 40% feldspar, including pink-weathering K-feldspar. Dark green to brown or black biotite and hornblende are the dominant mafic minerals; dark green pyroxene is locally present. Particularly conspicuous are black, knobby-weathering, very biotite-rich dikes which contain pink feldspar clots that commonly form resistant spikes. Mineralogical similarities to the main mass of the Fourth of July batholith are particularly evident in thin section where the mafic minerals include pyroxene mantled by hornblende and biotite (*cf.* Photo 12-7).

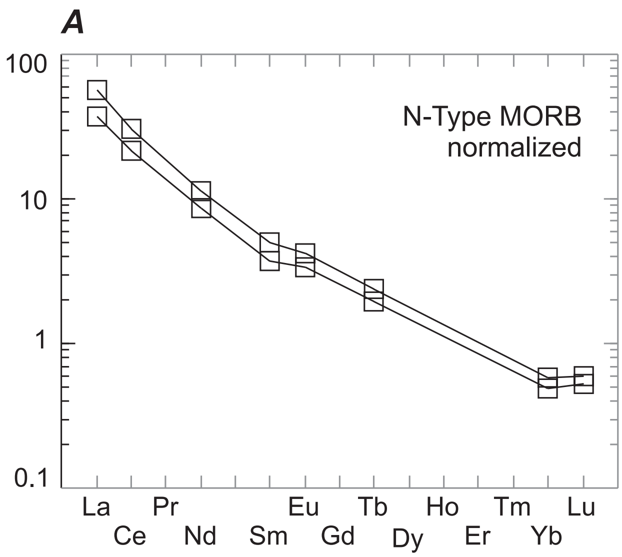
An alkali feldspar granite to alaskite "cupola" intrudes the border phase south of Deep Bay, and dikes of the same composition intrude the potassium feldspar megacrystic granite, the dioritic border phase, and lamprophyre dikes.

Geochemistry, Age and Interpretation

Mesonormative plots of major oxides from samples of the predominant intrusive phases in the Fourth of July batholith show a range from quartz monzodiorite to granodiorite composition (Figure 12-10). The same rocks are metaluminous (Figure 12-11b).

N-MORB and ocean ridge granite-normalized plots of Fourth of July batholith data (Figure 12-12a, b) show that they are most indicative of a volcanic arc granite, withboth Ba and Th greater than K_2O (Pearce *et al.*, 1984). The Fourth of July batholith typically displays K_2O values about 10 times those of ocean ridge granite and Ba that is 10 to 100 times values typical of within-plate granites. Some syncollisional granites may also display this signature. Ce and Sm are greater than expected for most volcanic arcs, although they are similar to values displayed by intrusions in mature continental arcs such as the Chilean Andes.

Major oxide geochemical data also indicate a magmatic source area with a volcanic arc signature (Mihalynuk *et al.*, 1992a; Figure 12-11c, d). Initial strontium ratios reported in Mihalynuk *et al.* (1992a) are 0.7038 and 0.7039; indicating little or no assimilation of old radiogenic crust. The implications of these geochemical results are discussed in a regional context in Chapter 15.



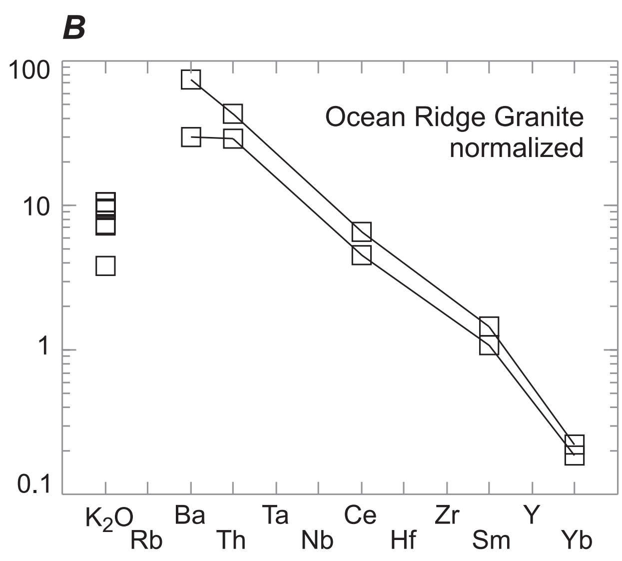


Figure 12-12. Fourth of July Batholith geochemistry: (a) normal mid ocean ridge basalt-normalized REE plot. (b) Ocean ridge granite-normalized multi-element plot (normalization factors of Pearce, *et al.*, 1984). Rb values are not available.

A synopsis of age data for the Fourth of July batholith including the most recent U-Pb zircon dates of 170.4 ±5.1Ma and 171.5 ±3.4Ma, are presented in Mihalynuk *et al.* (1991; and Tables AA1 and AA5). Recent U-Pb dates are in agreement with a K-Ar age determination on a small stock between Monarch and Union Mountains reported by Dawson (1988) as 167±3. Similar ages are reported by Ash (in preparation) for mariposite from several showings within the Atlin camp.

Fission track age determinations as old as 215 ±20 and 193 ±18 Ma have been reported for the Fourth of July batholith from Mount Hitchcock and Mount Minto, both just outside of the map area (Donelick, 1988). K-Ar ages as young as 73.3±2.6 Ma were obtained from Fourth of July samples collected by Christopher and Pinsent (1982), but these undoubtedly reflect thermal resetting due to intrusion of the nearby Surprise Lake batholith (between 84 and 72 Ma, *cf.* Mihalynuk *et al.*, 1991 and "Windy-Table Intrusive suite" below).

The polyphase Fourth of July batholith was probably intruded over a protracted time period from about 172 to 166 Ma. This age closely corresponds to the original age assignment of Aitken (1959) which was based upon a combination of geological arguments and intuition.

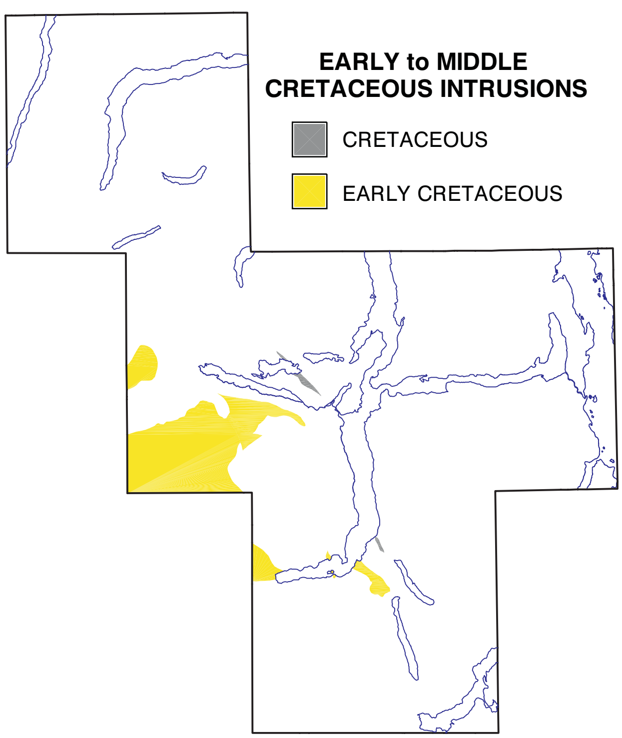


Figure 12-13. Distribution of Mount Lawson tonalite and other Mid Cretaceous bodies in the Tagish area.

Magmatic Lull (165 - 115 Ma)

Latest Jurassic to the first half of the Early Cretaceous (155 - 125) was a time in which Cordilleran magmatism was at a minimum (Armstrong, 1988). In northwestern British Columbia this magmatic lull may encompass an even greater time interval from 165 - 115 Ma (Figure 12-2) although a few plutons at the southern end of Tagish Lake fall within this age range. Age determinations on all but one of these bodies is by K-Ar methods which are cooling ages and of questionable reliability because they are subject to resetting during intrusion of younger plutons nearby. However, one good quality U-Pb zircon date of 127 Ma (Currie, 1994) on a peraluminous granite falls within the 135 - 125 period of "absolute quiescence" envisaged by Armstrong (1988).

Taku Bend Granodiorite (145±4 Ma?)

An elongated body of coarse-grained biotite hornblende granodiorite intruded and apparently altered and silicified schist of the Boundary Ranges suite on the outside of the southern Taku Arm bend (Figure GM97-1). The granodiorite is white to tan or orange and blocky weathering. Coarse grey quartz (35%) forms glomerophenocrysts within a matrix of pink and white potassium feldspar (15%). Plagioclase (40%) displays good albite and Carlsbad twins. Mafic minerals include subhedral hornblende laths (6%, less than 1 centimetre), euhedral biotite booklets (3%, less than 5 millimetres) and accessory sphene. Epidote and pyrite are local alteration products. Variations include zones with up to 3% potassium feldspar phenocrysts, zones with 1% hornblende phenocrysts and zones containing rounded xenoliths of hornblende-(70%) plagioclase-(20%) quartz-(10%) porphyry.

Bultman (1979, see Table AA5) K-Ar dated hornblende from this body at 145 ±4 Ma. A discordant biotite date of 123 ±2Ma points to thermal resetting of the isotopic system, Ar absorption by the hornblende analyzed, or both. Nevertheless, 145 Ma is currently the best age constraint on the intrusion.

Lawson tonalite (133±3 Ma eKt$_{1,2}$)

Foliated tonalite underlies much of the ridge just south of Fantail Lake (Figure 12-13). It may be correlative with a "Late Cretaceous or older, non-migmatitic orthogneiss of tonalitic composition" mapped by Barker *et al.* (1986) west of the Tagish area. Hornblende-quartz diorite at Ben-My-Chree (>*c.*120 Ma) is included with the Lawson tonalite although a connection with the main body has not been mapped. Within the map area, Lawson tonalite clearly intrudes schists of the Boundary Ranges metamorphic suite.

Two main phases are present; moderately to strongly foliated tonalite to granodiorite (Photo 12-10, Figure 12-14) is dominant over a mildly foliated dioritic phase. Unit lKg2 differs from unit lKg1 as it is generally megacryst-free (with local exceptions) and displays less compositional variability. Fine-grained varieties of both units are common since the contacts are typically chilled across 30 centimetres to many metres to form quartz-eye porphyries. Contact relations between the two are poorly established, but most cross-cutting relationships point to the mildly foliated phase as the younger of the two.

Foliated tonalite/granodiorite (eKt_1) is grey to white, and weathers to grey-green tabular blocks. It is typically medium grained with sparse, but conspicuous hornblende megacrysts (xenocrysts?). Hornblende most commonly occurs as grains less than 4 millimetres long in glomeroporhyritic patches that comprise 10 per cent of the rock. Hornblende also occurs together with biotite to form aligned, melanocratic, plate-like xenoliths up to 30 centimetres long. Individual grains are commonly chlorite altered and greenish in colour. Biotite comprises 5 to rarely 7 per cent of the rock as glomeroporphyritic and subidiomorphic booklets up to 3 millimetres in diameter. Plagioclase is the only feldspar readily identifiable in hand sample, it constitutes about 60 per cent of the rock. Quartz comprises 20 per cent of the rock as anhedral grains, generally less than 4 millimetres in diameter. Sphene, the most abundant accessory, forms conspicuous subidiomorphic grains up to 3 millimetres long.

Mildly foliated tonalite/hornblende diorite (eKt_2) is a fine to medium-grained, slightly more mafic equivalent of eKt_1. Weakly chlorite-epidote altered hornblende, which occurs as partly aligned 12 millimetre laths, comprises up to 18 percent, fresh, medium-grained biotite up

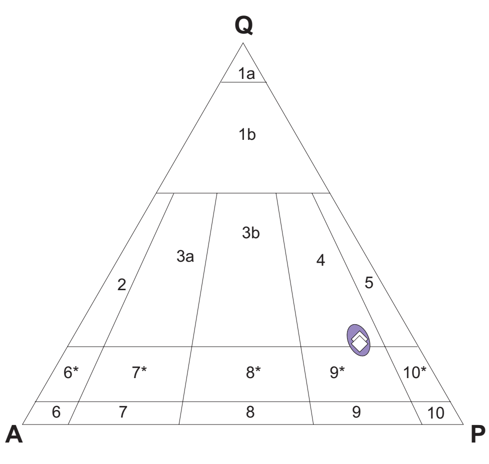


Figure 12-14. Mesonormative plot showing compositions of major intrusive phases within the Mount Lawson tonalite. It demonstrates that these samples at least, are quartz monzonite, not tonalite. Compositional range is greater than that indicated by the diagram, which is limited by the small number of samples analyzed. Fields 4 and 9* are granodiorite and quartz monzonite respectively. For other fields see Table 12-2.

Photo 12-10. Foliated Mount Lawson tonalite is cut by a dike of Late Cretaceous granite.

to 4 percent, quartz to 15 per cent, and plagioclase to 65 per cent of the rock. Potassium feldspar reaches 5 per cent in coarser zones. Sphene and lesser pyrite are conspicuous accessory phases.

Mesonormative Q-A-P calculations from whole rock analysis indicate a composition between quartz monzodiorite and granodiorite (Figure 12-14). The rock is somewhat more potassic than is suggested by the hand samples, but the field term "tonalite" is retained here. It is metaluminous (Figure 12-15b).

Foliated unit eKt_1 rocks yielded a potassium-argon date of 133 ±3.2Ma froma hornblende separate (Bultman, 1979; *see* Tables 12-1 and AA5). This age is consistent with the younger age of a crosscutting, unfoliated Late Cretaceous granite. Plutonic rocks of *circa* 133 Ma are unusual within the Canadian Cordillera since this falls near the middle of the western North American magmatic lull (155-125Ma, Armstrong, 1988).

The Lawson body is interpreted to extend to the southern tip of Tagish Lake, near Ben-My-Chree. Extreme compositional and textural variability of plutonic rocks at Ben-My-Chree serve to distinguish them from adjacent, more homogenous intrusive units of probable Early Eocene age. Bultman (1979) mapped five separate intrusive phases ranging in composition from coarse hornblende diorite and hornblende tonalite to biotite-quartze monzodiorite and granite. From these intrusions he obtained a spectrum of K-Ar ages ranging from 59-120 Ma. The youngest of these dates almost certainly reflect intrusion of the adjacent Early Eocene pluton to the east. A paucity of field information prevented local delineation of individual plutonic phases as part of this study.

At the border of the Mount Lawson pluton, Bultman (1979) observed porphyritic, green volcanic and metamorphic inclusions up to 30 centimetres in diameter. The

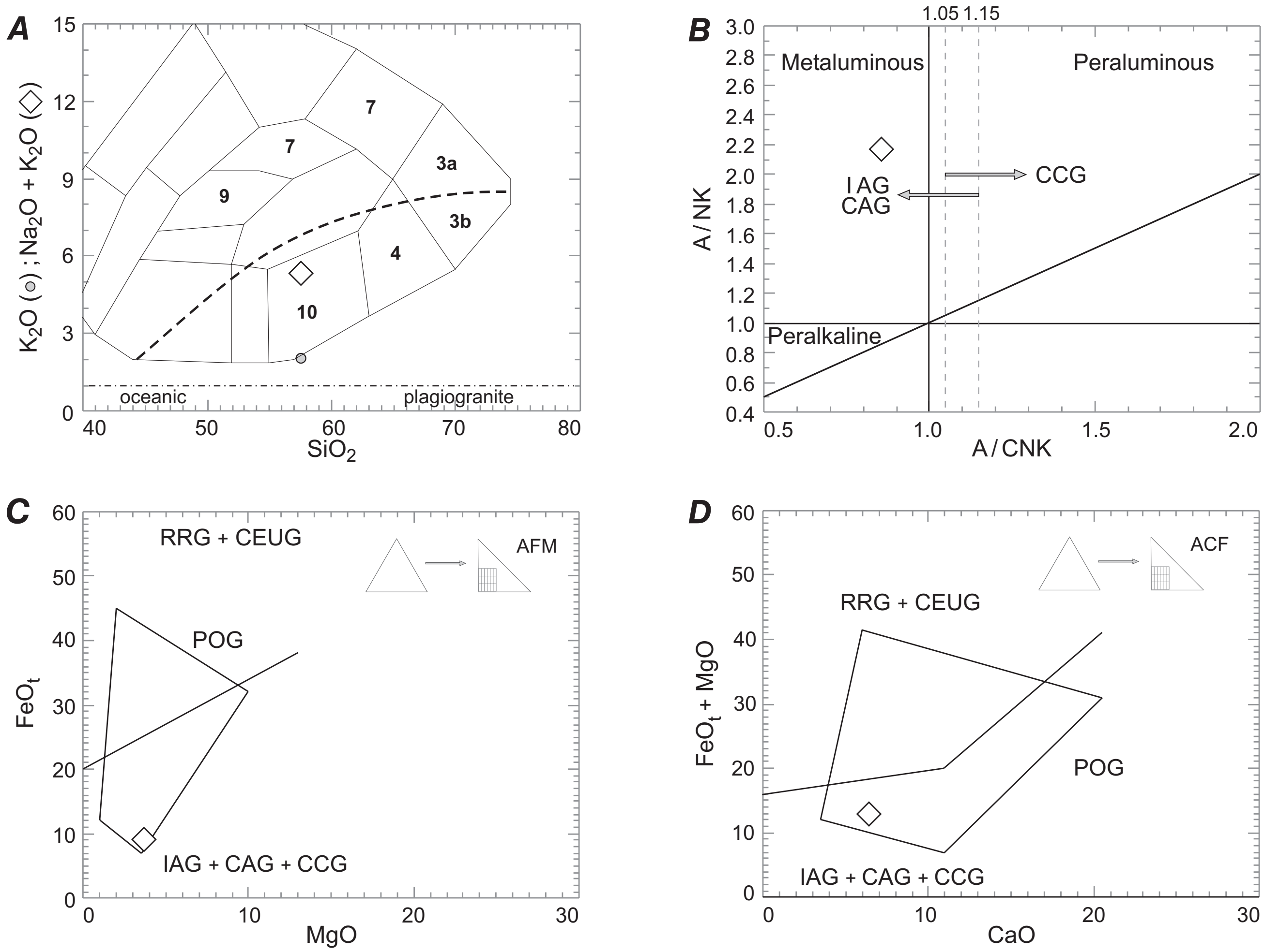


Figure 12-15. (a) alkalis versus silica diagram with superimposed volcanic rock compositional fields of Cox *et al.* (1979) assigned compositionally equivalent plutonic names (after Wilson, 1989; field numbers correspond to those in Table 12-2) shows that the Mount Lawson tonalite falls within the diorite/quartz diorite field, (b) ratios of A/(N+K) versus A/(C+N+K) where A= Al_2O_3, C=CaO, N=Na_2O, K=K_2O shows that the tonalite is metaluminous on the Shand index, (c) and (d) are granite discrimination plots where AFM and ACF space is projected into Cartesian coordinates following the method of Maniar and Piccoli (1989). They show that the batholith plots in the Post-orogenic granitoid field (POG) (IAG, CAG = island and continental arc granitoids, CCG = continental collision granitoid, RRG = rift-related granitoid, CEUG = continental epeirogenic uplift granitoid).

volcanic inclusions may be remnants of the western-most Stuhini Group within the map area. If this is true then it provides additional evidence of Stuhini arc deposition atop the Boundary Ranges metamorphic suite.

Peraluminous Granite (eKg 127 Ma)

Lenses of peraluminous granite occur at the contact between metamorphic rocks and the main mass of Coast Plutons along southern Taku Arm. The lenses, which are pink to orange, are comprised of equigranular, medium-grained quartz (25%, slightly smokey), K-feldspar (35%), plagioclase (30%), biotite (2%), and muscovite (5%±); plus fine-grained, euhedral, red garnets (1-2%).

U-Pb age determinations by Currie (1994) indicate that they are 127 ±0.6 Ma. Plutons of this age are not well represented in the Canadian Cordillera. Observed contacts with younger intrusives are faulted.

Coast Intrusions (Mid-Cretaceous to Tertiary)

Coextensive with the Coast Belt of British Columbia are enormous volumes of Jurassic to Tertiary granitoid rocks. These diminish both north and south of the province. Near their northern limit, they underlie the western margin of the Tagish map area (Figure 12-1). Jurassic to Early Cretaceous plutons within the belt include those of the Hale Mountain granodiorite, Taku bend granodiorite, Mount Lawson pluton and peraluminous granite that are discussed above. Plutons of known Middle to Late Cretaceous age like the Log Cabin pluton and satellite plutons like those at Jack Peak and Racine Lake, or those belonging to the mineralized Whitehorse plutonic suite (Figure 12-16), are discussed in this section. With the exception of bodies belonging to the Windy-Table, Surprise Lake, and Sloko plutonic suites, many cannot easily be categorized because of lack of robust age constraints. Only the youngest plutons, those of the Sloko magmatic epoch (Sloko suite), have demonstrably concordant K-Ar and U-Pb ages. K-Ar systems in older plutons were susceptible to thermal resetting during the widespread Early Eocene Sloko magmatic epoch.

Tectonized hornblende diorite (Kd)

Two northwest-elongated bodies of altered diorite crop out along the Llewellyn Fault at Brownlee Lake and along the lower Wann River. Outcrops are dark green to black, and weather variably to orange, white or pink (potassium metasomatism?). The Brownlee body intrudes Boundary Ranges schists on its western margin and has a faulted eastern contact. Deformation within these bodies varies from ductile foliation to brittle fracturing that produces rubbly to blocky outcrops. Locally, brecciated zones appear to include blocks of adjacent volcanic country rocks. Diorite textures vary from medium to fine-grained and from equigranular to blastogranular. Mineralogy is locally difficult to determine due to alteration, however, mafic minerals appear to have been dominated by prismatic hornblende, up to 0.75 centimetres, which is less than 10 to nearly 25 percent, and about 3 percent magnetite within a matrix of white, turbid plagioclase. Chlorite and epidote alteration of both hornblende and plagioclase is ubiquitous. Intensely altered zones may contain 3 to 10 percent pyrite, and 10 per cent epidote. Epidote, quartz and chlorite also occur as fracture linings or veins , the widest of which reach 3 centimetres.

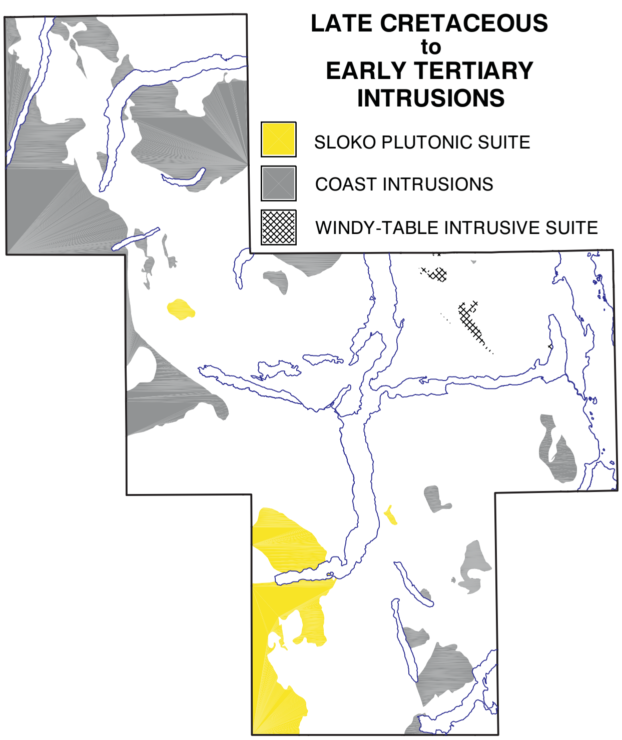


Figure 12-16. Distribution of Late Cretaceous to Early Tertiary plutons in the Tagish area.

Neither body has been directly dated, but their ages are geologically constrained. They are affected by pervasive brittle deformation related to motion on the Llewellyn fault. Latest major motion on the fault is older than the crosscutting *c.* 55 Ma Pennington pluton on Bennett Lake (Hart and Radloff, 1990). The diorites are less altered, and therefore, probably younger than a thoroughly sericitized lens of granodiorite (unit lTgd) only 200 metres from the Wann River diorite body; alteration in this lens is related to a *c.*132 Ma potassium - metasomatic event.

This unit has been tentatively included in the Whitehorse plutonic suite based on hornblende dioritic composition and permissive age limits. Magmatic ages of similar intrusions are isotopically well characterized in southern Yukon, where most fall within the 116-119 Ma range (Table AA5).

Whitehorse Magmatic Epoch (90-115Ma)

The Whitehorse magmatic epoch is principally represented by the Whitehorse plutonic suite in southern Yukon which is shown by Hart (1995) to have been emplaced in the Middle Cretaceous between about 112 and 108Ma. As such, it directly marks the cessation of the Early Cretaceous magmatic lull described by Armstrong (1988). Most Whitehorse plutonic suite bodies are zoned hornblende granodiorite to gabbro intrusions that are concentrated along the western margin of the Whitehorse Trough, and extend west into adjacent terranes (*cf.* Hart, 1995). Generally, hornblende is fresh and feldspars are sausseritized, although some intrusions display extensive chlorite-epidote alteration. In the Tagish Lake area, the most likely member of the Whitehorse plutonic suite is an undated, mineralized stock that does not crop out, but has been intersected by drilling near the “Sinwa Formation” limestone between the Klondike Highway and Tutshi Lake (*see* Chapter 14).

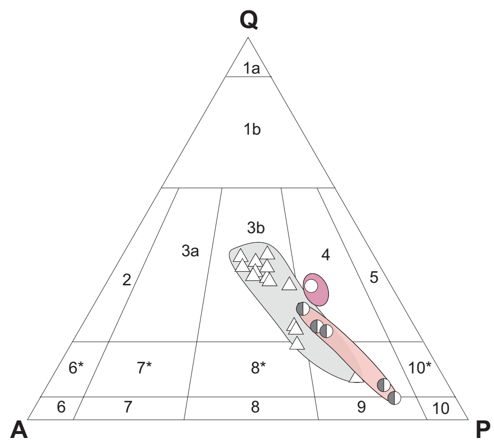


Figure 12-17. Mesonormative plot showing compositions of some representative samples of Jack Peak pluton (circles), Surprise Lake batholith (triangles) and Atlin Mountain pluton (half filled circles). Although the Jack Peak pluton is homogeneous, its compositional range is probably greater than that indicated by the diagram, which is limited by the small number of samples analyzed. Fields 3b, 4, 8* and 9* are monzo-granite, granodiorite, quartz monzonite and quartz monzodiorite respectively (for other fields see Table 12-2).

Carmacks Magmatic Epoch (85 - 70 Ma)

Many plutons comprising the northern Coast Belt, as well as large satellite bodies, were emplaced during the Late Cretaceous Carmacks Magmatic Epoch. Examples of satellite plutons include those at Jack Peak; mounts Racine, Clive, Cameron, and The Cathedral; and Atlin Mountain. Reliable age data area lacking on most of these bodies, but similarities in lithology and setting permit informal groupings. Where reliable age control has also been established, plutons have been assigned to the Windy-Table magmatic, or Surprise Lake plutonic suites.

Jack Peak & Related Plutons (lKg1 92Ma; lKg2 72Ma; lKgp)

Jack Peak and related plutons comprise most of the Coast Belt in the northern half of the map area, as well the two largest satellite bodies that intrude the Whitehorse Trough between Tutshi and Tagish lakes. These plutons are separated mainly into two units (lKg1 and lKg2). They are typically coarse-grained, orange-weathering, pink to tan or grey hornblende biotite-granite to quartz monzonite. Outcrops are rounded to blocky weathering and resistant. Unit lKg1 commonly contains 1 to 5 per cent perthitic, pink K-feldspar megacrysts up to 5 centimetres long which may display rapakivi textures. Total potassium-feldspar content is generally about 30 to 45 per cent. K-feldspar crystals are perthitic, zoned, and less than 1 centimetre in diameter. Plagioclase occurs as white-weathered or fresh translucent hypidiomorphic grains less than 6 millimetres across that comprise 10 to 40 per cent of the rock. Anhedral quartz occurs interstitially (20-40 per cent). Euhedral booklets of biotite are fine to, less commonly, medium grained (2 to 12 per cent). Fine grains of sphene can be identified petrographically, but coarse sphene, common in both Jurassic and Eocene granitoids, is generally absent. Due to high level emplacement of the intrusives, the country rocks are not extensively hornfelsed, although skarn development occurs locally within calcareous units tens of metres away from contacts. Mariolitic cavities were observed at one locality along the eastern shore of Bennett Lake. Restricted zones are peraluminous, containing up to 3% medium-grained euhedral, pink garnet and local muscovite. Where such zones are large enough to show on the map (Figure GM97-1), they are denoted as lKgp. Most are less than 1 kilometre in long dimension and are near Bennett Lake. Jack Peak is intruded by a swarm of east-west-oriented, basalt and rhyolite dikes that comprise up to 15% of its volume (50% over tens of metres, Photo 12-11). No similar dike swarms have been reported for other Coast plutons in the area.

A mesonormative plot of major oxide data from a single sample of the Jack Peak pluton lies in the centre of the granodiorite field (Figure 12-17). The sample is aluminous (Figure 12-18b).

A 92Ma K-Ar age from biotite of the Jack Peak pluton (lKg1) is reported by Bultman (1979, recalculated). Barker *et al.* (1986) report a U-Pb zircon age of *c.* 72Ma from a sample of a body that they called the "Log Cabin pluton"; part of unit lKg1 near its contact with lKg2 southwest of Tutshi Lake. This age is significantly younger than the Jack Peak pluton. However, the com-

Photo 12-11. Abundant dikes of alternating basalt and rhyolite within the Jack Peak pluton locally constitute 50% of the body. Rhyolite and basalt dikes typically alternate and are 1 to 3 metres thick.

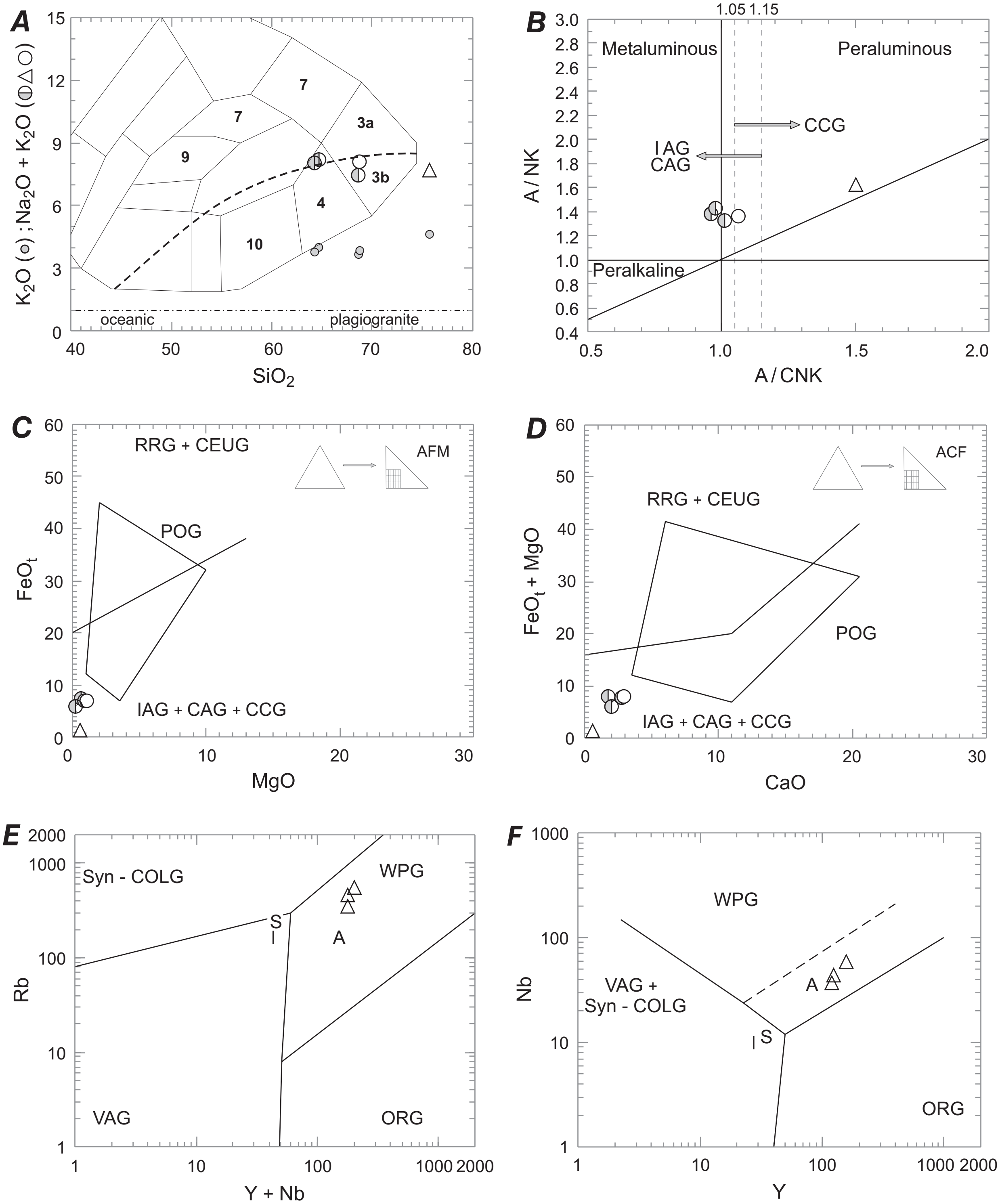


Figure 12-18. Geochemistry of the Jack Peak pluton (circles), Surprise Lake batholith (triangle is the average major element composition based on 54 analyses from Ballantyne and Littlejohn, 1982) and Atlin Mountain pluton (half filled circles). (a) alkalis versus silica diagram with superimposed volcanic rock compositional fields of Cox *et al.* (1979) assigned compositionally equivalent plutonic names (after Wilson, 1989; field numbers correspond to those in Table 12-2) shows that the plutons fall in the granite and granodiorite fields, with the Surprise Lake average composition falling to the silica-rich side of the granite field. (b) ratios of molar A/(N+K) versus A/(C+N+K) where A=Al_2O_3, C=CaO, N=Na_2O, K=K_2O shows that the bodies are aluminous on the Shand index, (c) and (d) are granite discrimination plots following the method of Maniar and Piccoli (1989) that show the bodies plot in the field of island arc (IAG), continental arc (CAG) and continental collision (CCG) granitoids (RRG = rift-related granitoid, CEUG = continental epeirogenic uplift granitoid). Note that CCG is eliminated on the basis of Al_2O_3 and CaO in the Atlin Mountain pluton, but that the Jack Peak pluton falls just to the aluminous side of the line at 1.07 in (b) and cannot be discriminated on this basis. Surprise Lake batholith is clearly peraluminous. Data of Ballantyne and Littlejohn (1982) for the Surprise Lake batholith is plotted on the (e) Nb-Y and (f) Rb-Y+Nb discrimination plots of Pearce (1984). The samples fall in the within-plate field with most other A-type granites (A = average of 148 A-type granite analyses compared with I- and S-type granite averages (I and S) from 1569 analyses as reported in Whalen *et al.*, 1987).

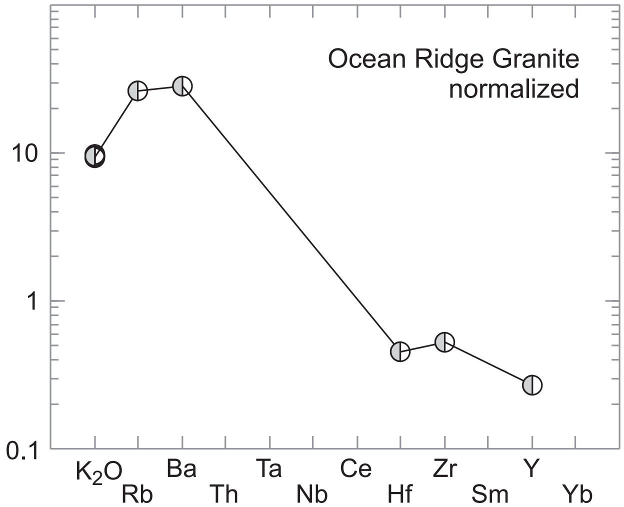


Figure 12-19. Ocean ridge granite normalized (factors of Pearce *et al.*, 1984) plot of K-feldspar porphyritic stock shows an arc signature (see text for explanation).

posite "Log Cabin pluton", straddles the assumed contact between Late Cretaceous intrusions comprising the uninterrupted crystalline Coast belt west of the Boundary Ranges Metamorphic suite as shown on Figure GM97-1. It is possible that the "Log Cabin Pluton" was emplaced as two or more separate bodies, a notion supported by variations in lithology, chemistry and modal mineralogy noted by Barker *et al.* (1986). The younger "Log Cabin Pluton" age suggests a correlation with a tabular body of unit lKg_2 between Jack Peak pluton and "Log Cabin pluton". The dike, which exhibits chilled contacts against Laberge Group strata (Photo 12-12), has yielded a K-Ar biotite age of *c.* 80 Ma (Bultman, 1979; recalculated) from a sample collected along the east shore of southern Tutshi Lake.

In the absence of both reliable age data and detailed field studies on contact relationships between different plutonic phases, it is difficult to assign the Jack Peak pluton to a suite. If the cooling age alone is considered, the pluton would be a young member of the Whitehorse plutonic suite. However, it is lithologically unlike Whitehorse suite plutons. It is more like the Racine pluton, parts of the "Log Cabin pluton" and the *c.* 80 Ma granitic dike at southern Tutshi Lake. Based on this lithologic similarity it is probably best included in the Windy-Table suite unless future, robust age dating confirms the 92 Ma K-Ar age.

Tabular-feldspar porphyry dikes

Numerous brown to green-brown-weathering tabular-feldspar porphyry dikes intrude Lower Jurassic Laberge Group strata. They most commonly trend northeast and are 0.5 to 20 metres thick. In places they comprise 10 - 20 per cent of the section. The feldspar (10 - 30 per cent, typically twinned plagioclase) is generally tabular (0.5 - 2 cm long), and may be trachytically aligned within a fine-grained to aphanitic brown-green matrix. Hornblende is a rare accessory phase. Contacts are invariably chilled. The age of these dikes is constrained by the Middle Jurassic deformation of the Laberge Group, because they cut folded strata, and by intrusion of the Racine pluton (*circa* 84 Ma) which crosscuts the dikes. None are large enough to show, except symbolically, on Figure GM97-1.

Racine pluton (lKgh 84±2.1 Ma)

The Racine pluton is a medium to course-grained homogeneous granite with 20 to 40 per cent potassium-feldspar which may be mantled by plagioclase, 20 to 40 per cent quartz, 30 to 40 per cent plagioclase, 3 to 6 per cent hornblende, and 3 to 8 per cent chloritized biotite. Locally K-feldspar may occur as megacrysts. Bultman (1979) dated biotite from the pluton using K-Ar techniques as 84±2.1 Ma (Table AA5). Porphyritic portions of this pluton resemble the Jack Peak pluton, but are distinguished from it on the basis of the apparently reliable age that is 8 m.y. younger.

Photo 12-12. Chill textures from the contact zone of a high-level, Late Cretaceous pluton. Mc = microcline, Qtz = quartz, long dimension of photo represents 2.5 mm.

Granodiorite like at mounts Clive & Cameron (lKgd, lKhgd)

The 3.5 kilometres long, ovoid Mount Clive stock crops out only 1.5 kilometres southwest of the Racine pluton. It is a locally K-feldspar megacrystic, medium-grained granodiorite with a composition of: quartz 30 to 40 per cent, plagioclase 30 to 50 per cent, white potassium-feldspar 15 to 25 per cent, biotite 10 to 15 per cent, and minor magnetite. Quartz is locally coarse grained and K-feldspar is commonly up to 1.5 centimetres long. A chilled, northeast trending apophysis of this body thins to 5 metres but persists for over 1.5 kilometres through the thin wedge of Laberge strata separating it from the Racine pluton. The apophysis may be the surface expression of a link between the two bodies; but, unfortunately its point of entry into the Racine pluton is obscured by glacial drift, so that a definite age relationship could not be established.

Zoned granodiorite-diorite like The Cathedral (lKgdt)

Zoned granodiorite to diorite bodies underlie The Cathedral Mountain, Engineer Mountain, Bee Peak and Mount Cameron. They are small, high-level poly-phase intrusives that range from 2 kilometres across on the southwest flank of Engineer Mountain, to 10 kilometres across where they underlie The Cathedral. Part of their non-homogenous nature reflects shallow erosional levels which expose only the roof phases which have incorporated large volumes of country rock.

Small bodies may be homogenous; however, larger bodies include more than one of the following: orange-weathering, olive-brown to greasy-grey fresh, medium to coarse-grained hornblende biotite diorite to "anorthositic" biotite diorite, most commonly as a border phase; tan to salmon, platey-weathering sparse potassium-feldspar and rare quartz-phyric rhyolite as irregular zones or dike-like bodies with sharp or digested margins; vari-textured fine to medium-grained hornblende granodiorite irregularly admixed with the rhyolite and locally containing abundant biotite-hornblende-rich mafic xenoliths; and white to pink, fine to medium-grained, hornblende granodiorite to tonalite with subhedral plagioclase and hornblende (1-5 mm and 2-7 mm respectively) and mainly interstitial quartz and K-feldspar.

Evenly distributed patches of finely intergrown acicular hornblende and plagioclase 0.5 to 2 cm diameter are characteristic of The Cathedral body, which was originally thought to be part of a Late Triassic intrusive suite (Bultman, 1979) based on the apparent lack of thermal alteration in adjacent Stuhini Group strata. An intrusive contact between the two is, however, well exposed at Splinter Peak where the roof of the Cathedral body incorporates blocks stoped from an overlying thin veneer of Stuhini Group strata.

Quartz monzonite like Pennington & Atlin Mtn. (lKqm 75 Ma)

Quartz monzonite occurs at widespread localities in the Tagish area. Parts of a quartz monzonite body that extends from northwest of Bennett Lake in the Yukon to the Llewellyn Fault zone east of Bennett Lake in British Columbia, belong to the Pennington pluton. Much of the body displays a peculiar honeycomb texture due to weathering out of altered feldspar from a fine-grained siliceous matrix. Hart (1995) reports a 55Ma K-Ar cooling age from hornblende within the Yukon segment of the pluton. He includes it with the Nisling Range suite, herein grouped with Early Tertiary K-feldspar porphyry and alaskite (unit eTqa). However, stream sediment geochemical response from *bona fide* Nisling suite plutons, including the Mount McAuley pluton (U-Pb dated at 53.7 ±0.3 Ma; Hart, 1995), differ significantly from other plutons. In particular, the lanthanide elements leutetium and terbium are markedly elevated (Jackaman and Matysek, 1993). Since the Pennington pluton does not produce an elevated geochemical response in these elements it may be older than indicated by the K-Ar cooling age.

Atlin Mountain pluton (lKqm)

Homogeneous, fine- to medium-crystalline K-feldspar porphyritic quartz monzonite comprises the Atlin Mountain pluton. It intrudes rocks of the Cache Creek complex and the Laberge Group. Mafic minerals total 10 to 25% of the rock, and include hornblende, biotite, and magnetite. The ratio of K-feldspar to plagioclase is difficult to distinguish in the field. Interstitial quartz ranges up to 15%. Rocks weather light grey to slightly pink or orange. Fine-grained margins and both dikes and sill-like apophyses of the intrusion are common.

A mesonormative plot of whole rock data from the Atlin Mountain pluton shows a compositional range from quartz monzodiorite to monzogranite (Figure 12-17), in accord with field observations. The pluton is weakly aluminous (Figure 12-18b). An initial strontium ratio of 0.70458 is consistent with those for other plutons in the area.

Age of the Atlin pluton is constrained by the Nahlin fault which cuts it, but is clearly plugged by the Birch Mountain pluton, (centred approximately 13 km to the southeast) which has yielded hornblende and biotite K-Ar ages of 48 ±1.1 and 58 ± 1.1 Ma, respectively (Bultman, 1979) and a questionable two-point Rb-Sr "age" of 50.4 ±4.5Ma (Mihalynuk *et al.*, 1992). Thus, Atlin Mountain pluton is apparently older than 58 Ma. It is younger than volcanic rocks that it intrudes and hornfelses which belong either to the Peninsula Mountain succession (mid to Upper Triassic as shown in Figure GM97-1) or to the Windy-Table suite (*circa* 70-85 Ma). In either case a highly speculative two point Rb-Sr isochron "age" of 75 ±28 for the Atlin Mountian pluton (Mihalynuk *et al.* 1992) falls within the constraints imposed by field relations.

Windy-Table intrusive suite (lKwqd, lKwp, lKwqs 70-85 Ma)

Numerous plutons and comagmatic intermediate to felsic volcanic rocks in the map area date from 84-75 Ma and are herein named the Windy-Table suite. Intrusions of this suite are generally small, only a few square kilometres in area, and are located within, or immediately flank, the Whitehorse Trough. Quartz dioritic compositions dominate (unit lKWqd), but granodioritic quartz-feldspar porphyries (unit lKWp) also occur. One small (0.5 km^2) but distinctive orange-weathering quartz syenite stock on the east flank of Ear Mountain is also included in the suite (unit lKWqs), although its age is poorly constrained.

Bultman (1979) originally included most intrusive bodies within the Whitehorse Trough as the "Whitehorse Trough intrusions". New isotopic age data and petrogenetic associations indicate that many of these plutons belong to either the Sloko suite or the Coast Intrusions. The name "Whitehorse Trough intrusions" has not been retained because of the potential for confusion with the "Whitehorse plutonic suite" of Hart and Radloff (1990).

Small dioritic intrusions in the Whitehorse Trough (lKwd)

Small dioritic stocks intrusive into rocks of the Whitehorse Trough include those on the south ridge of Bee Peak and in the broad valley east of Engineer Mountain. They are medium-grained and compositionally variable, ranging from diorite to granodiorite. Plagioclase may be euhedral and up to 50%, and interstitial quartz may comprise 30% of the rock. Biotite (2-15%) is commonly, but not always, more abundant than hornblende (5-10%). Both biotite and hornblende range from fresh to strongly altered. On the margin of the valley pluton, a series of decimetre to several metre-wide intrusive sheets with intervening screens of country rock suggests episodic emplacement.

A K-Ar (hornblende) age of 80 ± 3 Ma for tonalite from Bee Peak was determined by Bultman (1979).

Ear Mountain Quartz syenite (lKwqs)

Recessive-weathering, orange quartz syenite crops out on the southeast flank of Ear Mountain and in an unnamed drainage two kilometres to the east. It occupies the contact between probable Atlin complex massive cherts and Peninsula Mountain suite volcaniclastics. It is a miarolitic, high-level body thought to be coeval with late stages of Windy-Table volcanism. Locally it is pyritic and bleached. Contacts with adjacent strata are not directly exposed, but the closest outcrops to the presumed contact show little or no thermal effects of intrusion.

Altered Hornblende Feldspar Porphyry (lKwp)

Hornblende feldspar ± quartz porphyries crop out along the shores and north of Graham Inlet. Three distinct lithologies are included in the unit: intense argillic-altered stocks concentrated at the headwaters of Graham Creek; less altered, but compositionally identical dikes and sills; and weakly altered dacite-trachyte and rhyolite dikes, sills and local flow domes.

Medium to coarse-grained, altered hornblende-feldspar porphyry intrusions occur throughout the Penninsula Mountain volcanosedimentary package and within the lower Windy-Table volcanic package. Propylitic to intense argillic alteration of the porphyries commonly renders igneous classification impossible. However, outside the zones of intense alteration, relict crystal textures can be identified in an amorphous white, orange, yellow or green matrix. Hornblende is invariably ragged and chloritized, and feldspars are chalky ghosts of former subequant crystals up to 1 centimetre in diameter. Pyrite comprising several percent of the rock (up to 7%) is typically finely disseminated and dust-like, but can also form euhedral cubes (commonly up to 2 millimetres in diameter) or, in rare cases, veins one or two centimetres thick. Identification of this unit as an intrusion relies upon its uniform texture and irregular distribution. The possiblity that this unit is a coarse, lobate flow cannot be ruled out; however, a few relatively unaltered outcrops of the same composition are clearly dikes. Away from the influence of porphyritic stocks, northeast-trending dikes can be readily mapped. Such dikes are often accompanied by alteration halos up to a few metres thick in surrounding rocks, and are interpreted as subvolcanic feeders to hornblende-feldspar-porphyritic pyroclastic units in the Windy-Table volcanics. Thus, they were probably emplaced at very shallow levels just after explosive volcanic events that produced pyroclastics of about the same composition.

Hypabyssal dacite, trachyte and rhyolite bodies, like those formerly correlated with the Fourth of July Suite along the western margin of Graham Inlet (Aitken, 1959), are included in unit lKWp. Intense alteration is not common, permitting identification of light-orange weathering feldspar phenocrysts with accessory biotite, very fine grained hornblende, and rare quartz in this group of hypabyssal intrusions. Fresh matrix material is light to medium green and aphanitic, although in many places it has been subjected to argillic alteration and is light-orange in colour. Abundant vertical jointing and irregular cleavage development may be related to either emplacement or cooling. Similar feldspar porphyry dikes intrude the Peninsula Mountain suite and appear to be feeders to overlying 81.3 ±0.3Ma Windy-Table ash flows at Table Mountain (U-Pb zircon, Mihalynuk *et al.*, 1992; Table AA5).

K-Feldspar porphyritic dacite

Distinctive porphyritic dacite occurs as dikes and small stocks (too small to represent on Figure GM97-1) within the lower parts of the Penninsula Mountain suite stratigraphy and also cut the pillow basalt and ultramafic rocks of the Graham Creek suite. They are compact and difficult to break. Bright pink K-feldspar phenocrysts up to 2 centimetres across and grey, subidiomorphic quartz eyes up to 0.8 centimetres across are conspicuous. Outcrops have withstood glaciation and subsequent weathering to form light grey, resistant knobs.

The age of these intrusives is constrained as younger than the Peninsula Mountain volcanic units of mafic to intermediate composition, which they cut. They are older than youngest motion on the Nahlin fault because one small stock belonging to this unit is cut by the western strand of the fault (too small to show on Figure GM97-1; see Photo 6-1-2a) that was last active prior to 58 Ma (see preceding discussion).The stocks probably represent feeders to felsic Windy-Table volcanic units.

The incomplete ocean ridge granite normalized plot shown in Figure 12-19 reveals a topology most similar to that of the continental arc granites of Chile (Pearce *et al.*, 1984) with large ion lithophile elemental abundances most like the volcanic arc granite of Jamaica. The normalized Rb/Sr ratios that are much lower than those of typical syn- and post-collisional granites, although the Hf/Zr ratios are similar. Topology and abundances are very similar to those of the Stikine plutonic suite (Figure 12-7) suggesting a geochemically homogenous magmatic source area existed from Late Triassic to Cretaceous time. If the geological history of the Peninsula Mountain dacite is considered, it can be classified as a post collisional continental arc granitoid.

Surprise Lake batholith (84Ma, cooled 70-73 Ma)

The compositionally variable Surprise Lake batholith does not crop out within the map area, but occurs to the immediate east in the Atlin area. It is included here because it may be an intrusive equivalent to Windy-Table volcanic rocks and because it displays an unusual chemistry of economic importance, being elevated in uranium, thorium, fluorine, tin, rubidium, zinc, tungsten, molybdenum and boron. It is dominantly quartz monzonitic and lacks muscovite, although it is best known for alaskitic and volatile-rich phases and high uranium content.

Whole rock geochemical data were used to create the mesonormative plot shown in Figure 12-17 which shows a range from monzodioritic to monzo-granitic compositions. An average of 54 oxide analyses reported by Ballantyne and Littlejohn (1982) shows that the batholith is weakly aluminous and weakly peralkaline (Figure 12-18b). Granite discrimination plots of Y-Nb and Y-Nb-Rb show that it is a within plate granite. Major and trace element abundances are similar to those of A-type granites reported by Whalen *et al.* (1987, average and 1σ of 148 samples), with exceptions in the Surprise Lake pluton of marginally lower MnO and Na_2O values (0.01 and 2.97 percent versus 0.06 ±0.04 and 4.07 ±0.66) and elevated U, Th and Rb concentrations (22, 49 and 470ppm versus 5 ±3, 23 ±11 and 169 ±76).

An average of six K-Ar age determinations reported by Christopher and Pinsent (1982) is 70.6 ±3.8. Initial strontium ratios and Rb-Sr age determinations are geologically unreasonable, indicating significant isotopic disturbance (Mihalynuk et al., 1992a). Rubidium enrichment is indicated by trace element analyses and would have contributed to Rb-Sr isotopic disequilibrium. Only a single U-Pb age determination has been attempted because of anticipated problems with very high uranium, thorium and lead contents. It returned a date of 83.8 ±5 Ma that was reported in Mihalynuk *et al.* (1992a).

A-type granites are conventionally thought of as being linked to rifted anorogenic cratons; however, their genetic lineage requires no such restriction. In fact, Whalen *et al.* (1987) suggest that the depleted protoliths from which A-type granites are derived should be most common in reactivated orogenic belts. The most significant constraint on tectonic conditions under which A-type granite magmas form relates to attainment of the required high melting temperature (>830 °C). According to Whalen *et al.* such temperatures may be achieved through emplacement of mantle-derived magmas into the lower crust. Martin and Bonin (1976) suggested that hydration of a hypersolvus granite during its cooling history could lead to refusion of the body, serious disturbances in K-Ar and Rb-Sr systematics and enrichment in elements like Sn, W, Mo, Be, rare earths and F, in part scavenged from the host rocks by the fluid phase. Refusion is most likely to occur after the body has crystallized, but when a source of thermal energy is still available. Such a thermal source may be found in the location of the proposed 70Ma Yellowstone hot spot trace proposed by Johnston *et al.* (1996; see Chapter 15).

Sloko Plutonic Epoch

Plutonic bodies of the Sloko epoch in the Tagish map area include the Teepee Peak stock, large plutons at the south end of Tagish Lake and several bodies of less than $2km^2$ size near Engineer Mountain and Mount Switzer. In all cases, the intrusive bodies cut comagmatic Sloko Group volcanic strata. Small bodies display the greatest compositional variability; large bodies are granitic. All tectonostraigraphic terranes are cut by Sloko magmatic rocks (the Atlin complex is intruded just southeast of the map area; *cf.* Mihalynuk *et al.*, 1996). Plutons of this age also occur in the major "Coast plutonic belt I" of Brew and Morrell (1983).

Sloko granite (eEsg 55 Ma)

Sloko plutons greater than $5km^2$ in size are typically of granodiorite, tonalite or granite composition, like the 6 km^2 stock that underlies Teepee Peak, or the two large adjoining plutons that underlie approximately $90km^2$ and $45km^2$ of the southwestern mapsheet at White Moose Mountain and in the extreme southwest corner of 104M/8. Due to the hypabyssal nature of many of the Sloko intrusives, their geochemistry is presented in Chapter 11 along with Sloko volcanic rocks.

The Teepee Peak stock is a medium-grained granodiorite to tonalite. Near its northern contact it consists of: 10 per cent biotite, 15 per cent hornblende, 30 per cent quartz, 40 per cent altered plagioclase, and 5 per cent potassium-feldspar. On its eastern contact, a chilled margin 20 centimetres wide is cut by veins of pyrophyllite and carries 2 per cent coarse molybdenite rosettes. At this locality the modal composition is: 60 per cent quartz; 35 per cent feldspar (propylitically altered plagioclase?), 5 per cent muscovite; and minor altered biotite(?).

The pluton underlying southwesternmost 104M/8 displays only slight internal variations. It is a tan to pink, blocky weathering, medium-grained biotite granite, generally containing several per cent perthitic potassium-feldspar phenocrysts 1 to 2 centimetres long.

The White Moose Mountain pluton is dominated by non-foliated granite to granodiorite along the shores of southern Tagish Lake. It is pink to grey, medium to coarse-grained, contains 40-45% perthitic and zoned K-feldspar, 40% interstitial quartz, 10-15% plagioclase, and 2-5% euhedral biotite booklets. K-feldspar locally forms scattered (1-5%) megacrysts up to 5 centimetres long. Textural and compositional variants include mafic xenolith-rich zones, especially near contacts with overlying Sloko Group rocks, medium to fine-grained aplitic or micropegmatitic border zones, and interior zones with hornblende in amounts subequal to biotite. It is more texturally and compositionally heterogeneous along its western and southern margins, where it may be admixed with older plutonic rocks as indicated by K-Ar cooling ages older than Early Eocene (*cf.*, Bultman, 1979; Figure GM97-1). However, the pluton clearly cuts Sloko Group volcanic strata 5 kilometres south of the mouth of Swanson River.

A K-Ar biotite age date of 55.3±1.8 obtained from Teepee Peak is concordant with a U-Pb zircon date (within errors) from comagmatic rhyolite that it intrudes (Table AA1), and represents the emplacement age of this body. An exact K-Ar match for this date comes from the large pluton underlying southwestmost 104M/8, underscoring the regional importance of this magmatic pulse.

Biotite-hornblende quartz diorite (eEsdi. 55Ma)

A small stock (2 kilometres long) that crops out on the southwest flank of Engineer Mountain is the best example of this unit. However, quartz diorite also occurs locally at the contacts of the pluton that underlies White Moose Mountain where it extends south of Taku Arm. Grain size is variable and the quartz diorite may be locally admixed with K-feldspar-quartz porphyry (like the concentric dikes of unit eESr). Contacts with the surrounding country rocks tend to be sharp indicating high-level emplacement, consistent with its location subjacent to coeval Sloko volcanic rocks.

Hornblende syenite to quartz monzonite (eEsy 56Ma)

An orange hornblende syenite plug crops out south of Mount Switzer over an area of less than 1 square kilometre. It is medium to coarse-grained and varies slightly to quartz monzonite in composition. This body is important because it stitches the Wann River gneiss and Florence Range suites (Currie, 1994). A best age estimate was reported by Currie (1994) as 55.7 ±0.2Ma from the quartz monzonitic phase.

Rhyolite dikes (eEsr, many as symbols)

Two types of dikes are included in this unit: thin tabular bodies generally 0.2 to 5 metres thick and concentric large radius dikes commonly tens of metres thick. Chalky white, yellow-green or orange and platey-weathering dikes with sparse feldspar phenocrysts characterize this suite. Rarely quartz or, at one locality, pyroxene phenocrysts are also present. Dikes range from decimetres to over 150 metres across (one dike near Mount Fetterly is up to 700m thick); they generally have irregular margins and overall northeast strikes. These dikes commonly display flow foliation, perlitic zones and/or spherulitic devitrification features.

No direct age dating has been attempted, but the dikes are seen to cut the lower clastic part of the Sloko succession and are believed to be comagmatic with, and possible feeders to, the upper rhyolite flows and ignimbrites. West of Atlin Mountain they cut across the trace of the Nahlin fault and thus help to constrain the age of youngest motion on the fault.

Concentric rhyolite dikes are seen between the volcanic remnants at Mount Switzer and the two volcanic pendants to the west. They are tan to salmon-coloured, platey-weathering and sparsely quartz and K-feldsparphyric. Contacts with adjacent intrusions are sharp to gradational. Because they are concentric about the volcanic pendant, they are interpreted to be late volcanic feeders. The volcanic pendant may have survived because it was downdropped during caldera collapse. If this is so, the concentric dikes are typical collapse related ring dikes. Gradational contacts with the enclosing plutonic rocks may indicate that they are comagmatic and nearly coeval with the plutons.

Chapter 13 Structure

Like most of the Cordillera, the Tagish area is dominated by a northwest-trending structural fabric. This fabric persists across the area from the Atlin complex to the Nisling assemblage. Yet, to a large degree, this structural grain is a late-imposed fabric overprinting earlier fabrics that may not have originally been coaxial. Structural overprinting of disparate 'earlier' fabrics by a common 'late' fabric leads to structural styles that are unique to each terrane; reflecting their past evolution as separate entities.

In general, older rocks within the map area have been subjected to, and record, a greater number of deformational events - an observation well displayed through comparison of the metamorphic terrains with younger lithologies. Also, although sedimentary rocks of the Atlin complex and Whitehorse Trough both record shortening about a north-northwest axis, this overprints an early emplacement-related fabric displayed in harzburgite tectonites (Ash and Arksey, 1990b) of the Atlin complex. Late, northeast-trending, high-angle faults of the type found throughout the Intermontane Belt, are relatively pervasive; they affected even the youngest rocks in the area.

Four structural domains are recognized in the map area (Figure 2-2), based primarily on presence of, or differences in, older fabrics. Domain boundaries roughly correspond to terrane extents, but do not portray the limits of progressively younger deformational events which affect the amalgamated terranes. Most westerly is Domain I, which encompasses dominantly intrusive rocks of the Coast belt and does not represent a distinct terrane. Domain II includes mainly polydeformed Palaeozoic and older metamorphic rocks west of the Llewellyn fault. Domain III includes Mesozoic rocks of the Whitehorse Trough, dominantly Laberge Group, which is a fold and thrust belt. Most easterly is Domain IV which includes competent volcanic units of the Peninsula Mountain suite and the accretionary complex of the Cache Creek terrane, both east of the Nahlin fault.

Domain I, Intrusives of the Coast Belt

Late Cretaceous and younger intrusive rocks of the Coast belt within the map area do not display pervasive structural fabrics, however, discreet zones of late brittle to semi-ductile deformation are common. Brittle deformation zones within Late Cretaceous and Tertiary intrusive bodies probably represent faults related to uplift of the complex during the last 10 Ma (Donelick, 1988). Such zones are generally tens of centimetres across with unknown lateral extent. They are particularly well displayed along the shores of southern Tagish and Bennett Lakes (Photo 13-1).

A steep planar fabric is developed in the Early Cretaceous Mount Lawson tonalite between Fantail Lake and southern Taku Arm (Photo 12-10). It is produced by alignment of medium to coarse-grained hornblende or plate-like mafic-rich xenoliths which outline a hemispherical shell, but no consistent lineation has been recognized. These fabrics were probably produced during diapiric intrusion and inflation of the pluton. Older folds within the Boundary Ranges metamorphic suite are warped about the Mount Lawson pluton, supporting an interpretation of forceful intrusion.

Domain II, metamorphic rocks

Domain II is defined by the distribution of old metamorphic rocks within the Tagish area (see Chapter 3). Metamorphic rocks can be grouped into three main packages from north to south: greenschist to amphibolite grade arc rocks of the Boundary Ranges metamorphic suite (probable Stikine Assemblage, including the Wann River gneiss), Jurassic plutons of the Aishihik plutonic suite, and amphibolite grade miogeoclinal strata of the Florence Range metamorphic suite (regionally correlative with the Nisling Assemblage). Each metamorphic

Photo 13-1. Brittle deformation zone in *circa* 56 Ma Sloko pluton may have been produced during isostatic uplift.

package displays a different structural style: Boundary Ranges suite is characterized by polyphase, non-coaxial deformation (Table 13-1), whereas, farther south, in the Hale Mountain granodiorite, Wann River gneiss and Florence Range suite, fabrics are low-angle (Figure 13-1), produced or transposed by the latest pervasive ductile deformational event (Table 13-2). Differences in structural style are due primarily to contrasting protolith age and competency and structural level of deformation. Most evidence suggests that the structures preserved share a common lineage rather than having been produced in disparate paleotectonic environments.

Boundary Ranges metamorphic suite deformation

Five deformational events can be recognized in the Boundary Ranges suite; they are designated D1 through D5. Planar fabrics were produced, at least locally, during each of the oldest four events; these are designated S_1 to S_4. Associated folds are designated F_1 through F_4. The youngest four events were described by Mihalynuk *et al.* (1989a) and by Currie (1994). These papers do not present evidence for an older, cryptic deformation (D1). D1 folds (F_1) are rarely preserved in outcrop, evidence for their existence can more commonly be found through petrographic analysis. No clear examples of large scale F_1 folds have been identified in the Boundary Ranges suite,

Table 13-1. Deformation and metamorphism: Boundary Ranges metamorphic suite.

First Deformation-Metamorphism Event (D1)	
S_0	consists of original bedding/layering, such as carbonate in which layers are visible but thicknesses are distorted - both thickened and thinned. Competent layers are boudinaged.
S_1	is the oldest foliation, preserved as rootless, intrafolial isoclines (Photos 13-5) outlined by trails of fine-grained graphite and lesser muscovite in quartz.
F_1	apparently forms rare, outcrop-scale isoclinal folds, but none have been conclusively identified (a possibe lexample is in Photo 13-3); best represented by relict crenulations in probable hinge zones. Traces of F_1 are obliterated by the dominant and peak metamorphic foliation (S_2). D1 may not have been regionally developed.
Second Deformation-Metamorphism Event (D2)	
S_2	is the dominant foliation and generally parallels transposed compositional layering defined by the growth of chlorite, muscovite, actinolite, biotite, garnet, and in pelitic rocks, rare kyanite or staurolite.
F_2	forms relict D2 folds that are scarce (Photo 13-3), but in these, S_2 distinctly crosscuts fold hinges (Photo 13-4). F_2 are typically close to isoclinal.
Third Deformation Event (D3)	
Some evidence points to a continuum between D2 and D3. Two D3 fold styles are apparent depending upon lithologic competency:	
F_{3A}	folds with variable hinge-line orientations including sheath folds (indicate differential strain along hinge-lines) typically formed within chlorite schists adjacent to the Llewellyn Fault (Photo 13-10).
F_{3B}	folds occur in more competent units and produce styles that are open to close and commonly chevron in nature.
S_3	is a crenulation cleavage that is only locally developed (Photo 13-6). Crenulations may fold actinolite, biotite, chlorite and muscovite.
Fourth Deformation Event (D4)	
F_4	is observed on kilometre-scale as refolding of closed F_{2-3} folds, especially notable within the chlorite schist/marble succession (see Figure 13-2).
S_4	is sub-parallel to the limbs of tightly refolded F_2 and F_3 folds (Figure 13-2) and locally decapitates these F_2 and F_3 folds on an outcrop scale.
Fifth Deformation Event (D5)	
F_5	broadly folds F_4 and earlier structures as they are warped around intrusions such as the Mount Lawson tonalite salient, mainly as a result of forceful intrusion (*see* Figures GM97-1). No foliation is developed in response to this event although earlier fold limbs may be further attenuated.

Table 13-2. Deformation and metamorphism: Florence Ranges metamorphic suite.

First (Cryptic) Deformation-Metamorphism Event (D1?)	
S_1	consists of rare curvilinear inclusion trails in garnet porphyroblasts that may be the only relicts of the earliest deformation, although, Currie (1994) reports rare early folds with refolded axial planar foliation.
Second Deformation-Metamorphism Event (D2)	
S_2	is the dominant foliation into which original compositional layering has been transposed (*e.g.* massive marble bands), generally S_0, S_1 and S_2 are parallel and outlined by muscovite and biotite, and less commonly, garnet and kyanite concentrations. Muscovite, biotite and kyanite are wrapped around the D1? garnets. Peak pressures were attained during this event.
F_2	No major F_2 fold closures have been observed.
Third Deformation-Metamorphism Event (D3)	
F_3	folds were developed at scales ranging from kilometres to metre-sized parasitic folds or fine crenulations. Currie (1994) reports that most of the large folds are northeast-verging.
S_3	is locally developed, especially where S_2 is crenulated in fold cores. Idioblastic andalusite overgrows deformed biotite and mantles kyanite porphyroblasts.
Fourth (Isostatic) Metamorphic Event (D4)	
	Isostatic growth of randomly oriented fibrolite may mantle both andalusite and kyanite, or nucleate on biotite.

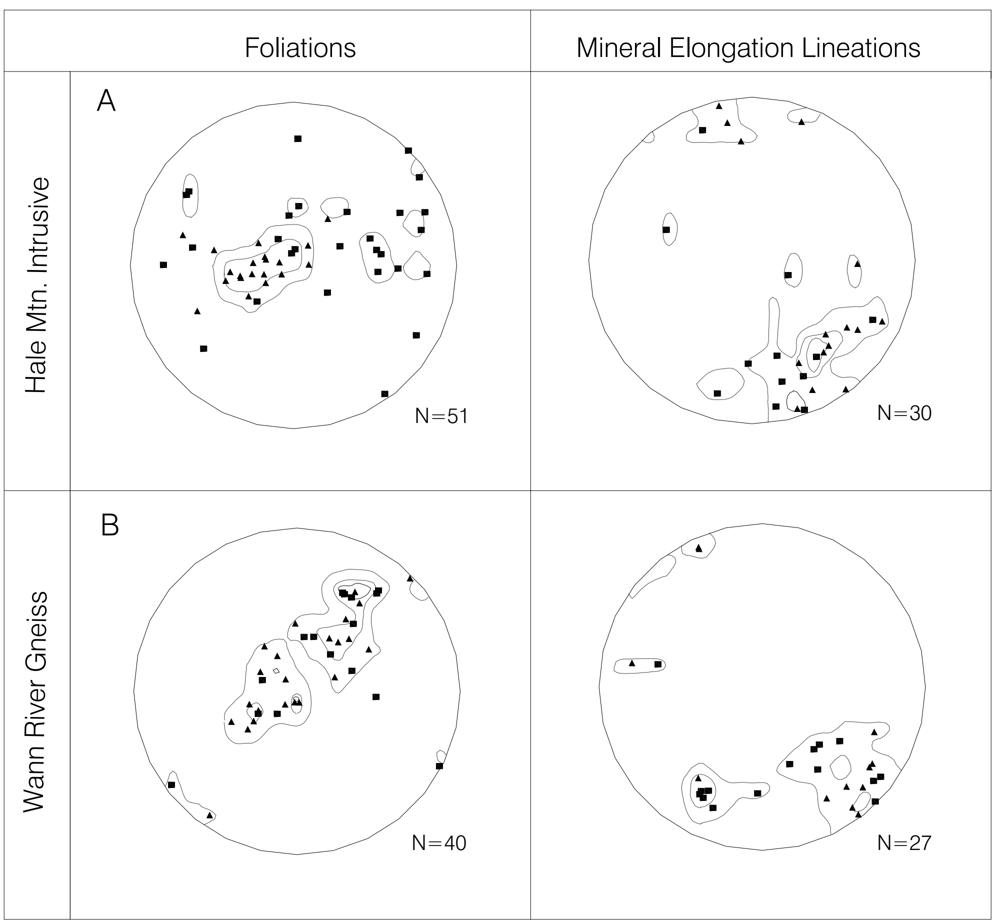


Figure 13-1. Equal area stereonet projection showing poles to foliation and mineral elongation lineations from (a) Aishihik plutonic suite, and (b) Wann River gneiss.

Photo 13-2. Folds with variable hinge-line orientations include sheath folds (indicate differential strain along hinge-lines) typically formed within chlorite schists adjacent to the Llewellyn Fault .

Photo 13-3. In a relatively rare occurrence, an equivocal second phase fold within Boundary Ranges metamorphic suite rocks is seen to deform a first phase fold. Irregular tight to isoclinal second and third phase folds are most typical of this rock package (S_{0+1} surface is highlighted in white).

but rare, outcrop-scale folds might be F_1 (Photo 13-3). Hand-sample-scale decapitated D1 microfolds are more common (Photo 13-4). They may be outlined where low grade assemblages like chlorite and actinolite in metatuffs are preserved (Photo 3-4) or by graphite and muscovite in pelitic rocks. Rootless hinges occur as inclusions in intrafolial (S_2) quartz microlithons (Photo 13-5) in pelitic rocks; they are interpreted to have formed during an early, lower grade deformational event. D2 and D3 are progressive deformational events. D2 appears to have produced the dominant foliation which is outlined by chlorite, epidote, actinolite (± hornblende), garnet and, in pelites, andalusite and rare kyanite. Idiomorphic garnet overgrows S_2 which may be folded by open microfolds prior to garnet growth. Microfold growth outlasted garnet growth with amplification of microfold amplitude and limb slip, and ultimately development of S_3 (Photo 13-6), presumably in the axial zones of F_3 folds. Kilometre-scale F_3 folds are commonly northeast-verging, such as those outlined by carbonate layers on Sections E-E' and F-F' of Figure GM97-1. D3 fold styles vary with lithologic composition. Competent lithologies commonly display open to close chevron fold development. Incompetent units like chlorite schist display variable F_3 hinge line orientations and sheath folds, especially adjacent to the Llewellyn Fault zone (Photo 13-2). Progressive D3 folding and concomitant retrograde metamorphism in such units has produced a curious alignment of nematoblasts (principally actinolite); adjacent schist layers within the same limb of the same fold display different orientations, or random orientations. Presumably individual schist layers acted as closed systems and metamorphic mineral growth occurred at slightly different stages in the progressive development of the fold limbs.

D4 is most readily recognized where F_4 and F_3 folds are noncoaxial. Good F_3-F_4 interference fold patterns are widespread, with the best examples outlined by carbonate such as is demonstrated at Brownlee Lake (Figure 13-2). Locally retrograde D3-D4 mineral assemblages (actinolite, chlorite, epidote) predominate in the axial regions of F_3 and F_4 (see planar fabric orientations in D3-D4 interference fold of Figure 13-2).

D5 is produced by broad warping of D3-D4 structures and fabric about near vertical axes. This warping is in response to forceful intrusion of Early (and ?Late) Cretaceous plutons, minor Jura-Cretaceous adjustments in the orientation of the Llewellyn Fault zone and shortening across the Whitehorse Trough. Peak thermal metamorphism was attained locally during D5 as a result of the huge volume of intrusive rocks emplaced on the western margin of the domain (Photo 3-1). One D5 fold is coeval with emplacement of the Mount Lawson Tonalite which returns a Middle Cretaceous K-Ar cooling age (133Ma, Bultman, 1979; Table 2-1). Here, F_4 folds and foliation wrap around the eastern end of the pluton (Figure GM97-1).

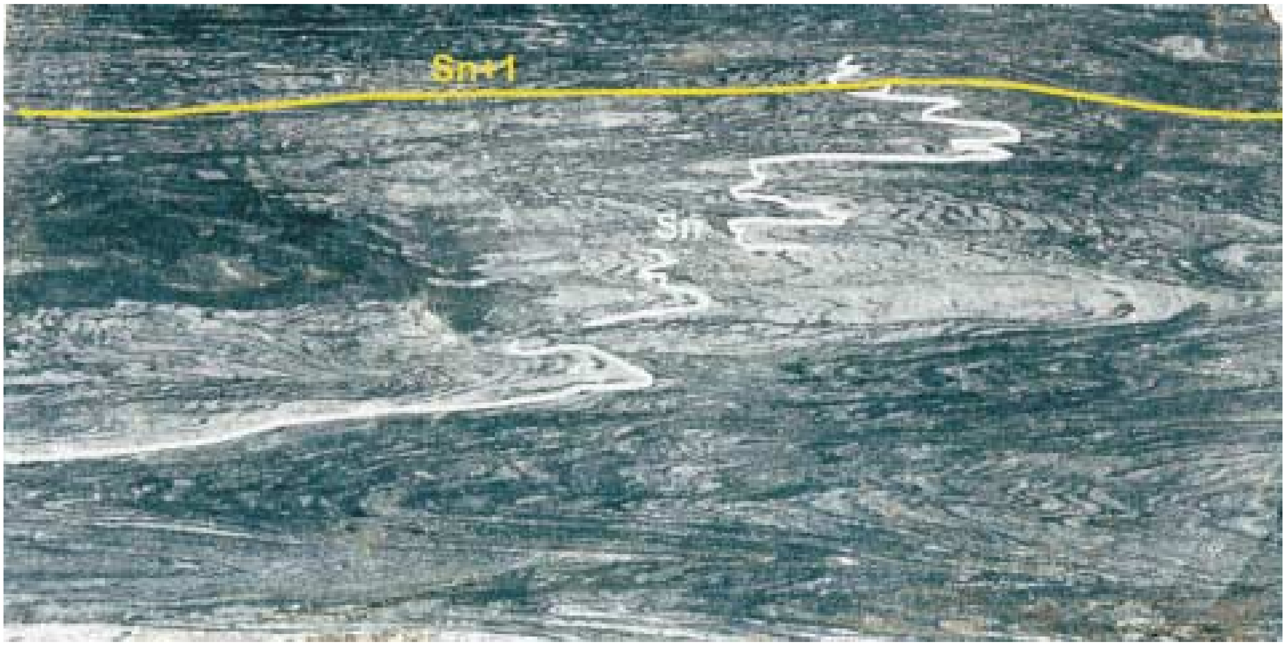


Photo 13-4. Dominant D2 fabric (S_{n+1}) masks earlier foliation (S_n) in outcrops of Boundary Ranges metamorphic suite rocks. While the early fabric is not apparent at the outcrop, cut and polished samples such as this clearly display the earlier fabric (S_1).

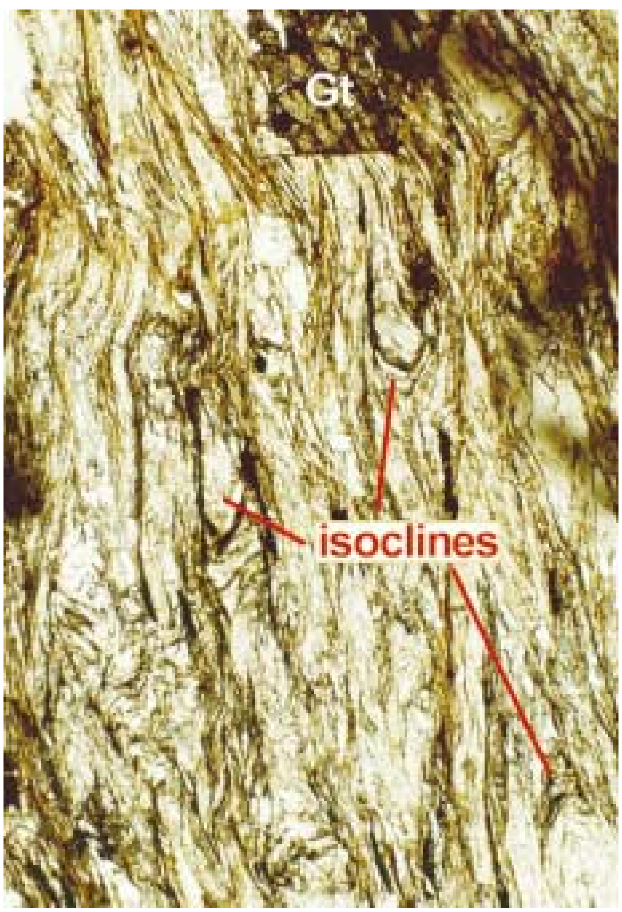


Photo 13-5. Rootless intrafolial isoclines preserve S_1 in a graphitic garnet (Gt)-muscovite schist dominated by S_2. Long dimension of photomicrograph represents 2.5 mm (sample CWA88-60-7).

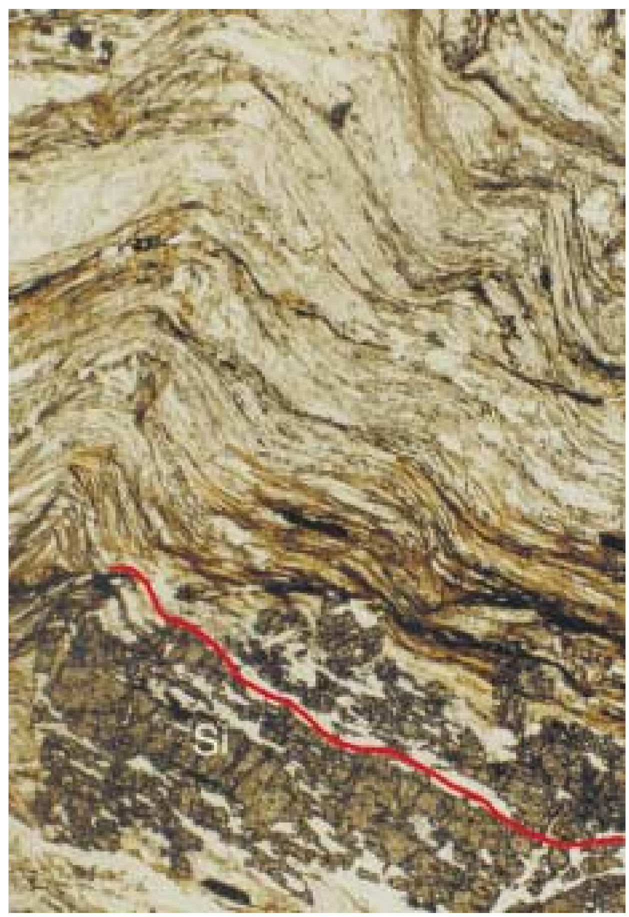


Photo 13-6. Idiomorphic garnet overgrows wavy S_2 (Si). Outside the garnet the microfold amplitude has increased and incipient S_3 is developed.

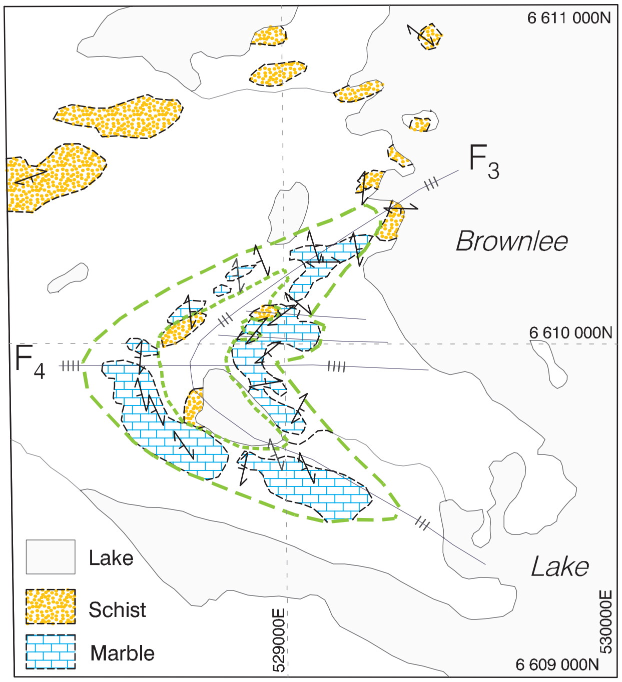


Figure 13-2. Detail of an interference fold just west of Brownlee Lake.

Florence Range metamorphic suite deformation

Four deformational events can be recognized in the Florence Range suite; they are designated D1 through D4. Associated folds are designated F_1 through F_4. Planar fabrics were produced, at least locally, during the three oldest events; these are designated S_1 to S_3. Deformation within the Florence Range suite is discussed in detail by Currie (1994) who presents an alternative interpretation of deformation and its relation to metamorphism than is presented here. In essence, she recognizes two major deformational events: an early deformation that produced the dominant transposition fabric, and a later deformation that folded and locally overprinted the earlier fabric. Petrographic analyses conducted as part of this study indicate that, as in the Boundary Ranges metamorphic suite, a cryptic deformational event predated the oldest event recognized by Currie (1994). Furthermore, a late, dynamothermal event resulted in oriented growth of andalusite at the expense of kyanite (Photo 3-7).

Microfolds outlined by inclusion trails of quartz and muscovite in garnet (Photo 13-7) are the primary evidence for an early cryptic event; denoted here as “D1?” (Table 13-2). D2 produced the dominant transposition fabric, S_2, within the Florence Range suite. It is generally layer parallel and is defined by formation of quartz ribbons, and muscovite and/or biotite-rich which layers which envelope cogenetic garnet, andalusite and kyanite. D2 records peak dynamothermal metamorphism. D3 deformed earlier-formed porphyroblasts and developed kilometre-scale northeast-verging folds (see Currie, 1994, Figures 4.5b and c) as well as several orders of subordinate parasitic folds. Idioblastic, oriented andalusite was developed locally during D3. Finally, D4 (and perhaps a later, localized deformational event) produced open folds in the hangingwall of the Wann and Willison Creek Fault zones as mapped by Currie. Fabrics developed in the axial regions of these folds are denoted by Currie (1994) as S_{3T} and S_{3+n}, respectively. Translated into the notation of this study, these fabrics are S_4 and S_{4+n}.

Structural history comparison

The foregoing descriptions record evidence of similar deformational histories in both the Boundary Ranges and Florence Ranges metamorphic suites. An early low grade metamorphic event produced a cryptic foliation, S1, that was all but obliterated during the later, dominant deformational event (D2) which was coeval with peak dynamothermal metamorphic conditions, as indicated by growth of kyanite in the dominant S2 foliation. During D3, mainly northeast verging folds resulted in formation of S3, deformation of S2 minerals, including kyanite

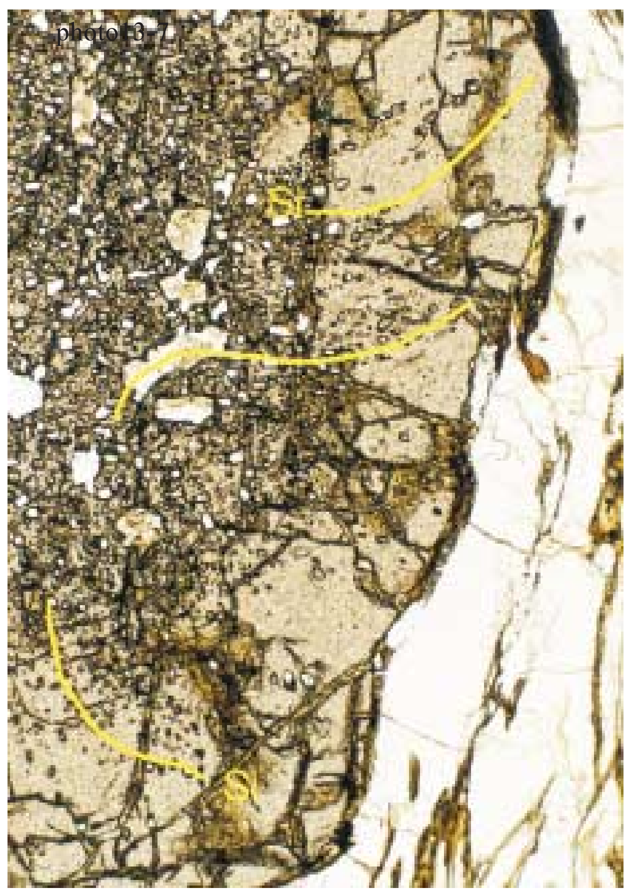


Photo 13-7. Garnet porphyroblast enveloped by S_2 encloses Si inclusion trails

(Photo 3-2a, b), and overgrowth of the S2 fabric by andalusite (Photo 3-3). Folds formed during D4 may be noncoaxial; those in the Florence Range metamorphic suite trend northeast. Examples of large-scale D4 interference folds where mapped in the Florence Ranges suite south of Tagish Lake by Currie (1994; Hale antiform and Willison synform) and, in the Boundary Ranges suite, near Brownlee Lake (this study; Figure 13-2).

Currie (1994) identified and isotopically dated the Wann River shear zone that apparently affects rocks over a thickness of more than 4 kilometres. Shear zone fabrics are principally developed in the Wann River Gneiss of the Boundary Ranges suite, but also extend up to 1 km into structurally overlying Florence Range suite and 3 km into the upper parts of the structurally underlying Boundary Ranges metamorphic suite (structurally underlying rocks are mainly Aishihik plutonic suite, see cross sections K and L, Figure GM97-1). Best constraints place the age of motion at between 184 and 176 Ma. Age limits are provided by the youngest unit caught up in the deformation, the Mount Caplice quartz monzodiorite; the age of metamorphic monazite (180.9 ±3.1 and 177.5 ±1.5 Ma; Currie, 1994) formed at the same time as minerals that apparently overprint the early transposition fabric of the Wann River shear zone; and the age of pegmatites dykes that are both concordant and discordant with fabrics in the Hale Mountain granodiorite (Photo 13-8d) and are dated at 178.8 ±0.9Ma . Early penetrative transposition fabrics display top to the south-southeast sense of shear and south-southeast mineral-elongation lineation (Figure 13-1a, b). Fabrics in the Wann River shear zone formed under transitional greenschist - amphibolite conditions that are typical of the Boundary Ranges suite.

Currie correlates the Florence Range with Tracy Arm assemblage and called them both Tracy Arm Terrane. Currie's main terrane-defining criteria are the quartz-rich, pericratonic nature of protoliths and the "scarcity of rocks with igneous protoliths". However, in the type locality, Gehrels *et al.* (1990a) states that the Tracy Arm assemblage "grades (up section?) westward into a sequence that contains quartzite, metapelite, and minor marble, but is dominated by metarhyolite (with blue quartz eyes) and metabasalt." (the Endicott Arm assemblage; further documented by Gehrels *et al.*, 1992). If this is the case, the Tracy Arm assemblage must contain some related felsic magmatic rocks as plutons or feeder dikes in addition to the metamorphosed basalt and tuffs that are recognized by Currie (1994) as part of the Tracy Arm Terrane. Indeed it does, and in the Tagish area these are also recognized by Currie (1994) as part of the Florence Range suite. They are rare quartzo-feldspathic gneiss layers less than one metre thick. It is possible that the scarcity of felsic meta-igneous rocks in the Tracy Arm Terrane as defined by Currie (1994) is more apparent than real, and has more to do with the abundance of such rocks in her small study than with regionally important, terrane-defining characteristics.

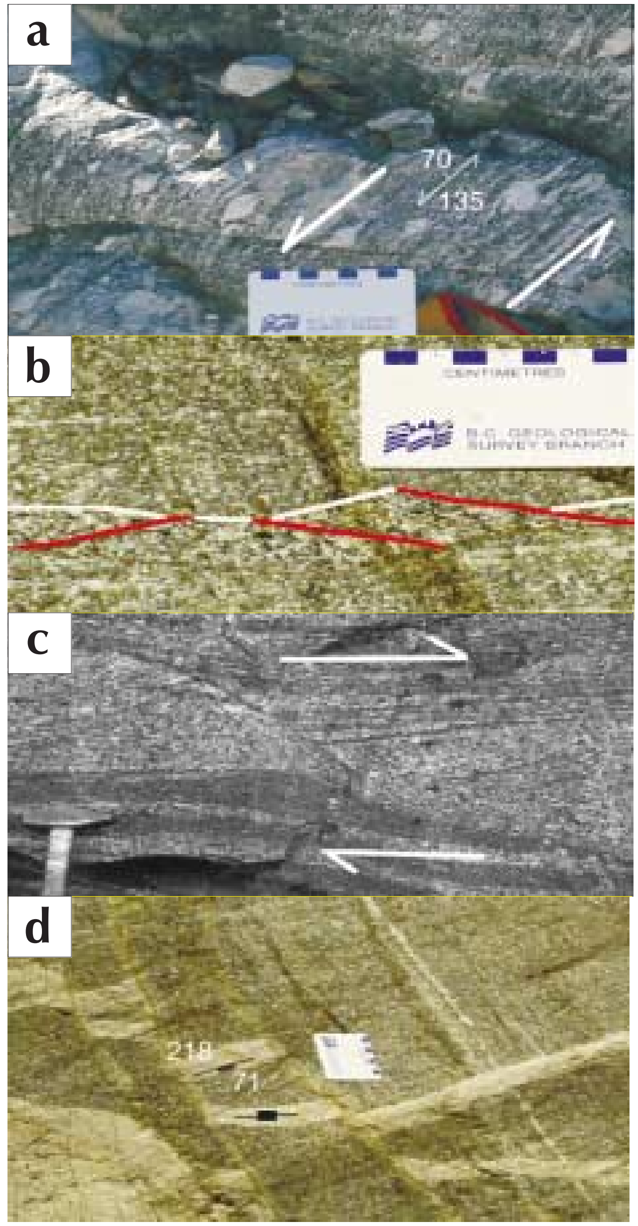


Photo 13-8a. Deformation within the 185Ma Hale Mountain hornblende granodiorite produced sigma-type augen indicating top-to-the-left (south) motion. A well- developed mineral lineation outlined by hornblende is approximately parallel to the outcrop surface; (b) Offsets within a light-coloured and relatively coarse-grained layer within the Hale Mountain hornblende granodiorite. Anisotropy within the light layer is discordant with that of the bounding gneiss (compare with 8c) providing slip planes which accommodate rotation and flow partitioning in a domino fashion. Notice that the left-most shear band cuts layer anisotropy and the block is back-rotated. Both shear sense indicators are consistent with bulk sinistral strain (viewed down to the west); (c) Back rotated asymmetric pull-aparts in Hale Mountain granodiorite. View is to the east-northeast with indicated offset of top-to-the south; (d) Pervasive brittle faults offset abundant pegmatite dikes intruding the Hale Mountain granodiorite. Offset is mainly east-side-down and dextral. Some of the pegmatite dikelets are ductilely deformed such as the one boudinaged on the right of the photo. U-Pb zircon age dating of these pegmatites points to an age of 178.8 ±0.9Ma (Tables AA1, AA2). A change from sinistral ductile deformation to brittle dextral deformation probably occurred at this time.

Photo 13-9. Mafic-rich layers within the Hale Mountain intrusive locally display tight to isoclinal folds with axes parallel to the regionally developed mineral lineation.

An additional possible link between the Tracy Arm and Florence Range assemblages are Rb-Sr cooling ages of 210 and 244 Ma (Werner, unpublished, 1978) from the Florence Range that correspond to U-Pb isotopic disturbance ages of 210 ±25 and 242 ±97Ma from zircons of the Tracy Arm assemblage (Gehrels *et al.*, 1991b). However, because limits of error are so large, the age similarities may be more perceived than real. Nevertheless, isotopic disturbance ages may be a useful tool for metamorphic correlation by future investigators.

The youngest units to be affected by dynamothermal metamorphism in Domain II are intrusive rocks of the Hale Mountain granodiorite. Kinematic indicators are locally well developed and show top-to-the-southwest sense of motion (Photos 13-8a, b, c). In contrast with younger plutons, it is clearly folded. It contains limbless, recumbent enclaves of Boundary Ranges metamorphic suite rocks and mafic xenoliths that display a strong axial parallel, north northwest lineation (Photo 13-9; Figure 13-1a).

Domain III (Whitehorse Trough)

Laberge Group

Sediments of the Laberge Group record a continuum of deformational events that began during deposition of the strata and peaked during contraction of the basin in Toarcian to Bajocian times during terrane amalgamation. Evidence of earlier deformation is ambiguous. Intraformational conglomerate (Photo 9-7) and unconformities (Photo 9-3), numerous clastic dikes (Photo 9-6) and slump folds (Photo 9-5) may all be attributed to early deformation, but could also result from deposition on unstable submarine fans. Clear evidence of syndepositional tectonism such as widespread coherent folds, or reverse growth faults, is lacking. However, numerous slope failure and dewatering structures in the Whitehorse Trough are suggestive of deformation-related seismic events within the basin. Early Jurassic basin architecture was probably controlled in part by the Llewellyn fault which today is coincident with the western limit of the contiguous Laberge Group. Outliers of Laberge Group west of the fault resemble Toarcian strata and rest on Boundary Ranges metamorphic suite rocks, indicating a radical westward thinning of the Laberge Group across the fault (Figure 9-2). Thus, syndepositional motion on the Llewellyn fault and genetically related deformation in the basin, probably played a large role in controlling the distribution of Laberge Group strata.

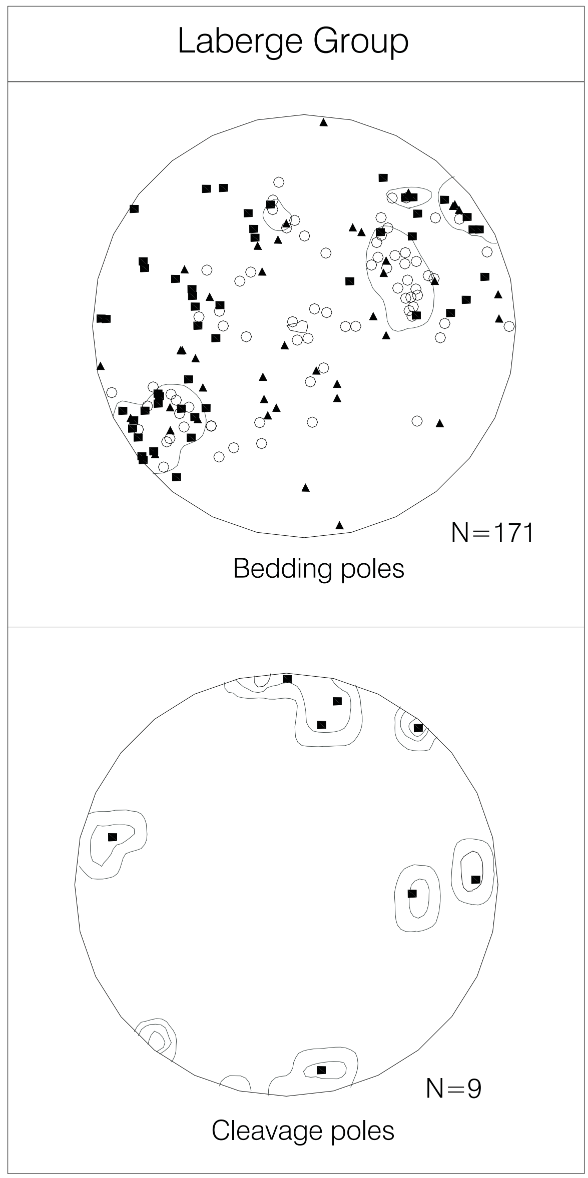


Figure 13-3. Equal area stereonet projection showing contoured poles to bedding and cleavage measurements from the Laberge Group.

Only one example of an early fabric, (fracture cleavage) which is folded by the dominant deformation that affects the trough, has been seen. The outcrop is located about a kilometre from the Llewellyn Fault, south of Racine Lake. This early cleavage probably formed during an early folding event. However, it may also have developed during the early stages of the dominant deformational episode and was subsequently folded as the deformational event progressed .

Perhaps the best evidence for an early Laberge deformation is a conglomerate comprised dominantly of Laberge Group clasts which is interbedded and then folded along with volcanics of suspected Early to Middle Jurassic age (Figure 10-2). However, the age of the volcanic rocks is not well constrained (*see* Chapter 10).

Deformation within the Whitehorse trough is extensive (Bultman, 1979: Mihalynuk and Rouse, 1988a,b; Mihalynuk, et al., 1990b, 1989b; and Mihalynuk and Mountjoy, 1990a). At the latitude of Graham Inlet, shortening has reduced the preserved basin width by at least 50 percent, based upon bed length measurements in the interpretive cross sections of Figure GM97-1. This shortening has been accommodated by a series of north-northwest-trending thrust faults and pervasive closely-spaced, open to close, upright to overturned folds (Figure 13-3) with half-wavelengths of up to 500 metres or more. Actual shortening is probably much greater (perhaps twice as much) because a conservative approach was followed in creating the cross sections. Also, lack of fossil age data does not permit the identification of cryptic thrusts, motion on thrusts such as those at Deep Bay cannot be constrained due to lack of hangingwall-footwall cutoffs, and the pop-up structure projected into sections H'-H" and I-I' (Figure GM97-1) represents an unknown bed length that could be tens of kilometres.

Overall fold and thrust vergence is mainly toward the southwest, but near the eastern margin of the trough is dominantly northeast. Laberge Group rocks near Atlin Mountain are tight to isoclinal with steep to west-dipping axial surfaces. Fold axes plunge gently to moderately southeast. Asymmetric extension within the axial zones of high amplitude folds near the Llewellyn fault is recorded by brittle deformation of cobbles within paper shale that has a vertical fabric. Rotation of the clast fragments suggests sinistral shear (Figure 13-4). Numerous joint sets and bedding parallel shears also affect these rocks.

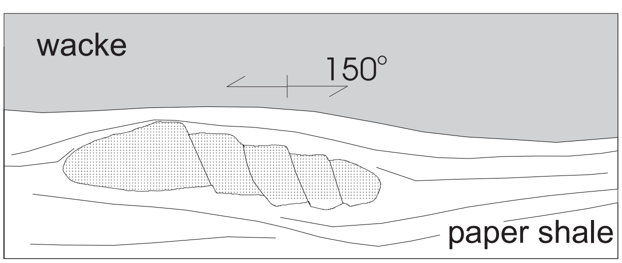


Figure 13-4. A reproduced field sketch of an extended clast within the axial portions of a high amplitude fold in Laberge Group shale near the Llewellyn Fault. An intense fracture cleavage in the paper shale (almost phyllitic) is vertical. Rotation of the clast fragments indicates a component of sinistral shear. Seen in plan view.

Constraints on the age of major shortening are good but not precise. Folding definitely postdates the youngest Laberge strata deposited in mid to Late Toarcian time (181 to 178Ma on time scale of Pálfy *et al.,* 1998), and folds are cut by plutons as old as Late Cretaceous (*e.g.* 92 Ma Jack Peak pluton; Bultman, 1979). However, the folding appears to be kinematically linked to emplacement of the Cache Creek Terrane. Slivers of mantle tectonite and MORB occur sporadically along faults within the trough north of Graham Inlet and into the Yukon (*cf*. Hart and Orchard, 1996; and "Nahlin Fault" section below). Early fabrics including emplacement structures are clearly cut by the Fourth of July batholith (*c.* 172Ma; Mihalynuk *et al.,* 1992a). Folding probably occurred during the crustal thickening event responsible for the formation of leucosome during peak metamorphism in the Florence Range metamorphic suite, dated by Currie as 177 Ma. Thus, major basin shortening formed between 183 and 172 Ma, and probably prior to the 177 Ma age of peak metamorphism in the Florence Range.

Stuhini volcanic strata

Widespread folding that affects the Laberge Group does not persist down into Stuhini Group strata. Instead, the Stuhini Group appears to have deformed as a series of semi-rigid, east-dipping blocks. No clear duplication of stratigraphy by large, mountain-scale folding or thrust faults has been identified, although high angle normal faults and minor outcrop-scale folds locally thicken the section. One clear example of isoclinal folding on the south shore of Willison Bay is attributed to soft sediment deformation.

A strain discontinuity occurs at the top of the Sinwa Formation, which locally acts as a detachment horizon. Where Stuhini Group strata border the Llewellyn fault, they are variably foliated and shuffled. North of Racine Lake, Stuhini conglomerate appears to be folded in the hangingwall of a reverse fault. Displacement on the reverse fault decreases to the north. The geometry of Laberge Group units immediately overlying the conglomerate suggest a low angle thrust, but this configuration could also arise from rapid facies changes and part of the conglomerate could be Jurassic in age.

Domain IV

Domain IV covers the western margin of the Cache Creek terrane (Figure 2-2). Deformation in the domain is dominated by north-northwest-trending high angle faults kinematically linked to late motion on the Nahlin fault (see 'Nahlin fault"), and east to northeast faults related to Late Cretaceous volcanism.

Deformation of Peninsula Mountain volcanic strata

Like volcanics of the Upper Triassic Stuhini Group, the Middle to Upper Triassic Peninsula Mountain strata appear to have acted mainly as a rigid body, and were only deformed by broad open folds (cross sections H"-H''' and I-I'). In contrast, Laberge Group strata within this domain outline upright chevron folds (as in cross section I-I', Figure GM97-1). Deformation of the Late Cretaceous Windy-Table volcanics has resulted mainly in variable tilting of the strata. Most synvolcanic dikes in the Table Mountain area are parallel to the east to northeast fault set, supporting a cogenetic origin for this fault set. Broad warping of the young volcanics may be due to draping over pre-existing topography and/or variable compaction.

Deformation of the Atlin complex

Rocks of the Atlin complex within the map area are dominated by units interpreted to have formed in an accretionary complex. In such environments, broken formation and discontinuous, fault-bounded units as seen in the Atlin complex are typical. Three families of structures probably contributed to deformation of the complex: thrust faults accompanying accretionary prism development during accumulation of hemipelagite and ocean crust fragments scraped off subducting oceanic lithosphere; west-verging folds and thrusts related to emplacement of the Cache Creek terrane; and high angle fault and shear zones related to late motion along the Nahlin fault. Due to the limited extent of the Atlin complex in the map area, lack of age data, lack of continuous marker horizons, complexity of deformation and apparently incoherent folding, the study did not significantly advance the understanding of Cache Creek deformation. Only structures related to the Nahlin Fault were clearly distinguished, and only in some instances. Timing and extent of earlier structural events remain unresolved.

Crustal-scale Faults

Understanding the timing and magnitudes of motion on major fault segments, as well as their relationship to other structures, is a key exercise in unravelling the tectonic history of the Cordillera. In the Tagish area, three crustal-scale faults influence the distribution of major lithologic packages and their past interrelationships. The Llewellyn fault Tally-Ho shear zone system (LFZ-THSZ)

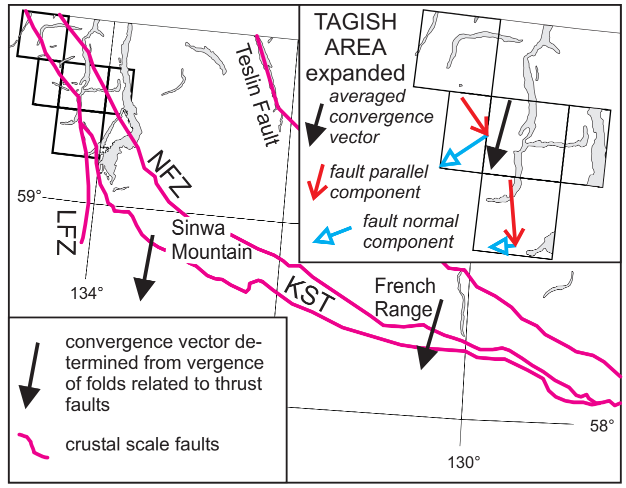


Figure 13-5. A sketch of crustal scale fault geometries in northwestern British Columbia. Generalized mid Jurassic convergence is assumed to be consistent across the Atlin complex, and are extrapolated from those unambiguously determined in the Dease Lake area. South-southeast vergence on the southern portion of the Nahlin Fault zone (NFZ) is interpreted to translate northward to dominantly dextral motion as the fault orientation changes. Likewise, the King Salmon Thrust (KST) may merge with the Llewellyn Fault zone (LFZ) north of Atlin Lake where strike slip motion is dominant. The Tagish area is expanded in the inset to show more detail.

coincides with the boundary between structural domains II and III and the eastern limit of polydeformed metamorphic rocks; the Nahlin fault zone (NFZ) marks the division between domains III and IV and the western limit of oceanic crustal slivers within the Whitehorse Trough; and the King Salmon thrust (KST), although not unequivocally isolated within the study area, is important because of its kinematic linkage with the Llewellyn fault and its role in terrane amalgamation regionally. Regional fault geometry is shown in Figure 13-5.

Nahlin Fault

Regionally, the Cache Creek Terrane is bounded to the west by the Nahlin fault zone which coincides along much of its length with a belt of alpine ultramafites (Figure 5-2). The fault extends far beyond the limits of the map area. To the south, it is particularly conspicuous because it outlines the southwestern limit of the largest ultramafite in British Columbia, the Nahlin Ultramafic body (*c.f.* Terry, 1977); and to the north, small slivers of ultramafic crop out along the fault at irregular intervals.

In the Tagish area, the NFZ extends from northern Torres Channel to north of Sunday Peak. It generally juxtaposes deformed marine sediments of arc provenance belonging to the Laberge Group and dismembered oceanic rocks of the Atlin or Graham Creek complexes. In many occurrences oceanic crustal rocks include lenses of tectonized mantle harzburgites. Outcrop patterns show this fault to be a high angle structure, but it probably originated during Cache Creek Terrane emplacement as a low angle, west-directed thrust.

In detail, this fault is an anastamosing network of subparallel strands of varying age that record various amounts of offset. A structural unit along the western shore and inland of Torres Channel is coincident with the mapped trace of the NFZ. It is characterized by a chaotic mix of fine to medium-grained volcanic wacke and mudstone with subordinate sheared basalt, localized zones of black cataclastic rock and lenses of diorite to ultramafite. Small rootless isoclinal folds and dismembered compositional layering on millimetre to centimetre scale are overprinted by an outcrop to regional scale penetrative shear fabric.

North of Torres Channel the fault is more complex, consisting of several strands that occupy valleys on the mountain above the Channel. The fault can be traced further to the northwest as a series of notched ridges on the north side of Atlin Mountain. North of Atlin Mountain the fault is obscured by alluvium and passes under Graham Inlet. The western-most fault strand cuts Laberge Group strata near Mount Fetterly (Figure GM97-1). It is a

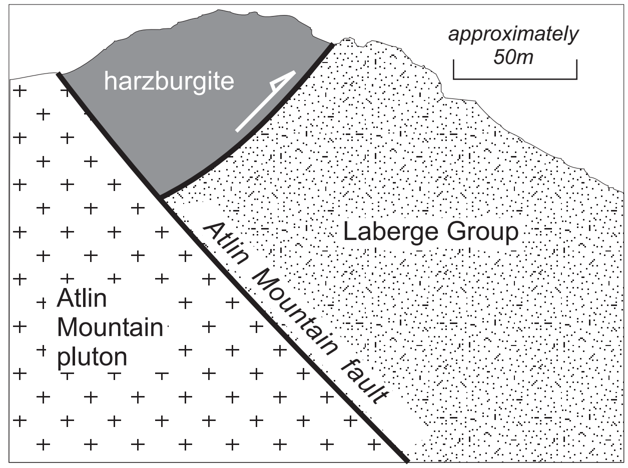


Photo 13-10. A sketch of a photograph showing an ultramafic block that sits above Laberge Group strata along the Atlin Mountain fault, a reactivation plane rooting in the Nahlin Fault zone (*cf.* Bloodgood and Bellefontaine, 1989). View is to the south.

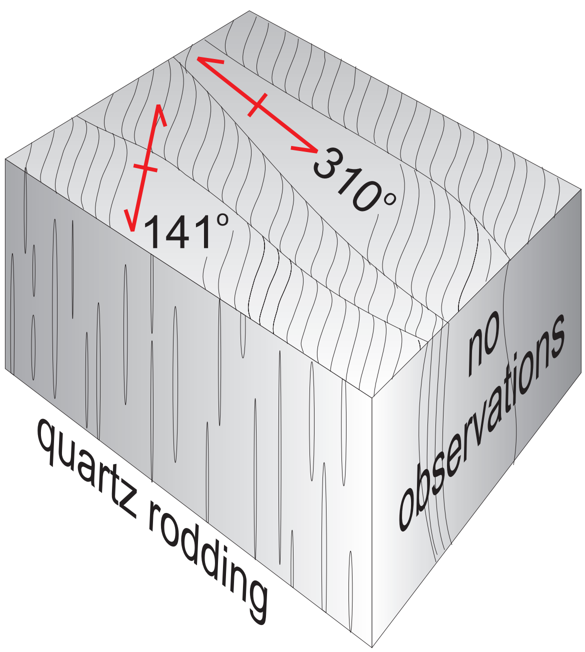


Figure 13-6. Diagrammatic representation of structural features within a fault strand of the Nahlin fault. A preexisting schistosity (~141°) is interpreted as having been rotated in a sinistral sense into shear bands oriented ~310°. Quartz veins oriented obliquely to the instantaneous stretching axes within the shear zone have lost rheological competency and divided into poorly developed rods which outline a lineation. Because the rods are subparallel, bulk flow within the shear zone must have been insuffiecient to have caused significant variable rotations of the rods .

dominantly brittle structure with slickenside striae on anastomosing shears which indicate that latest motion was dominantly dextral. Northwest-striking bedding planes within the fault zone contain moderately east-plunging slickenside striae with sinistral shear sense on antithetic shear surfaces, consistent with overall dextral movement on this fault segment.

Where the fault emerges north of Graham Inlet, the west-most fault strand is outlined by an elongate body of tectonized harzburgite. To the west are argillites and lesser wackes of the Laberge Group, and to the east are volcaniclastics of the Peninsula Mountain suite. On the low sloping hillside to the west of Shaker Creek, a deformed 50m diameter dacite stock is structurally interleaved with Laberge Group strata and is tectonically admixed with serpentinized harzburgite tectonite. Semi-ductile fabrics in the stock display a dip-slip component (Photo 6-2); however, the kinematics of this deformation zone are uncertain due to lack of a well developed lineation. If crude quartz lineations on shear planes are intrafolial quarz veins rodded by non-coaxial simple shear (Figure 13-6), then the shear zone is dominantly sinistral and bulk strain is minimal, such that quartz rods have not experienced variable degrees of rotation into parallelism with the maximum instantaneous stretching axis of the bulk flow. Sinistral motion on this fault segment is not opposite to that predicted by overall fault geometry (Figure 13-5), perhaps indicating an antithetic fabric. Farther north, near the southwestern margin of Peninsula Mountain, faults related to the Nahlin system may step farther west. There a chert-wacke unit surrounded by Laberge Group argillite is contorted and crosscut by several discreet fault zones that trend due north (000/64, 180/74).

The eastern limit of the NFZ system is difficult to determine. A separate fault strand may follow the north-trending eastern end of Graham Inlet, but it is totally obscured by alluvium and the inlet. For the most part the fault is obscured because it occupies topographic depressions that are infilled by surficial deposits.

Age and Interpretation

Motion on the NFZ is likely not restricted to a single time interval; more likely, various segments were active at different times. Latest motion predates intrusion of the Birch Mountain stock on Teresa Island (Figure TC-1) which clearly cuts across the main fault trace and has returned a K-Ar date of about 50Ma (Bultman, 1979; Table AA5). Latest motion on the westernmost fault strand between Atlin Mountain and Mount Fetterly postdates deposition of the Sloko Group (*c.* 55Ma) because Sloko Group volcanics are juxtaposed across the fault with folded Laberge Group rocks. A similar relationship was noted by Bultman (1979), but he was not able to determine whether the contact is a fault or a product of deposition at a fault scarp. The relationship was also recorded by Aitken (1959) who mapped the NFZ near Pike Bay (southeast of the map area) as forming the contact between Cache Creek and Sloko Group strata.

Latest motion on the easternmost fault strand has emplaced an ultramafic block above Laberge Group strata within the fault zone (Photo 13-10; too small to represent on Figure GM97-1). The fault responsible for this juxtaposition has been called the Atlin Mountain fault by Bloodgood and Bellefontaine (1990) as it transects the flank of Atlin Mountain a few kilometres west of the peak. Motion on the Atlin Mountain fault has probably been accommodated through reactivation of a coextensive portion of the older NFZ, into which it apparently roots. Atlin Mountain pluton appears to be crosscut on its western side by the Atlin Mountain fault; however, apophyses of the intrusion extend into Laberge strata on the western side of the fault (Bloodgood and Bellefontaine, 1990) indicating that the intrusion was localized along the fault, and not displaced by it. Foliated chert and basalt adjacent to the fault zone are cut by undeformed granitic dikes believed to emanate from the Atlin Mountain pluton, indicating that motion on this part of the Atlin Mountain fault predates emplacement of the pluton, and that intrusion of the Atlin Mountain pluton is probably not synkinematic. Although the Atlin Mountain pluton age is not known, a two-point Rb-Sr isochron suggests that it is comagmatic with the Late Cretaceous Windy-Table volcanics (Mihalynuk *et al.*, 1992a, Chapter 13).

In southernmost Yukon, the NFZ has most recently been mapped by Hart and Pelletier (1989a). There it varies from a single strand of protomylonite and argillaceous gouge to a zone of imbricate thrusts involving rocks of both the Intermontane Belt and the Cache Creek terrane. It dips northeast (65°) and is thought to have accommodated westward thrusting of the Cache Creek terrane over the Whitehorse Trough. Latest motion is constrained by the 88 Ma Montana Mountain complex which is involved in thrusting, and the 64 Ma Carcross pluton which crosscuts the thrusts (Hart and Pelletier, 1989a).

Information needed to unravel the early history of the NFZ is lacking. To what extent the NFZ in the map area was involved in Cache Creek terrane emplacement is uncertain. Our present level of understanding does not permit unambiguous separation of structures that led to offscraping and accumulation of the Atlin complex at a convergent plate margin, such as faulting related to underplating of sediments and growth of the Atlin accretionary complex, from those related to terrane emplacement, such as the Nahlin fault. Bloodgood and Bellefontaine (1990) suggest that deformation related to the NFZ affected a zone 5 kilometres wide along the western margin of the Cache Creek terrane in the Pike Bay area (southeast of the map area). Similarly, near Telegraph Bay, lensoid stratigraphic domains tens of metres to a kilometre or more in length, are structurally juxtaposed across sheared boundaries that parallel, but are up to 15 kilometres east of the mapped trace of the NFZ (Mihalynuk and Mountjoy, 1990; Mihalynuk *et al.*, 1991). All of these structures are cut by the Middle Jurassic Fourth of July batholith and, if related to the NFZ, reflect pre -172 Ma motion that clearly predates the oldest motion determined in southernmost Yukon (Hart and Pelletier, 1989).

Much further southeast, the northern Bowser Basin probably records foredeep development in response to loading by the Cache Creek Terrane as it was emplaced along southwest-verging faults, principally the King Salmon and Nahlin faults (Ricketts and Evenchick, 1991). Oldest foredeep strata may be of latest Early Jurassic age (Late Toarcian). Although the influx of Cache Creek-derived chert pebble conglomerate into the Bowser Basin was delayed until the Bathonian (Ricketts and Evenchick, 1991), similar conglomerate was deposited in the Whitehorse Trough by Aalenian time (Mihalynuk *et al.*, 1995a; Tulsequah map area). Early to Middle Jurassic radiolarians identified in Cache Creek cherts in southern British Columbia (Cordey *et al.*, 1987) and recently recognized within cobbles from Bowser Basin conglomerate (Lower Jurassic, Cordey, personal communication, 1991) provide tight constraints on the timing of Cache Creek uplift and perhaps major motion on the NFZ.

Faulting to produce these earlier structures must be pre-to Early Middle Jurassic, in agreement with the age constraints of Gabrielse (1985) and Ricketts and Evenchick (1991). In the map area, the NFZ parallels the northwest structural grain of the Cordillera; whereas, in the Dease Lake area, it trends more easterly and is a south-southwest-verging thrust. This geometry necessitates predominantly dextral transcurrent motion on the Atlin portion of the Nahlin (Figure 13-5). Near vertical fabrics and limited but mainly dextral kinematic indicators within the NFZ zone (Mihalynuk and Mountjoy,

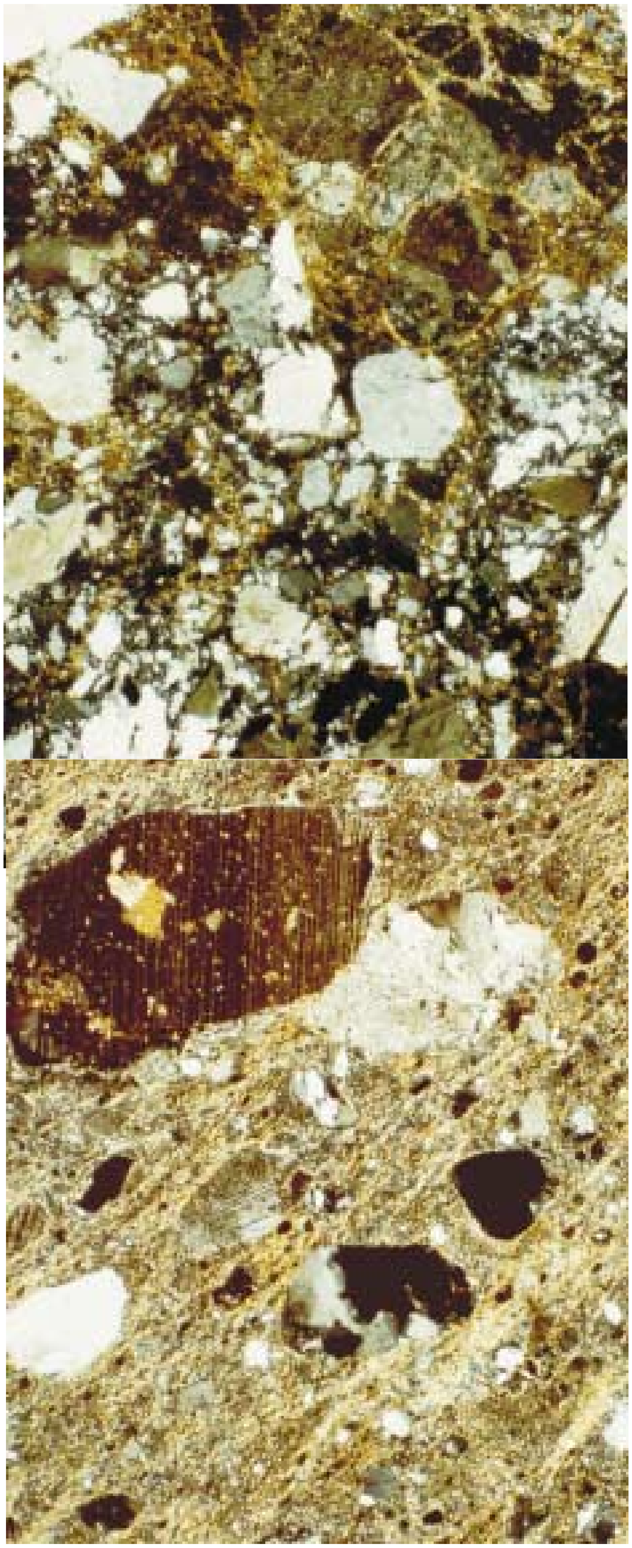


Photo 13-11. Photomicrograph of deformed granodiorite along the Llewellyn Fault zone near the Klondike Highway. The top photo is of protomylonite in which grain-size reduction by crystal-plastic strain resulted in a high proportion of porphyroclasts within a fine grained matrix. The bottom photomicrograph is of an adjacent sample of mylonite. Lenticular porphyroclasts of polygonized quartz and feldspar are subordinate to fine-grained, comminuted matrix.

1990; Bloodgood and Bellefontaine, 1990) support this model.

Llewellyn Fault zone

Earliest references to the Llewellyn fault (LFZ) are by Bultman (1979) who recognized it as a system of northwest-striking, steeply northeast-dipping to vertical strands. In many respects the character of the LFZ is similar to that of the subparallel NFZ to the east. Like the Nahlin, it forms the present boundary between two terranes within the map area, but deformation related to it may not be confined to this boundary. As with the Nahlin, it records a protracted deformational history. Furthermore, a possible linkage with the southwest-verging King Salmon thrust (KST) yields a strike-slip to thrust transition just like that of the Nahlin (Figure 13-5).

Along much of its trace the LFZ marks the contact between Mesozoic Whitehorse Trough strata on the east and Florence or Boundary Ranges metamorphic rocks on the west. In British Columbia, the LFZ is locally a discreet, near vertical structure only a few tens of metres across. Lithologies within the fault zone are commonly silicified, sericitized, argillically altered, and pervasively cleaved; locally protomylonite and orthomylonite textures are preserved (*sensu* Wise *et al.*, 1984; Photo 13-11a, b). More commonly, LFZ is one to three kilometres across and comprised of numerous elongate lenses of various, nearly vertical lithologies. These may represent strike-slip duplexes (Figure GM97-1, cross-sections F-F' and G-G'), but their exact nature is not well known due to the generally recessive nature of the faulted zone. The most obvious southern continuation of the LFZ proper has been mapped in the Tulsequah area by Nelson and Payne (1984) and Mihalynuk *et al.* (1994a,b, 1995a, b; Figure 1-1). There it marks the boundary between a Paleozoic volcano-sedimentary arc succession (Stikine 'basement') and metamorphic rocks of the Nisling assemblage. Where the fault crosses the British Columbia - Alaska border it is plugged by a granodioritic pluton belonging to a belt of 45-55 Ma intrusives (Brew, 1988). The age and magnitude of oldest motion on this segment of the THFZ-LFZ system is not known, however, the presence of Upper Triassic (Stuhini Group) conglomerates containing a large proportion of metamorphic clasts (J.L. Nelson, pers. comm. 1990; Souther, 1971), points to a tectonic history similar to that of the LFZ to the north. Between Tulsequah and the southern limit of the map area, the Llewellyn fault may merge with the King Salmon fault as shown on many small-scale compilation maps (*e.g.* Wheeler and McFeely, 1991) and as indicated by zones of strong foliation in Stuhini Group strata (Mihalynuk, 1990, unpublished data; Wilton, 1971; Bultman, 1979).

Near the British Columbia-Yukon border the LFZ merges with a 1 to 4 km wide steep southwest dipping, northwest-trending ductile deformation zone known as the Tally Ho Shear zone (THSZ; Hart and Radloff, 1990). The THSZ is exposed for 45 kilometres before it disappears beneath a cover of Mio-Pliocene basalt at its northern end (Doherty and Hart, 1988; Hart and Pelletier, 1989a). A discreet zone of anastomosing brittle faults localized on the eastern margin of the THSZ, is attributed to the LFZ by Yukon workers.

Ductile deformation fabrics are commonly developed along the LFZ in British Columbia, but no continuous mappable ductile zone like the THSZ is recognized. However, similar ductile fabrics are superimposed on the moderate to steeply-dipping foliation within the Boundary Ranges metamorphic suite (as is well displayed between Tutshi and Skelly Lakes). Perhaps the THSZ is a northern extension of the Boundary Ranges metamorphic suite and deformation fabrics are genetically related (*see* Chapter 3).

Age of faulting

Evidence points to motion on the LFZ at various crustal levels over a protracted time interval. In the Tagish area, ductile fabrics are largely overprinted by cospatial brittle fabrics, although in the Yukon, these fabrics can be mapped separately as: (1) the steep southwest-dipping, ductile Tally Ho shear zone (THSZ) and, (2) the dominantly brittle, Yukon portion of the LFZ which is localized along the eastern margin of the THSZ.

Obviously, a clear picture of the proto-LFZ-THSZ has yet to be developed, but this fault system appears to mark a fundamental tectonic boundary that has been intermittently active at least since the earliest Late Triassic (pre-220Ma). Motion may be recorded by the conglomerate deposited unconformably atop the Willison pluton between 217Ma (the age of the Bennett - Willison bodies, Table AA5) and late Norian (*c.* 209Ma is the minimum age), assuming that erosion was in part due to west-side-up motion on the fault. Perhaps the clearest indication is provided by regional changes in stratigraphic thicknesses across the fault. Strata of the Whitehorse Trough occur on both sides of the THSZ-LFZ, but they are much thicker immediately east of the fault zone (Figures 8-2 and 9-2) indicating significant west-side-up motion on the fault system perhaps as early as Late Triassic to Early Jurassic times. Gross stratigraphic facies suggest that Late Triassic motion along the Tally Ho shear zone-LFZ created the western margin of the Whitehorse Trough, uplifted the Nisling Assemblage, and controlled consequent deposition of widespread Stuhini Group conglomerate that locally contains abundant metamorphic clasts of the Nisling assemblage. Evidence of synsedimentary deformation is common throughout the Lower Jurassic sedimentary succession and is attributed to episodic motion on the LFZ.

Ductile fabrics are well displayed at Willison Bay in the *c.* 217 Ma Willison Bay pluton and the leucogabbro which it intrudes. Fabrics are intense adjacent to the fault, where the leucogabbro has been reduced to chlorite schist, and persist a kilometre or more from the fault, where a foliation is still apparent. Such relationships suggest that a large component of strain along the LFZ is coeval with early emplacement of the Late Triassic intrusive suite, and congruent with earliest motion on the Tally Ho Shear Zone in the Yukon. A very weak to moderate foliation developed in both the Bennett and Willison bodies could also be emplacement-related, but grain size reduction of and development of authigenic minerals within the foliation suggest a synkinematic origin for this fabric (Photo 12-6).

Elongate, strongly foliated biotite granodiorite lenses with well developed cataclastic fabrics (Photo 13-11a, b) occur along the LFZ. They are interpreted to be synkinematic with ductile motion on the LFZ, but cataclastic fabrics are probably formed during late movement on the fault. Brittle textures with dextral offset locally overprint ductile fabrics in the LFZ zone. The transition between dominantly brittle and dominantly ductile deformation was probably diachronous, occurring mainly in the Early Cretaceous, but probably extending from Middle Jurassic to Late Cretaceous. A strongly sericitized lens of the Willison Bay pluton crops out at the Brown occurrence near the mouth of the Wann River. A K-Ar age from this lens yielded an age of 132 ± 5 Ma, indicating that hydrothermal alteration ceased and/or the rocks were cooled along this strand of the LFZ by the Early Cretaceous. If there is a kinematic linkage between the LFZ and fabrics within the adjacent Hale Mountain granodiorite, then the change from ductile, sinistral dip-slip motion to dominantly brittle, dextral movement can be constrained by the 178.8 Ma age of a pegmatite dike (Tables AA1, AA2) that cuts the ductile fabric and intrudes along pervasive brittle faults that cut the Hale Mountain granodiorite.

Observed drag folds northeast of a LFZ strand indicate right-lateral, oblique-west-side-up normal fault movement (Bultman, 1979). Most other brittle structures associated with the LFZ are ambiguous because of a lack of mineral lineation development within them. Furthermore, distinguishing between synthetic and antithetic structures can become a problem of scale, thus it is important to look at for large scale indicators of motion sense which are less prone to ambiguities.

Youngest brittle deformation must have extended at least into the Early Eocene as indicated by the juxtaposition of Eocene Sloko Group volcanic rocks with Stuhini Group rocks across the fault in Hoboe Creek (Werner, 1978; unpublished mapping in 104M/). However, Eocene motion must be mainly dip-slip with only minor translational motion since a granite body which is part of a Late Cretaceous suite (*c.* 76 to 92 Ma; Bultman, 1979) in northwest 104M/15, plugs one of the major fault strands and shows little significant offset. About 20 kilometres to the south, lithologically similar granitoids returned a U-Pb zircon age of 72 Ma (Barker *et al.*, 1986).

In the Yukon, the Tally Ho shear zone displays an early ductile fabric with sinistral shear sense that is of probable Late Triassic age (*cf.* discussion by Hart and Radloff, 1990). Mafic volcanic and volcaniclastic rocks, augite porphyry, gabbro, marble and ultramafite of the Upper Triassic Lewes River Group (equivalent to the Stuhini Group in British Columbia) were penetratively mylonitized and metamorphosed to upper greenschist facies within the Tally Ho shear zone in Early Jurassic time based upon the late-synkinematic relations of the crosscutting *c.* 177 Ma Bennett pluton. Structural and kinematic studies of this pre to syn *c.* 177 Ma fabric demonstrate an early component of sinistral displacement (Radloff *et al.* 1990; Hart and Radloff, 1990 and Hansen *et al.*, 1990). Likewise, a *c.*115 Ma K-Ar (hornblende) age from a foliated gabbro in the Tally Ho shear zone indicates that the ductile portion of the fault zone cooled through the closure temperature of around 685 ± 53ºC (Berger and York, 1981) in the Early Cretaceous.

Amount of Offset

In the Yukon, youngest motion on the main trace of LFZ is constrained by a granite plug, the Pennington pluton dated at 55 Ma (Hart, 1995; Table AA5). Numerous shear bands and brittle fracture zones subparallel to the LFZ cut plutons of this suite and may be attributed to relatively minor late motion on the fault system. This latest deformation affects rocks as young as 78 Ma with up to 10 km of displacement, and may disrupt dikes as young as 65 Ma which have 1 to 2 km of cumulative offset (U-Pb and K-Ar dates respectively; Hart and Radloff 1990)

Offsets older than Cretaceous are less clear, but units that **might** be offset across the fault since the Late Triassic include parts of both the Aishihik batholith and the Willison Bay pluton. Mississippian and older units that may have offset equivalents include the Bighorn orthogneiss and the quartz-rich strata in which it is enclosed.

One possible location of the northern extension of the Tally-Ho shear zone is near the foliated western margin of the Aishihik batholith (*e.g.* Tempelman-Kluit pers. comm., 1992 *in* Johnston, 1993). This idea is intriguing because possible offset portions of the Aishihik batholith and enclosing strata exist in the Tagish Lake area where they are bounded to the east by the LFZ zone. In particular, the Hale Mountain granodiorite is coeval with, lithologically and chemically similar to, and displays top-to-the southwest ductile fabrics like the Aishihik batholith. Boundary Ranges schists, including the Mississippian Bighorn orthogneiss, envelope the Hale Mountain body on its northern margin and, according to Currie (1994) it is structurally overlain by quartz-rich Nisling Assemblage rocks across the Wann River shear zone to the southwest. Similar units are in contact with the northern and western Aishihik batholith. If these units were originally contiguous, a sinistral offset of approximately 280 kilometres is indicated. Sinistral offset is consistent with early ductile fabrics within the THSZ - LFZ system. The location of such a fault is, however, problematic. Johnston (1993) interprets the strong fabric developed on the western margin of the Aishihik batholith to be a product of diapiric inflation, not a regional shear zone. Thus, the actual trace of the Tally-Ho shear zone may be farther to the west where it is obscured by younger Coast Belt plutonism, or it may disappear as strain is distributed across a broad zone. Concerted mapping efforts will be required to trace the Tally-Ho shear zone northward.

The Willison Bay pluton (Chapter 12) and the coarse pyroxene and hornblende gabbros that it crosscuts form a distinctive magmatic pair east of the LFZ on the southern margin of the map area. Remnants of these intrusives and possible offset portions can be found within or adjacent to the LFZ as far north as Tutshi Lake, where they occur within and west of the fault zone and are denoted Mgd on Figure GM97-1. However, some Mgd occurrences are clearly unlike the Willison Bay body, age constraints are poor, and cross-cutting relations with gabbros are lacking. If these bodies are parts of a formerly more local body or series of bodies, then dextral offset on the order of 70 to 90km is indicated. Such motion is not necessarily inconsistent with that which might be indicated by the

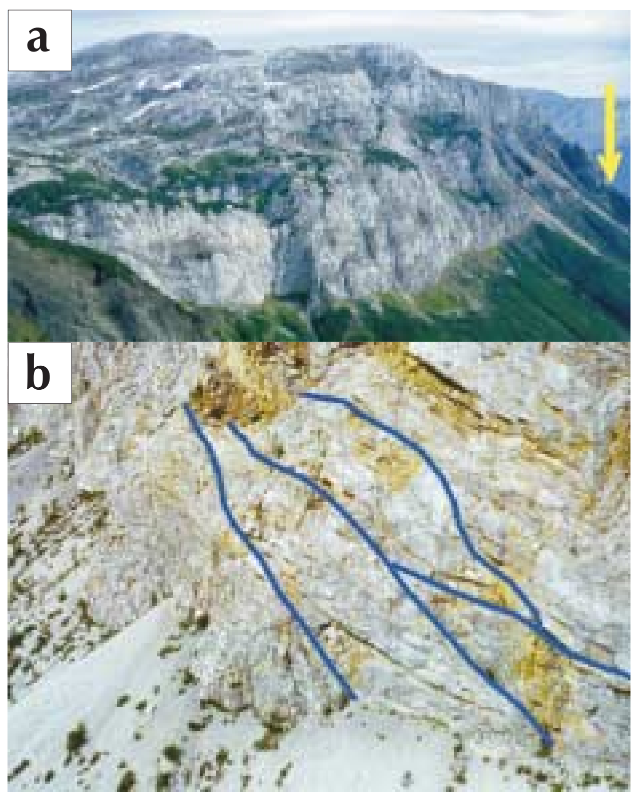


Photo 13-12. (a) Sinwa Formation limestone in the hangingwall of the King Salmon thrust at Sinwa Mountain Tulsequah map area viewed towards the southeast. (b) A closer view of locality indicated by the arrow in (a) of the structurally lowest southern exposures (view to the north) shows that they are strongly imbricated.

Aishihik body (280 km sinistral), but would require that the Willison Bay pluton segment west of the LFZ be translated 350 kilometres in a dextral sense (for which structural textural evidence is lacking) followed by 280 kilometres in a sinistral sense. Furthermore, the likelihood of significant young, brittle, dextral offset on the LFZ necessitates that these offset are minimum estimates. Detailed field studies across the British Columbia - Yukon border will be required to validate the displacement history. Kinematic linkage with the King Salmon thrust, if it can be proven, will also provide constraints on the amount of Middle Jurassic offset. Field based studies in the rugged terrain between southern Atlin lake and the Taku River will be required to test for kinematic linkage.

King Salmon Fault

Where well described in the Cry and Dease Lakes areas, the King Salmon fault is a moderately north to northeast-dipping structural discontinuity (Thorstad and Gabrielse, 1986) that carries relatively deep water Inklin strata over conglomeratic Takwahoni strata along much of its length. Its hangingwall is characterized by a zone of pervasively cleaved to schistose volcanic and sedimentary strata several kilometres wide in which strong down-dip stretching lineations are developed near the sole of the thrust. Nowhere within the Tagish map area is a structure having characteristics like the KSF recorded within Mesozoic strata, although high angle zones of ductile deformation within the LFZ are similar. Nevertheless, Bultman (1979) proposed that the King Salmon fault carried the belt of "Sinwa" carbonates from the southern tip of Atlin Lake to north of Tutshi Lake. Bultman cites several lines of evidence in support of this interpretation, but acknowledges possible alternative explanations, particularly along the southern shore of Atlin Lake where a "tectonic melange" may, in fact, be a conglomerate or debris flow deposit.

Stratigraphic relationships recorded as part of this study indicate that, although disrupted, the contact between Late Norian carbonate ("Sinwa" Formation in Bultman, 1979) and overlying strata is at least locally conformable, for example, near the Klondike Highway. Carbonate content of underlying strata increases towards the Sinwa Formation along both Willison Bay and northern Tutshi Lake. The Sinwa Formation appears to be the locus of deformation because strain has been partitioned as a result of the competency contrast between underlying, massive volcanic units and overlying shales of the Laberge Group. Thus, shearing has definitely occurred, but it is not like the strong foliation developed in hangingwall strata several kilometres above the King Salmon thrust near Dease, nor a severely imbricated zone such as occurs at Sinwa Mountain (Photo 13-12). Certainly, no structure with the characteristics or magnitude of the KSF, has affected this part of the stratigraphy in the Tagish area.

Photo 13-13. Light-weathering Sinwa Formation north of Tutshi Lake is cut by numerous high angle, northeast-trending faults (outlined) that result in offset up to tens of metres. Such faults are too small to show on Figure GM97-1. The clearing at the centre right-hand edge of the photo is the Venus mill site.

It is possible, however, that the KSF extension into the Tagish Lake area would bear little resemblance to its Dease Lake counterpart. Just south of Willison Bay the KSF may merge with the LFZ (Figure 13-5), as is implied on various-scale compilation maps (*e.g.* Tipper *et al.,* 1981; Wheeler and McFeeley, 1991). Because of the northward arcing geometry of the fault, the top to the south-southwest motion vector recognized near Dease Lake would become largely translational near Tagish Lake. If KSF motion fed into the LFZ a large part of the late dextral motion displayed by the LFZ in the Tagish area could be kinematically linked to the KSF. In this scenario, the LFZ would form the dextral strike-slip segment of a classical transpressional fault system. However, earliest dextral motion on the LFZ appears to predate the early Toarcian to middle Bajocian age (Lower to Middle Jurassic; Thorstad and Gabrielse, 1986) of the main south-southeast directed KSF thrusting. Thus, lateral motion along the northern continuation of the KSF was probably accommodated by offset on a pre-existing LFZ. Bultman (1979) reached the same conclusion with respect to relative timing of motion on these faults. He noted that motion on the LFZ appears in part to predate motion on the KSF as a splay from the "SW Boundary Fault" appears to terminate against the KSF on southwest Copper Island.

If the KSF does merge with the LFZ, then displacement on the Tulsequah component of the LFZ south of the area of KSF-LFZ convergence, should be less than that on the THSZ-LFZ to the north. The magnitude of this difference should correspond directly to the cumulative amount of overthrusting on the KSF and related structures. Unfortunately, we have yet to recognize reliable indicators of the absolute amount of thrust displacement on the KSF.

Young, northeast-trending faults

Northeast-trending faults are abundant, although most have offsets that are too small to be displayed on Figure GM97-1. Typically, they are vertical or nearly so, and display sinistral offsets of tens of metres or less. A few of these high-angle faults with kilometre-scale offset are shown on Figure GM97-1: the south end of Tutshi Lake; south of Moon Lake, the western end of Racine Lake, and at Golden Gate (the junction of Graham Inlet and Taku Arm). Where the small faults cut distinctive units, such as the Sinwa Formation north of Tutshi Lake (Photo 13-13) and south of Torres Channel, they have a spacing of 400 to 500 metres (*cf.* Mihalynuk *et al.*, 1996) and display mainly sinistral, but also dextral apparent sense of motion.

The amount and sense of offset on these faults is not easily determined within the map area. Distinctive marker units are lacking, faults may be localized and obscured at facies changes, and surface exposures are rare so the mineral lineation information required to establish sense of offset is lacking. In fact, only the Golden Gate fault was seen at surface. It is a 3 metre wide zone of silica-cemented argillite breccia. Cockscomb silica encrusts angular, silicified and argillically-altered fragments with several percent open space preserved. Slickensides are generally subhorizontal, with no consistent sense of motion. However, motion on both this and Moon Lake fault may be determined from the facies distribution and available age data. These suggest dominantly scissors-like motion with offset decreasing to the northeast. Rocks immediately north of the west Graham Inlet fault are cut by centimetre-scale dextral faults that trend 150^{o}, possibly antithetic to the Golden Gate fault. If kinematic linkage can be demonstrated, then a sinistral component on the main fault is indicated.

Motion on the northeast-trending Racine Lake fault is interpreted to postdate that on the LFZ. Sense of motion can be determined from map patterns as south side up. Similarly, just outside of the map area (104M/16SW; Mihalynuk *et al.*, 1996) the Racine pluton appears to have been offset in an oblique dip-slip sense with the south side moving up to the east.

North-northeast to east-trending faults also cut Stuhini Group rocks north of The Cathedral, Windy Table volcanics between Table and Taku Mountains, and Sloko Group strata at Engineer Mountain. They may be reactivated syndepositional faults. Coarse breccias and rapid facies changes along these faults probably represent fault scarp talus intermixed with locally derived volcano-sedimentary rocks.

Deep Structure

Hypothetical crustal cross section

Speculations on crustal scale structural geometry are humbling. Existing geological mapping can help to constrain crustal sections only to a depth of about 5km. Lacking in the region are gravity, magnetic and teleseismic studies which could provide direct clues about crustal thickness and composition. However, speculations can be guided by what is known about the geological history, and by analogy with other well studied parts of the globe which might approximate paleogeographic "snapshots" in the history of the study area. Crustal cross sections are useful tools for outlining deficiencies in the geological knowledge base, as a platform for discussion, and as capsules of geological fact and interpretation on which to build. They are also useful for guiding mineral exploration, especially with the trend to increasingly more sophisticated application of plate tectonics and far-travelled endogenous indicator elements in the search for mineralizing systems.

Figure 13-7 is a hypothetical crustal section extending from the plutonic margin of the Coast Plutonic complex to the Teslin Fault at Teslin Lake. This extends far beyond the limits of the Tagish map area, but provides a much more complete picture of possible terrane relationships. No specific cross section line has been followed, instead, the areas providing the best control and displaying important structural relationships or characteristic structural styles have been incorporated as shown by the inset and discussed following.

West of the Llewellyn Fault zone

Data constraining the segment of Figure 13-7 between the Coast Plutonic complex and the LFZ are derived from near the southern end of Tagish Lake. Contacts between the Boundary Ranges suite (deformed Stikine Assemblage) and Florence Ranges suite (Nisling Assemblage) are shown as a low angle fault, but this fault

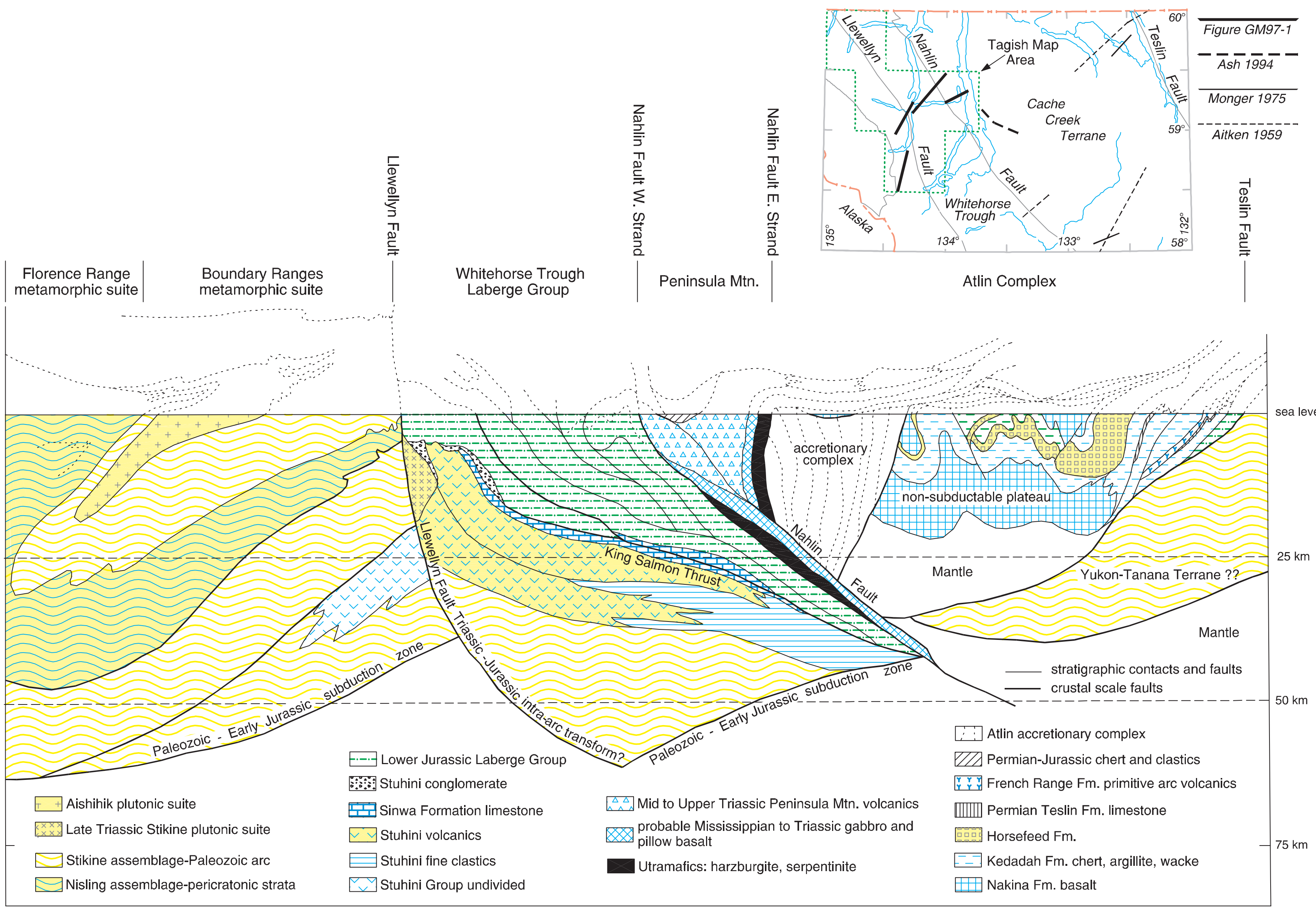


Figure 13-7. Hypothetical crustal scale cross section stretching from the Coast Belt to the Teslin Fault. Sources of data constraining the near surface geology are shown in the inset. The Tagish Lake area is shown by the boxed outline.

is not necessarily a terrane contact. Indeed, geological relationships to both the north (Aishihik Lake; Johnston, 1993) and south (Tulsequah; Mihalynuk *et al.*, 1994a and unpublished) favour an interpretation in which discontinuous crustal fragments of Nisling Assemblage locally form the basement to Stikine Assemblage (see also arguments in Chapters 3 and 15). In the Tulsequah map area, a strong case can be made that rocks of the Stikine Assemblage are protoliths for the Boundary Ranges metamorphic suite because the structural transition can be walked out along strike (Mihalynuk *et al.*, 1994b, 1995b) and protolith ages are similar (Currie, 1994).

Top-to-the-southwest kinematic indicators in the Early Jurassic metaplutonic rocks of the Aishihik suite, and peak metamorphic ages of around 177.5 Ma (Currie, 1994) point to crustal thickening as a product of southwest-vergent thrusting in the Early to Middle Jurassic. However, a west to east change in fold vergences in the Florence Ranges and Boundary Ranges metamorphic suites may indicate the presence of a large-scale fold, perhaps a nappe structure. Similarly, infolding of the Wann River gneiss and Florence Range rocks on White Moose Mountain might be parasitic folds within the core region of such a nappe. Indeed, it is difficult to reconcile varying contact relationships from north and south of southern Tagish Lake without invoking some repetition of the metamorphic section by thrusting, or by folding in the core of a nappe. Thrusting would probably have produced more tectonic mixing than is observed and would not explain the apparent change in fold vergences. The nappe hypothesis is more consistent with the geology as it is presently understood, but it is difficult to test because younger intrusions of the Coast Belt obscure contact relationships where Florence Range rocks should be enveloped to the west by Boundary Ranges rocks. However, the nappe hypothesis is strengthened by the existence of Boundary Ranges suite rocks west of Florence Range rocks (Currie, 1994; Mihalynuk *et al.*, 1996) and the possibility that upper crustal portions of the "nappe" are represented by Stuhini Group strata at the same latitude in nearby Alaska (Brew *et al.*, 1994) . Arguments can be made against direct comparisons with the Alaskan rocks because of the possibility of intervening, large scale faults, now obscured by late plutonism (*e.g.* Currie and Parrish, 1994), but no such structures have been mapped directly. As a result, this simple nappe hypothesis is incorporated in the crustal cross section which implies that the Florence Range rocks originated as a crustal fragment beneath the Stikinian arc complex prior to southwest-directed thrust emplacement.

Unequivocal evidence that Stuhini Group arc strata were deposited atop the Boundary Ranges suite is lacking. Augite porphyry of unit uTS west of Tutshi Lake and north of Paddy Pass is shown to be deposited unconformably on chlorite-muscovite schist of the Boundary Ranges (Figure GM97-1), but the unit is undated and nearly identical augite porphyry occurs within the Stikine Assemblage along the Tulsequah River Mihalynuk *et al.*, (1994a). However, both Logan *et al.* (1994) and Brown *et al.* (1996) show that Early to Late Triassic strata, including the Stuhini Group, rest with angular discordance atop deformed Stikine Assemblage rocks in the Galore Creek and Telegraph Creek areas to the south, and, as argued in Chapter 3, Stikine Assemblage is the most likely protolith for the Boundary Ranges metamorphic suite.

Llewellyn Fault zone to Nahlin Fault

To a large extent, the distribution of Laberge Group strata outlines the Whitehorse Trough. In the Tagish area, it is mainly located between the Llewellyn and Nahlin fault zones. It is thickened by widespread, open to close, west-verging folds and thrust faults that are more numerous than could be shown in Figure GM97-1.

Considerable thickening within the Whitehorse Trough is indicated by the regional development of authigenic epidote and albite. Cretaceous and Tertiary intrusions that intrude and flank the trough could also have contributed to an elevated geothermal gradient and the development of epidote-albite facies metamorphism, although fission track analyses from the Whitehorse Trough do not support this interpretation. They indicate that the rocks cooled through 200°C between 133±7 and 84.4±10.9 Ma (Donelick and Dickie, 1991), prior to most plutonism within the trough. If the Whitehorse Trough was shortened by more than 50 percent as suggested above, then structural thicknesses would have been in excess of 6 kilometres, and perhaps as much as 12 kilometres, equivalent to 2 to 3 kilobars. At 2 kilobars epidote (clinozoisite) may form by the reactions: 2laumontite + prehnite = 2clinozoisite + 5quartz + 8H_2O or magnesian pumpellyite + quartz = clinozoisite + chlorite + prehnite + H_2O at 240°C and 250°C respectively (Mihalynuk and Ghent, 1997). These P-T conditions may have been attained with a geologically reasonable geotherm of 25°C and thicknesses of 6 kilometres or more, consistent with the structural thickness estimated here.

Nahlin Fault to Teslin Fault

Structural geometry between the Nahlin and Teslin faults is constrained largely by projections of cross section and surface data from Monger (1975), Ash (1994) and Aitken (1959). Very little data from the Tagish map area is used in this segment of the cross section, but this part of the cross section is needed to constrain terrane interactions and processes that helped to shape the geology of the Tagish area.

The cross section relies on the fundamental interpretation that the accretionary complex is restricted to the region of Atlin Lake, and that Cache Creek terrane lithologies along the remainder of the section can be treated as relatively coherent, albeit disrupted, stratigraphy. Thicknesses of major units are probably much more variable than shown, for example, Monger (1975) argues that relict fault scarps on the flanks of ocean islands can be identified.

Interleaving of Laberge Group strata with a dismembered and condensed ophiolitic succession at Graham Creek suggests that the Whitehorse Trough was deposited on MORB-like crust, and that the entire thickness of Laberge Trough strata was involved in thrusting. Fabrics within the ophiolitic succession mainly dip eastward, probably a reflection of the original fault geometry. This relationship raises several questions. For example, is the oceanic crustal package sandwiched between Laberge Group strata west of Graham Creek a sliver of Cache Creek MORB? Cache Creek basalts display signatures of either MORB or ocean island parentage (C.H. Ash, personal communication, 1997). Thus, they are unlike the basalts of most alpine ophiolitic successions, which display a supra-subduction zone signature. Although both the Cache Creek and Graham Creek ophiolitic assemblages display the same relatively unusual MORB parentage, they are of different apparent ages. Graham Creek pillow basalts are apparently conformably overlain by a Middle Triassic interbedded chert and wacke succession, lithologically similar to rocks elsewhere in the Cache Creek terrane, but younger than the expected age of most Cache Creek basalt. If Graham Creek basalts originated in the Panthalassic ocean basin, relicts of which are preserved in the Cache Creek terrane, then they should be Permian to Early Mississippian in age. If this oceanic crust formed during rifting of the ancestral north American margin, and was later built upon by Stikine assemblage and Stuhini arc successions, then it could be Eocambrian to Devonian in age. One explanation of the Triassic age is that these rocks are a coherent landward portion of an outer arc ridge (accretionary prism) as shown in the cross section. Laberge strata east of the frontal Nahlin thrust may have been deposited unconformably atop exposed thrust sheets that comprised the outer arc ridge or were offscraped in the inner trench. Reflected turbidites (recording landward as opposed to basinward paleoflow directions) reported by Johansson (1994) are consistent with a paleotopographic high, such as an outer arc ridge, east of the Whitehorse Trough axis. Future efforts should be directed towards isotopic age dating of ophiolitic basalt assemblages in order to test the associations suggested here.

What was the eruptive setting of the Peninsula Mountain volcanics? Are they a forearc succession of tholeiitic rhyolite to basalt like that seen in the French Range Formation (*e.g.* Mihalynuk and Cordey, 1997)? This is the interpretation presented in the cross section. Peninsula Mountain rocks are carried in a thrust sheet between rocks of accretionary complex origin. Isotopic age dating is required to more accurately delineate the limits of Peninsula Mountain volcanics and distinguish them from the overlying Windy-Table suite volcanics.

What are the subsurface extents of the Nahlin ultramafic body? It is shown in the cross section to extend down dip a distance equivalent to its map extent. Gravity surveys and modeling will be required to test this assumption.

Is the reversal of structural vergence across the Cache Creek terrane real? If so, what causes it? Could it be due to structural repetition of the Horsefeed limestone at depth, or due to local backthrusting? Does it bear on the interrelationship of the Cache Creek Terrane and the Big Salmon Complex east of Teslin Lake? Treatment of this problem is outside the scope of this report; however, limited data supports the hypothesis that both mechanisms aided structural vergence reversal. Horsefeed carbonate east of Windy arm in the Yukon is repeated in a stack of west-verging thrust sheets (Monger, 1975), and this deformational style may be typical of the unit. East-verging thrusts (back thrusts?) along the western shore of Teslin Lake may place Kedahda chert and argillite structurally above west-dipping wackes that are identical to Laberge Group wackes (Mihalynuk, unpublished mapping, 1996). It is clearly apparent that much more mapping needs to be done within most parts of the northern Cache Creek terrane in order to advance the understanding of this complexly deformed piece of crust.

East of Teslin Fault (Teslin Lake)

Paleomagnetic data from Northern British Columbia and the Yukon Territory consistently indicate northward displacements of rocks outboard of the Teslin Fault zone by approximately 1200 to 1900 kilometres since mid-Cretaceous times (Johnston, *et al.*, 1996; Harris *et al.*, 1997 and references therein). Because of geological constraints, the Teslin fault is the most likely structure to have accommodated motion of this magnitude. The paleomagnetic data are difficult to support geologically, but if correct, there may be offset fragments the northern Cache Creek terrane near the latitude of Kamloops (or farther south).

Contacts between the Big Salmon Complex and the Cache Creek terrane across the Teslin Fault have not been observed. Paleomagnetically indicated offsets of 1000 to 2000 kilometres since the Cretaceous (*e.g.* Johnston *et al.*, 1996) imply that deformation within the Big Salmon complex might have little in common with deformation in the northern Cache Creek terrane. However, only a moderate metamorphic and structural discontinuity is apparent across the Teslin fault (beneath Teslin Lake). Cache Creek terrane rocks west of the lake consist of weakly foliated prehnite-pumpellyite grade chert, and minor limestone and mafic volcanics. Big Salmon Complex rocks east of the lake are foliated greenschist grade basaltic tuff and tuffaceous sediment. Both metamorphic grade and degree of fabric development increase eastward in the Big Salmon Complex where amphibolite grade is attained (Mihalynuk *et al.,* 1998, deKeijzer, *et al.*, 1997, 1998). Fold vergence is also consistent from one side of Teslin Lake to the other. Fold vergence in northern Cache Creek terrane changes from west-verging to east-verging near Teslin Lake. Folds in western Big Salmon Complex are also east-verging. Thus, field criteria show no strong basis for a significant offset along the Teslin fault. The data could support a model in which the eastern margin of the northern Cache Creek terrane was thrust above Big Salmon Complex on a precursor of the Teslin Fault, although such an interpretation is not favoured here. Thus far, no klippen of Cache Creek terrane have been identified above the Big Salmon Complex and further field observations are clearly required along the Teslin fault in order to validate its role as a crustal-scale structure.

Although the cross section is largely a cartoon, it forces speculation and illuminates some fundamental questions about crustal architecture: What is the nature of the basement west of the LFZ zone? Is it a great thickness of the Boundary Ranges suite and, if so, does it at some point rest stratigraphically on rocks equivalent to the Florence Range suite as the section suggests? What forms basement to the Stuhini arc? Is it built directly upon, or flanking deformed Stikine Assemblage rocks (Boundary Ranges suite)? No unequivocal contact between Stikine Assemblage and Stuhini Group strata has been observed in the Tagish area (they are well documented to the south; Logan *et al*., 1994; Brown *et al*., 1996), although deformed Stikine assemblage clasts within Stuhini conglomerates are common. The section shows the Stuhini arc as being built upon transitional Stikine assemblage rocks and oceanic crust, although the amount of oceanic crust shown in the section is exaggerated since only scraps are likely to remain with most removed due tectonic erosion. What happens to the LFZ at depth? Does it shallow to the east like the King Salmon thrust with which it has merged near the latitude of the section? A west-verging thrust configuration is shown for the LFZ in order to accommodate crustal thickening and top-to-the-southwest kinematics during early mid-Jurassic peak metamorphism. Future field work will help to further constrain the crustal cross section and address many of the outstanding questions.

Chapter 14 Mineral & Hydrocarbon Potential

The Tagish Lake area is part of a geochemical province with high background gold, arsenic and antimony (Schroeter, 1986; Figure 14-1). The area encompasses a wide variety of lithotectonic terranes, it records several intrusive events, and it is cut by major, long-lived faults. Thus, it provides tectonic and lithologic environments favorable for a wide variety of mineral occurrences. Past exploration, however, has mainly focused on precious and base metal mineralization in both sulphide-poor and sulphide-rich veins.

Exploration History and Regional Metallogeny

The Tagish area has a recorded history of exploration dating back to 1878. However, the remains of abandoned Russian placer operations discovered near Atlin may predate historical accounts by 50 years (Bilisand, 1952). Prospectors began to filter into the area *en route* to the Klondike gold fields between 1897 and 1898, and the Atlin gold camp was established between 1901 and 1903. As prospectors combed the area via the Tagish and Atlin Lake systems, they discovered and developed many small vein-type gold occurrences. Only the Engineer mine, discovered in 1899 by engineers surveying a route for the White Pass railroad, became a significant producer, yielding approximately 560,000 grams of gold (Photo 14-1).

Several mines with a history of past production occur immediately north of the British Columbia border in the Yukon (Yukon MINFILE). For example, just a few kilometres up the Klondike Highway is the Venus silver-gold-base metal sulphide vein deposit (Figure 1-1) which has been sporadically worked since the early 1900's. It contains sufficient reserves to warrant continued mining operations should favorable economic conditions return in the future. Farther northwest, the Mount Skukum gold mine recently closed after epithermal gold vein ore there was completely mined out. Production was 29 622 270 g of gold from 201 461 tonnes of ore, with an average grade of 13.0 g/t. North of Carcross is the southern end of the Whitehorse Copper belt, one of the most important metallogenic elements in the region. It is a 32 kilometre long string of 28 separate copper-iron skarn deposits formed at contacts between Cretaceous plutons cutting a belt of Upper Triassic carbonates and clastics which extends southeast from Whitehorse. Approximately 10.25 million tonnes of ore were mined between 1967 and 1982. Of this, 2.85 million tonnes graded 1.06% copper and the remainder, 7.4 million tonnes graded 1.50% copper. This same geologic environment extends into the northern Tagish Lake area where encouraging copper skarn mineralization has been intersected at the Mill property (see following).

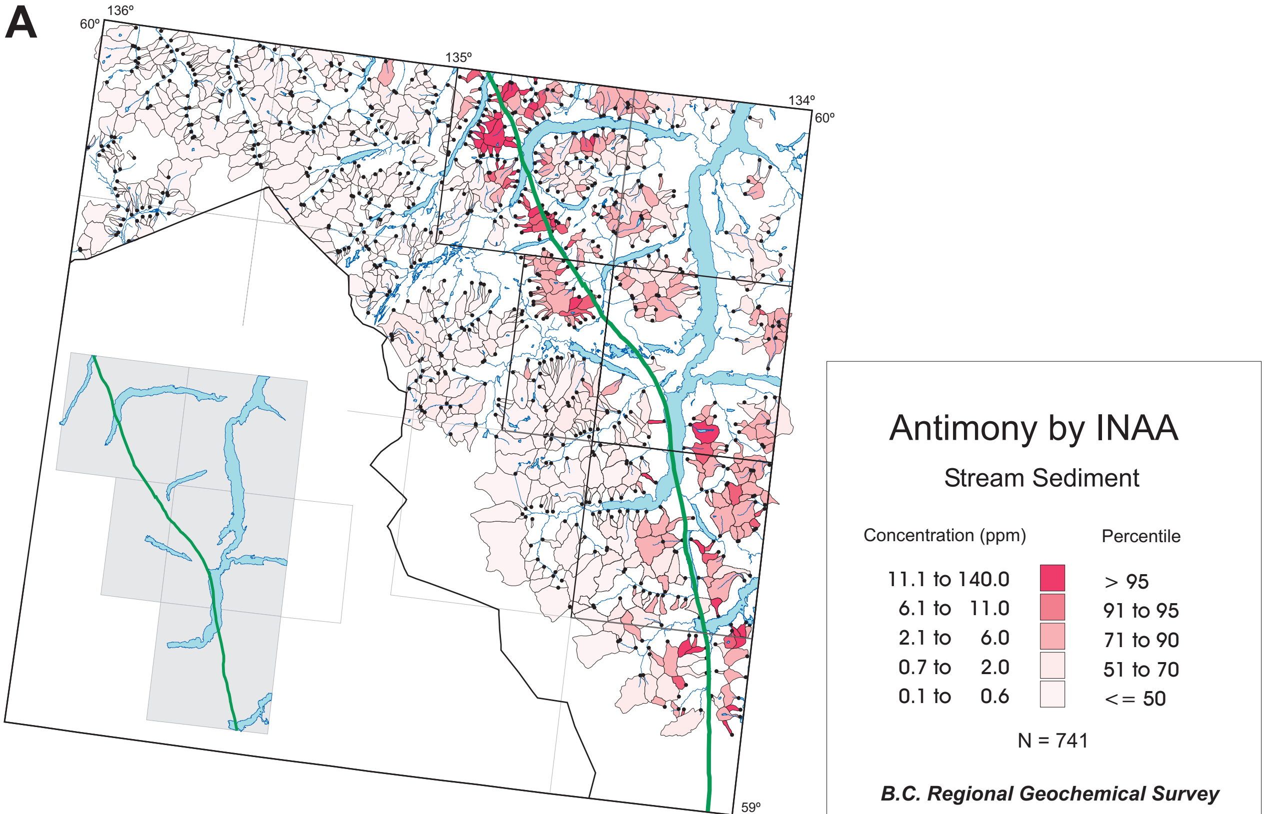
Sources of Information

Two sources of information that are referred to extensively here are MINFILE and British Columbia Deposit Profiles. MINFILE is a database of all mineral occurrences in British Columbia, which currently numbers about 12 000. British Columbia Deposit Profiles are a collection of mineral deposit models with known examples, or those with potential for discovery in the province. Both are available as British Columbia Geological Survey Branch publications or in electronic format over the Internet at http://www.em.gov.bc.ca/mining/Geolsurv.

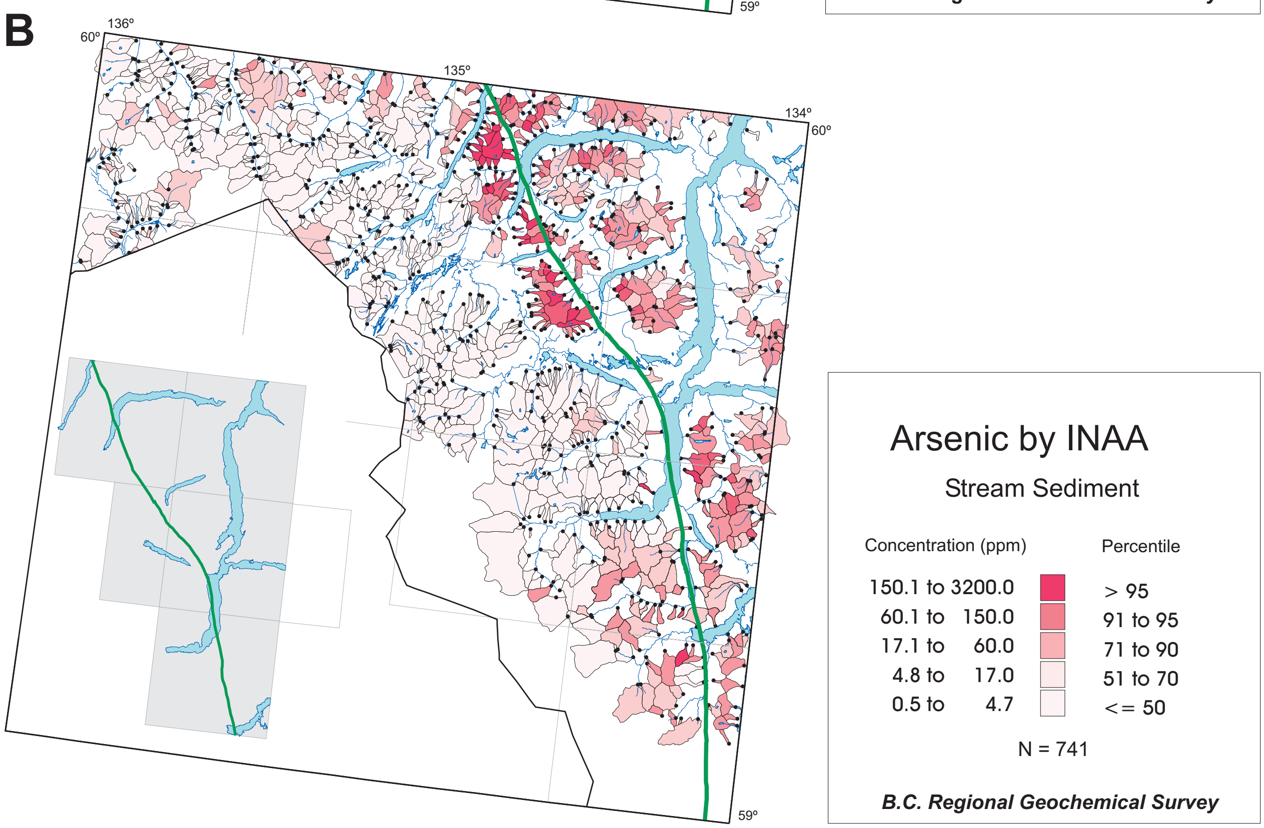
A synopsis of mineral occurrence data is presented in Tables 14-1and 14-2 for historical reference. It is based primarily on MINFILE data last updated in 1993. Mineral occurrence names are subject to change as successive operators conduct work on specific properties, therefore, an effort is made here to present the unique

Photo 14-1. Remnants of the 100 ton mill at the Engineer Mine as it appeared in 1989.

A


136°
60°
135°
134°
60°
59°
Antimony by INAA
Stream Sediment
Concentration (ppm)
Percentile
11.1 to 140.0
> 95
6.1 to 11.0
91 to 95
2.1 to 6.0
71 to 90
0.7 to 2.0
51 to 70
0.1 to 0.6
<= 50
N = 741
B.C. Regional Geochemical Survey

B


136°
60°
135°
134°
60°
59°
Arsenic by INAA
Stream Sediment
Concentration (ppm)
Percentile
150.1 to 3200.0
> 95
60.1 to 150.0
91 to 95
17.1 to 60.0
71 to 90
4.8 to 17.0
51 to 70
0.5 to 4.7
<= 50
N = 741
B.C. Regional Geochemical Survey

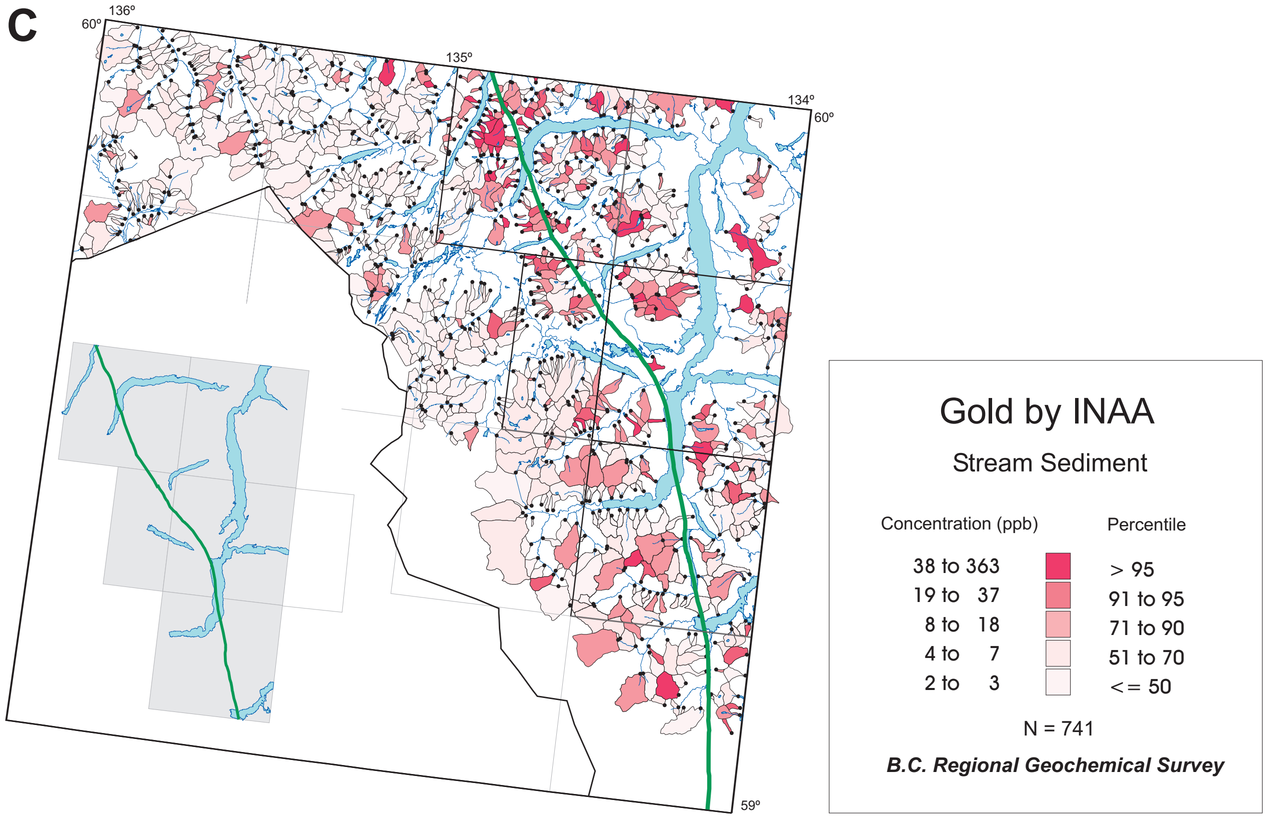


Figure 14-1. Regional geochemical stream sediment results showing ranked antimony (a), arsenic (b), and gold (c) values and the drainage basin area of influence of these samples. Note the coincidence of elevated geochemical results adjacent to the Llewellyn fault (thick line). This expression is muted to the south as the fault, which is well exposed in the highlands of the Tutshi Lake mapsheet, occupies lake-filled valleys of the Fantail and Edgar Lake mapsheets.

mineral MINFILE number (*e.g.* Engineer (104M014) with the mineral occurrence name (Figure 14-2). For up-to-date, systematic descriptions of mineral occurrences, refer to MINFILE online.

Mineral deposit profiles for British Columbia were published as a two volume set (Lefebure and Ray, 1995 and Lefebure and Höy, 1996). In the discussion that follows, deposit types are introduced with profile codes (*e.g.* copper skarn (K01)). Mineral deposit profiles change with time as new deposits are studied and others are discovered. For up-to-date deposit models, see British Columbia deposit profiles online.

Tagish area deposit types

Little work has been conducted towards classifying the many occurrence types of the Tagish area. In contrast, those in neighbouring Yukon are relatively well studied; for example: Mt. Skukum Gold Mine (Love, 1990a,b; McDonald, 1987; McDonald and Godwin, 1986 and McDonald *et al.*, 1986); gold in skarns in the Yukon (Meinert, 1986); gold-silver veins on Montana Mountain (Roots, 1982); fluid inclusion and oxygen isotopes of precious metal-bearing veins in the Wheaton River district (Rucker, 1988; Hart and Radloff, 1990); the Venus Au-Ag-Pb-Zn deposit (Walton, 1987); and the Ram zinc-lead-silver property (Watson *et al.*, 1981). The findings of many of these studies can be extrapolated to northern British Columbia. There is much room for work aimed at understanding metallogenesis in the Tagish Lake area, and occurrence classifications proposed here are open to revision.

To the north, Hart and Radloff (1990) classified deposits in southwest Yukon based primarily on the composition of ore forming fluids. In the Tagish area, however, reconnaissance fluid inclusion microthermobarometric investigations of only a few mineralized systems have been conducted as part of this study, and stable isotope data are completely lacking. Therefore, classification of occurrences in the Tagish area (Table 14-1) relies upon characteristics shared with documented deposit types, primarily those described in British Columbia Mineral Deposit Profiles (Lefebure and Ray,1995; Lefebure and Höy, 1996) and USGS Bulletin 1693 (Cox and Singer, 1986). Characteristics considered include: geologic setting, mineral textures, structures, ore controls and mineralogy (Table 14-2). Where possible, geochemical characteristics are also compared (Table 14-3), but geologic criteria are more reliable in establishing occurrence classification in all but a few instances. Table 14-3 is organized according to the classification scheme discussed in the following paragraphs.

Three quarters of the 88 mineral occurrences in the Bennett (Skagway, NTS 104M) mapsheet occur in the Tagish area (Tables 14-1, 14-1b; Figure 14-2). Of the re-

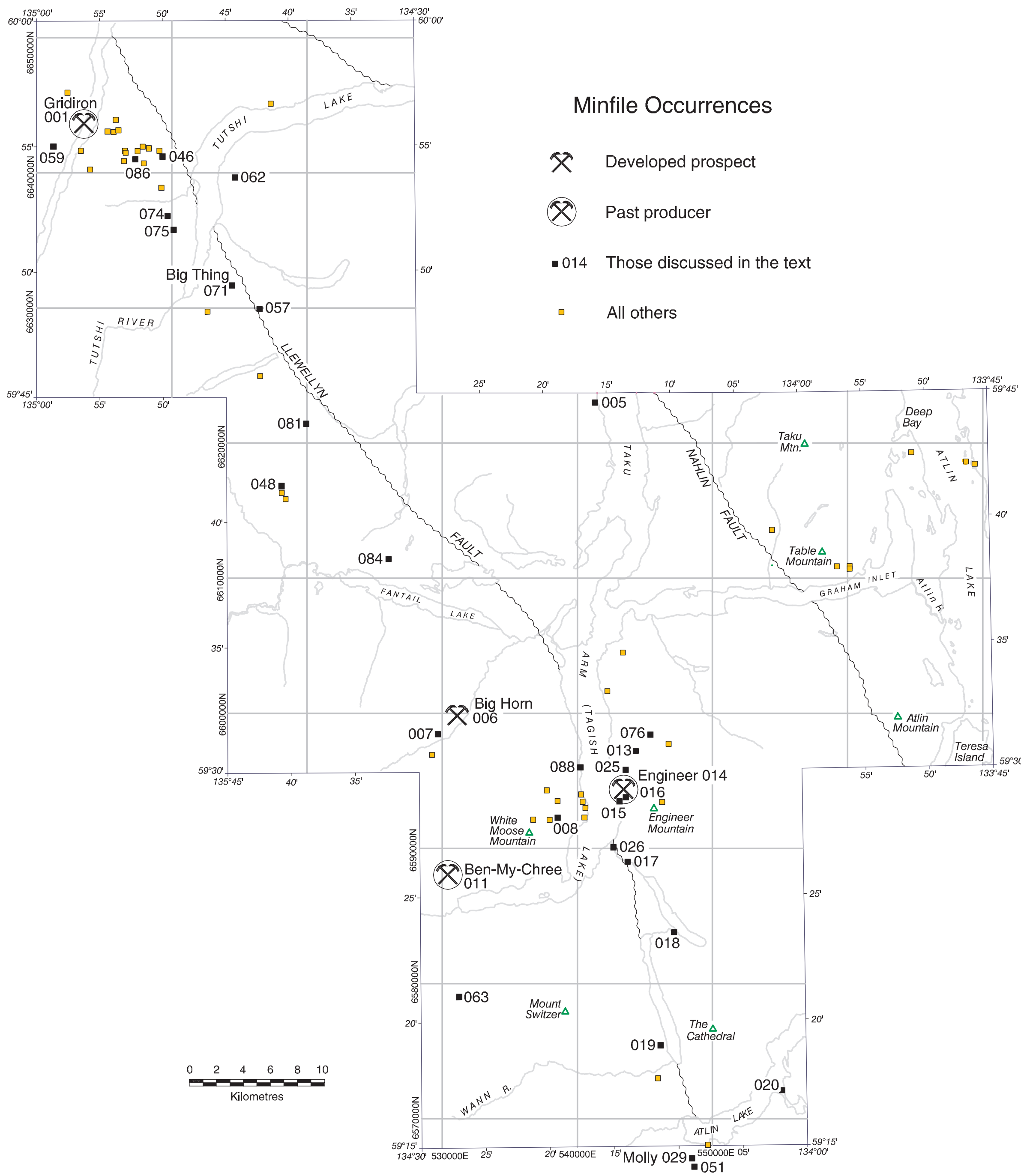


Figure 14-2. Tagish area MINFILE locations.

Table 14-1. Classification of MINFILE occurrences in the Tagish and adjacent areas (104M, 104N12W)

Minfile Number	Occurrence Name	Status	Latitude	Longitude	Commodities	Deposit Type
104M 001	GRIDIRON	PAPR	59.93	134.94	AG AU PB AS ZN	I05
104M 002	SILVER QUEEN	SHOW	59.90	134.93	AU CU AG	I05
104M 003	BEN 1	SHOW	59.91	134.87	AG AU PB ZN SB	I05
104M 004	TUTSHI LAKE	SHOW	59.95	134.42	PB ZN	I05
104M 005	LAKEFRONT	SHOW	59.74	134.27	SB PB	I09
104M 006	SPOKANE	DEPR	59.54	134.45	AU AG ZN PB CU	I05
104M 007	BIGHORN	SHOW	59.53	134.48	AU AG PB CU	I01 I05
104M 008	RUPERT	PROS	59.47	134.32	AG AU PB ZN CU	I05
104M 009	WHITE MOOSE-NORTH (L. 1279)	SHOW	59.48	134.29	CU PB ZN AG	I05
104M 010	WHITE MOOSE-SOUTH (L. 12)	SHOW	59.47	134.28	AG PB CU	I05
104M 011	BEN-MY-CHREE	PAPR	59.43	134.46	AG AU CU PB ZN	I05
104M 012	WHITE MOOSE-SHAFT (L. 3282)	SHOW	59.48	134.29	AU AG PB CU	I05
104M 013	HAPPY SULLIVAN	PROS	59.51	134.22	AU AG	H05
104M 014	ENGINEER	PAPR	59.49	134.23	AU AG SB TE	H05
104M 015	KIRKLAND	SHOW	59.48	134.24	AU	H05
104M 016	GLEANER	SHOW	59.48	134.23	AU AG	H05
104M 017	ANYOX-RODEO (L.4657,4670)	SHOW	59.44	134.23	CU NI CO	
104M 018	EDGAR LAKE	SHOW	59.39	134.17	CU	M01
104M 019	NELSON LAKE	SHOW	59.32	134.19	AG AU CU PB	I05
104M 020	COPPER ISLAND	SHOW	59.29	134.03	CU	M01
104M 021	CALLAGHAN	SHOW	59.25	134.13	AU AG	H05
104M 022	LAVERDIERE	PROS	59.22	134.12	CU AG AU MO WO CO	K01
104M 023	GRAHAM CREEK	SHOW	59.66	134.03	AU	C01
104M 024	RED RUPERT	SHOW	59.51	134.48	AU AG	H05 I05
104M 025	SWEEPSTAKE	SHOW	59.50	134.23	AU	H05 I05
104M 026	BROWN	SHOW	59.45	134.25	AG AU CU PB ZN MO	I05
104M 027	JESSIE	SHOW	59.81	134.77	AG AU CU PB ZN	I05
104M 028	BALD PEAK	SHOW	59.93	134.90	AU AG PB SB	I05
104M 029	MOLLY	PROS	59.24	134.15	MO CU SB PB	L05
104M 030	MUSSEN	SHOW	59.19	134.09	CU	M01
104M 031	JACKIE	SHOW	59.16	134.32	AG ZN PB CU AU	J01
104M 032	BENNETT LAKE	SHOW	59.95	134.96	LS	R09
104M 033	TALAHA BAY	SHOW	59.97	134.14	LS	R09
104M 034	PENINSULA MOUNTAIN	SHOW	59.82	134.23	MT	I17
104M 035	BUCHAN CREEK	SHOW	59.49	134.33	AU AG PB CU ZN	I05
104M 036	RUPERT-NORTH	SHOW	59.48	134.32	AU AG PB CU ZN	I05
104M 037	FEE GLACIER	SHOW	59.47	134.35	AG CU PB	I05
104M 038	GAUG-WEST	SHOW	59.93	134.91	AU AG PB SB AS	I05 I09
104M 039	GAUG 2	SHOW	59.93	134.89	AU AG ZN CU PB	I05 I09
104M 040	GAUG 1	SHOW	59.93	134.90	AG CU FE	I05
104M 041	BEN-POND	SHOW	59.91	134.88	AG PB AU ZN SB	I05 I09
104M 042	BEN-CAMP	SHOW	59.91	134.88	AG AU PB ZN	I05
104M 043	BEN-GLACIER	SHOW	59.91	134.88	AU AG CO	I05
104M 044	BENNETT	PROS	59.92	134.86	AU AG ZN CU PB	I05
104M 045	BEN-NORTHEAST	SHOW	59.91	134.84	AU AG	I01

104M 046	BEN-SOUTHEAST	SHOW	59.91	134.83	AG PB AU CU	I05
104M 047	BEN-FOUR	SHOW	59.91	134.86	AU AG	I01
104M 048	TP-MAIN	PROS	59.69	134.68	AU AG CO CU FE MA	K03
104M 049	TP-CAMP	SHOW	59.69	134.68	MA FE	K03
104M 050	TP-CENTRAL	SHOW	59.68	134.67	AG AU CO CU MA	K03
104M 051	MOLLY-SOUTH	SHOW	59.24	134.15	MO CU PB	L05
104M 052	SELLY	SHOW	59.76	134.71	CU PB	K01
104M 053	RAD	SHOW	59.95	135.56	MO	L05
104M 054	SILT	SHOW	59.97	135.61	MO	L05
104M 055	PIT CREEK	SHOW	59.98	135.61	MO	L05
104M 056	RIO CREEK	SHOW	59.96	135.60	ZN PB CU SN FL	L06
104M 057	MOON LAKE	SHOW	59.81	134.71	AG ZN PB AS CU AU	I05 J01
104M 058	NET 6	SHOW	59.91	134.94	UR TH	I15
104M 059	NET 3	SHOW	59.92	134.98	AG UR TH MO WO	I15
104M 060	JONES	SHOW	59.97	135.32	UR TH	I15
104M 061	CATFISH	SHOW	59.89	134.84	AG AU ZN PB SB CU	I05
104M 062	PIKE	SHOW	59.90	134.74	AU AG CU	H05
104M 063	KIM	SHOW	59.35	134.45	CU ZN AG AU	I05
104M 064	NA 5062	SHOW	59.21	134.13	CU AG AU	I05
104M 065	MIP	SHOW	59.93	135.24	AG AU CU PB ZN	I05 H05
104M 066	YAK	SHOW	59.97	135.35	AG AU CU PB ZN	I05 H05
104M 067	YAK NORTH	SHOW	59.97	135.35	PB AG CU AU ZN	I05
104M 068	YAK SOUTH	SHOW	59.97	135.35	AG PB ZN CU AU	I05
104M 069	JULIA	SHOW	59.96	135.32	AG AU PB ZN CU	I05
104M 070	EAGLE	SHOW	59.98	135.40	AG AU PB	H05
104M 071	BIG THING	SHOW	59.82	134.74	AU AG PB ZN CU	I05
104M 072	WHITE MOOSE-B	SHOW	59.48	134.28	AG PB	I05
104M 073	RUPERT-L	SHOW	59.47	134.33	AG AU PB ZN CU	I05
104M 074	CATFISH-MIDDLE RIDGE	SHOW	59.87	134.83	AU AG CU PB ZN AS	I05
104M 075	CATFISH-SOUTH MOUNTAIN	SHOW	59.86	134.82	AG AU CU PB ZN AS	I05
104M 076	GOLDEN BEE 2	SHOW	59.52	134.20	SB AG AU	I09
104M 077	BEE PEAK	SHOW	59.52	134.17	PB AG AU AS	I05
104M 078	GLEAN	SHOW	59.48	134.18	AG AU CU PB ZN AS	I05 H05
104M 079	MASS	SHOW	59.55	134.25	AU AG	H05
104M 080	QUANTITY	SHOW	59.58	134.23	AU AG CU	H05
104M 081	CRINE	PROS	59.73	134.65	AU AG PB ZN AS CU	I05
104M 082	DELTA	SHOW	59.29	134.19	AU AG CU PB	I05
104M 083	MILL	SHOW	59.95	134.69	CU AG AU	K01
104M 084	UM	PROS	59.64	134.54	AU AG	I01
104M 085	SKARN	PROS	59.92	134.85	AU CU	K01
104M 086	COWBOY	SHOW	59.91	134.87	AU AG SB PB CU	I09
104M 087	FALCON	PROS	59.16	134.32	AG AU ZN PB CU AS	I05
104M 088	MM05-1	SHOW	59.50	134.29	AU AG CU	I01
104N 001	HUSSELBEE	SHOW	59.71	133.85	UR TH FL PB MO	K07 I15
104N 002	ISLAND MOLY	SHOW	59.70	133.78	MO	L05
104N 003	DUNDEE	PROS	59.63	133.93	PB CU	I05
104N 004	PETTY	SHOW	59.63	133.93	PB CU AG	I05
104N 014	NORSK	SHOW	59.70	133.77	MO	L05
104N 102	GRAHAM INLET	SHOW	59.63	133.95	MT	I17

maining 22 occurrences, all but one, a limestone occurrence, lie within 10 kilometres of the study area. Part of the Atlin area (NTS 104N12W) is also covered by the Tagish study. It includes an additional 6 mineral occurrences.

Half of the occurrences are classified as polymetallic veins (Table 14-1b). However, from an economic perspective, the most historically interesting class of deposit is the low sulphidation epithermal type, and these deposits account for less than 12% of the occurrences. The Engineer mine is of this type.

Porphyry molybdenum (L05), gold quartz vein (I01), copper skarn (K01), basaltic copper (M01), iron skarn (K05), and stibnite vein (I09) showings account for about 7, 5, 4., 4, 3 and 3 percent of all occurrences respectively. Seven other deposit types each account for 2 percent or less of the total number of occurrences.

Several significant mineral occurrences in the area are difficult to classify. For example, zones of sheared and quartz-carbonate-altered basalt, such as the Moon Lake base metal property (104M057), can be traced for at least 2.5 kilometers within Stuhini volcanics and interbedded carbonates. The main mineralized zone at Moon Lake measures about 100 by 300 metres and contains up to 25% combined galena and sphalerite (over narrow widths) and significant amounts of chalcopyrite, arsenopyrite, and gold. While the mineralization is like carbonate-hosted Zn-Pb-type deposits, the deposit form is vein-like with replacement style mineralization that has been strongly deformed within the Llewellyn fault zone. The Moon Lake occurrence is one of a number of shear related vein occurrences reported in the Tagish Lake area. Most are polymetallic and spatially associated with the Llewellyn fault zone. They are probably geneti-

Table 14-1b. Mineral occurrence statistics for the Tagish and adjacent areas (104M, 104N12W).

Number of occurrences within the immediate study area	**66**
Number of occurrences within 10 km of study area in NTS 104M	**21**
Total number of occurrences in NTS 104M	**88**
Number of occurrences in study area in NTS 104N (104N12W)	**6**
Total number of occurrences considered	**94**

Deposit Type		**Code**	**Number of occurrences**
Placer	**C**		
	Placer gold	C01	1
Vein Breccia and Stockwork	**I**		
	Gold quartz veins	I01	5
	Polymetallic veins	I05	46
	Stibnite veins	I09	3
	Classical U veins	I15	3
Epithermal	**H**		
	Epithermal Au-Ag: low sulphidation	H05	11
Manto	**J**		
	Polymetallic manto	J01	1 (?)
Skarn	**K**		
	Copper skarn	K01	4
	Gold skarn	K03	3
	Molybdenite skarn	K07	1 (?)
Porphyry	**L**		
	Porphyry Mo (Low F- type)	L05	7
	Porphyry Sn	L06	1 (?)
Ultramafic/Mafic related	**M**		
	Basaltic copper	M01	4
Industrial Minerals/Dimension Stone			
	Cryptocrystalline magnesite veins	I17	2
	Limestone	R09	2

Table 14-2. Representative MINFILE occurrences.

MINFILE NO.\NAME	METALS	METALLIC MINERALS	HOST ROCKS	PRODUCTION/RESERVES or BEST ASSAY
104M 001 Gridiron	Ag, Au	Galena, Tetrahedrite, Arsenopyrite, Sphalerite	Boundary Ranges metamorphic suite & hypabyssal andesites; intrusive equivalent to Early to Mid Jurassic volcanics.	Production (1901) 68 tonnes ore mined average recovered grade: 2582 g Au 156 g Ag (EMPR AR 1901)
104M 002 Silver Queen (Ruby, Net, Dick)	Ag, Cu	Chalcopyrite, Pyrite, Pyrrhotite	Boundary Ranges metamorphic suite & Coast Plutonic intrusive contacts. Feldspar-quartz monzonite porphyry, phyllite, marble, gneiss.	Grab sample 14.8g/t (EMPR AR 19186)
104M 003 Ben Creek	Ag, Au, Pb, Zn, Sb	Galena, Sphalerite, Stibnite, Arsenopyrite, Pyrite	Boundary Ranges schists	Best Assay: 1983 chip sample 10.m Au 0.32 g/t Ag 108.10 g/t (EMPR AR 12554)
104M 005 Lakefront	Cu, Pb, Zn, Sb	Stibnite, Galena	Quartz vein, Lower Laberge Group argillite	Best Assay: 1988 Pb 0.01 % Zn 0.01 % Cu 0.01 % Sb 6.48 % (EMPR FW 1990)
104M 006 Spokane	Au, Ag, Zn, Cu, Pb	Au, Galena, Sphalerite, Chalcopyrite, Pyrite	Quartz vein, Boundary Ranges hornblende-chlorite schist and amphibole gneiss, and feldspar porphyry	Best Assay: 1933 Au 23.31 g/t Ag 6.17 g/t (EMPR AR 1933)
104M 007 Bighorn	Au, Ag, Pb, Cu	Galena, Chalcopyrite, Sphalerite, Au	Quartz vein, Boundary Ranges hornblende-chlorite schist and amphibole gneiss, and feldspar porphyry	Ag 13.71 g/t Au 44.56 g/t (EMPR Annual Report 1933)
104M 008, 035, 036, 037 Rupert Claim Group (Rupert & Rupert North and G to L occurrence)	Au, Ag, Pb, Zn, Cu	Au, Galena, Chalcopyrite, Pyrite	Quartz vein, Florence Range pelitic and semipelitic schist and amphibolite	Best Assay: 1980 chip sample 1.10 m Au 21.26 g/t Ag 244.80 g/t Pb 12.80 % Cu 0.35 % Zn 0.08 % (EMPR AR 8384)
104M 009, 010, 012 White Moose Claim Group (North, South & Shaft, and A to E occurrence)	Au, Ag, Pb, Zn, Cu	Chalcopyrite, Bornite, Galena, Tetrahedrite, Pyrite	Quartz vein, Boundary Ranges pelitic schist	Best Assay: 1980 grab sample Au trace Ag 53.14 g/t Pb 0.13 % Cu 0.01 % (EMPR AR 8384)
104M 011 Steep Claim Group (Ben-My-Chree)	Au, Ag, Pb, Cu, Zn	Galena, Chalcopyrite, Pyrite	Quartz-calcite vein, Late Cretaceous to Early Tertiary granite	Production (1911) 7 tonnes Au 91 grams Ag 31103 grams Best Assay: 1985 grab sample Au 11.00 g/t Ag 450.00 g/t Cu 0.14 % Pb 4.25 % Zn 0.04 % (EMPR AR 9133)

104M 013 Happy Sullivan	Au, Ag	Au, Ag, Arsenopyrite, Pyrite	Quartz vein, Lower Jurassic Laberge Group greywacke	Best Assay: 1933 grab sample Au 323.60 g/t Ag 226.20 g/t (EMPR AR 10511)
104M 014 Engineer Mine	Au, Ag, Sb, Te	Au, Berthierite, Tellurides, Pyrite, Chalcopyrite, Antimony	Lower Jurassic Laberge Group argillite and greywacke	Production (1913-1952) 560 kilograms Au average recovered grade : Au 36.00 g/t Ag 17.90 g/t (EMPR FW 1986)
104M 015 ENGINEER GOLD CAMP Kirkland Claim Group (Kirtland, Jersey Lily)	Au, Ag	Au	Quartz vein, Lower Jurassic Laberge Group argillite and greywacke	NA
104M 016 ENGINEER GOLD CAMP Gleaner Claim Group	Au, Ag, Te	Au, Tellurium, Pyrite	Quartz vein, Lower Jurassic Laberge Group argillite and greywacke	Grab sample 1.23 g/t (EMPR AR 22075)
104M 017 Anyox-Rodeo	Cu, Ni, Pt, Pd, Co	Pentlandite, Bornite, Pyrite, Chalcopyrite	Paleozoic to Proterozoic Boundary Ranges chlorite schist	Best Assay: 1989 grab sample Au 0.02 g/t Cu 0.15 % Ni 0.60 % Co 0.12 % Pt <15 ppb Pd 90 ppb (EMPR OF MAP 1990)
104M 018 Edgar Lake	Cu	Native copper, Chalcopyrite, Bornite	Calcite vein, Upper Triassic Stuhini pyroxene-phyric lapilli tuff	NA
104M 019 Nelson Lake	AU, Ag, Pb, Cu	Galena, Chalcopyrite	Quartz vein, Florence Range pelitic and semipelitic schist, and marble	Best Assay: 1989 Au 4.60 g/t Ag 198.00 g/t Pb 3.90 % Cu 1.25 % (EMPR OF MAP 1990)
104M 020 Copper Island	Cu	Cu, Cuprite, Tenorite	Calcite vein, Upper Triassic Stuhini group phreatomagmatic pyroxene-phyric breccia and pyroxene-phyric flows	NA
104M 023 Graham Creek	Au (placer)	Au (placer)	Mid to Upper Triassic Peninsula Mountain volcanic suite and Graham Creek igneous suite may host lode source	Best Assay: 1986 rock sample: 2.5 km upstream from placer camp, EMPR Property File Au 0.10 g/t Ag 10.00 g/t Pb 0.26 % Zn 0.18 % Cu 0.03 %
104M 024 Red Rupert	Au, Ag	Au	Quartz vein, Boundary Ranges chlorite-actinolite and biotite-plagioclase-quartz schists	Best Assay: 1983 Au 34.30 g/t Ag 13.72 g/t channel sample: 30 cm (EMPR AR 1933)
104M 025 Sweepstake	Au	Au		NA
104M 026 Brown (Jackpine, Wann Fraction)	Au, Ag, Pb, Cu, Zn	Tetrahedrite, Chalcopyrite, Pyrite, Molybdenite, Galena, Sphalerite	Quartz vein, Paleozoic to Proterozoic Boundary Ranges chlorite-actinolite schist and Upper Triassic Stuhini Group volcaniclastics	Best Assay: 1989 Au 94.27 g/t Ag 1227.22 g/t grab sample (EMPR OF MAP 1990)

104M 027 Great Northern (Jessie, Tuts, Tut6)	Au, Ag, Sb, As	Chalcopyrite, Pyrrhotite, Galena, Sphalerite	Boundary Ranges metamorphic suite chlorite schist, amphibole gneiss & andesite.	"Average" Assay: 1929 Au 5.14 g/t Ag 809.14 g/t Cu 4.90 % chip sample 1.5m (EMPR Ann.Rpt. 1929)
104M 028 Bald Peak (Gaug-South)	Au, Ag, Sb, As	Galena, Stibnite, Arsenopyrite, Pyrite	Quartz-eye porphyry rhyolite or hypabyssal intrusive of Early to Mid Jurassic age.	Best Assay: 1982 Au 8.02 g/t Ag 212.30 g/t As 4.75 % chip sample 70cm (EMPR AR 11044)
104M 032 Bennett Lake	Limestone	Limestone	Limestone within Boundary Ranges metamorphic suite	NA
104 038 Silver Queen North (Gaug-West)	Au, Ag, Pb, Cu, Sb, As	Arsenopyrite, Stibnite, Pyrite, Chalcopyrite, Galena	Quartz vein, granite and rhyolite of Early to Mid Jurassic age	Best Assay: 1983 Au 8.02 g/t Ag 212.23 g/t As 4.75 % chip sample 1.0 m (EMPR AR 12554)
104M 039 Gaug 2	Au, Ag, Zn, Cu, Pb	Arsenopyrite, Sphalerite, Chalcopyrite, Galena, Stibnite	Quartz vein, Late Triassic granodiorite, dacite and basalt dikes	Best Assay: 1982 Au 12.07 g/t Ag 327.43 g/t Zn 0.32 % Cu 0.10 % chip sample 1.0 m (EMPR AR 11044)
104M 040 Gaug 1 (Copper Zone)	Ag, Cu, Fe	Chalcopyrite, Bornite, Malachite, Magnetite, Pyrite	Vein, Late Triassic granodiorite	Best Assay: 1982 Cu 9.49 % Ag 93.94 g/t grab sample: massive sulphide (EMPR AR 11044)
104M 041 Ben-Pond	Ag, Pb, Sb, Zn, Au	Galena, Stibnite, Sphalerite, Pyrite	Quartz vein, gneiss, argillite (contact between Boundary Ranges metamorphic suite and Lower Jurassic Laberge sediments)	Best Assay: 1983 Au 0.03 g/t Ag 90.60 g/t Pb 1.47 % Sb 1.30 % chip sample 3.27 m (EMPR AR 11044)
104M 042 Ben-Camp	Ag, Au, Pb, Zn	Galena, Sphalerite, Arsenopyrite, Pyrite	Quartz vein, gneiss, argillite (contact between Boundary Ranges metamorphic suite and Lower Jurassic Laberge sediments)	Best Assay: 1983 Au 12.45 g/t Ag 2136.00 g/t grab sample (EMPR AR 12554)
104M 043 Ben-Glacier	Au, Ag, Co	Erythrite, Pyrite	Quartz vein, Lower Jurassic Laberge greywacke	Best Assay: 1983 Au 6.62 g/t Ag 1.70 g/t Co 0.37 % (EMPR AR 12554)
104M 044 Paddy	Au, Ag, Zn, Cu, Pb	Sphalerite, Chalcopyrite, Galena, Arsenopyrite, Pyrite	Quartz vein, Boundary Ranges metamorphic suite gneiss & schist, and Lower Jurassic Laberge argillite	Best Assay: 1983 Au 3.70 g/t Ag 338.00 g/t Pb 2.30 % grab sample (EMPR AR 12554)
104M 045 Ben-Northeast	Au, Ag	Arsenopyrite	Vein, Early to Mid Jurassic volcanics	Best Assay: 1983 Au 13.37 g/t Ag 1.20 g/t grab sample (EMPR AR 12554)
104M 046 Ben-Southeast	Ag, Pb, Cu, Au	Galena, Chalcopyrite	Quartz vein, Early to mid-Jurassic volcanics	Best Assay: 1983 Au 0.07 g/t Ag 253.70 g/t Pb 1.34 % grab sample (EMPR AR 12554)

104M 047 Ben-Four	Au, Ag	Arsenopyrite	Quartz vein, Boundary Ranges metamorphic suite	Best Assay: 1993 Au 22.66 g/t Ag 8.00 g/t grab sample (EMPR AR 12544)
104M 048 TP Main	Au, Ag, Co	Au, Erythrite, Arsenopyrite, Magnetite, Chalcopyrite, Galena	Skarn, Boundary Ranges metamorphic suite chlorite-actinolite schist Plagioclase-quartz banded chlorite-actinolite schist & marble	Best Assay:1988 Au 27.45 g/t Ag 6.40 g/t Co 0.05 % chip mple (EMPR AR 18766)
104M 049 TP Camp	Au, Ag, Zn, Pb, Cu	Magnetite, Pyrrhotite	Skarn, Boundary Ranges metamorphic suite chlorite-actinolite schist, Plagioclase-quartz banded chlorite-actinolite schist and marble	Best Assay: 1983 Au 0.05 g/t Ag 0.50 g/t Zn 0.53 % Pb 0.13 % Cu 0.02 % composite sample (EMPR AR 11300)
104M 050 TP Central	Au, Ag, Co, Pb, Fe	Chalcopyrite, Arsenopyrite, Pyrrhotite, Magnetite	Skarn, Boundary Ranges metamorphic suite chlorite-actinolite schist, plagioclase-quartz banded chlorite-actinolite schist and marble	Best Assay: 1983 Au 10.83 g/t Ag 147.40 g/t Co 1.68 % Pb 4.65 % grab sample (EMPR AR 11300)
104M 052 Selly	Cu, Pb	Chalcopyrite, Galena, Pyrite, Pyrrhotite	Boundary Ranges metamorphic suite limestone & quartzite, and granodiorite	NA
104M 057 Moon Lake	Ag, Zn, Pb, Sb, Cu, Au	Tetrahedrite, Galena, Sphalerite, Arsenopyrite, Pyrite	Quartz vein, Upper Triassic Stuhini Group porphyry, tuff and volcanic breccia	Best Assay: 1985 Ag 490.00 g/t Au 6.40 g/t Cu 4.00 % Pb 1.39 % Zn 0.26 % As 1.37 % grab sample (EMPR AR 15500 & EMPR FW 1986)
104M 058 Net 6	Ur, Th	Unknown	Pegmatite, aplite, feldspar porphyry, quartz monzonite	Best Assay: 1978 Ur 34.00 ppm Th 7.00 ppm rock sample (EMPR AR 6882)
104M 059 Net 3 (Ag Gully)	Ag, Mo, W	Native silver, Molybdenum, Scheelite	Biotite-garnet-quartz monzonitic porphyry, feldspar-quartz monzonite	Best Assay: 1979 Ag 65.17 g/t (EMPR AR 7417)
104M 061 Catfish (Friendship Silver, Linda)	Ag, Au, Zn, Pb, Sb, Mo, Sn	Arsenopyrite, Galena, Stibnite, Pyrite, Molybdenum	Quartz vein, granite, diorite, Boundary Ranges metamorphic suite sericite-chlorite schist & quartz-feldspar-chlorite gneiss	Best Assay: 1987 Au 23.32 g/t Ag 147.10 g/t grab sample (EMPR AR 18522)
104M 062 Pike	Au, Ag, Cu	Pyrite, Chalcopyrite	Pyritic andesite, feldspar porphyritic andesite	Best Assay: 1986 Au 0.59 g/t Ag 0.50 g/t grab sample: from veinlets (EMPR AR 15808)
104M 063 Kim	Cu, Zn, Ag, Au	Chalcopyrite	Paleozoic to Proterozoic Wann River Gneiss, and Late Cretaceous to Early Tertiary hornblende-biotite granite	Best Assay: 1985 Cu 4.03 % Zn 0.82 % Ag 109.70 g/t Au 0.69 g/t sample across 4.5 to 6.0 m (EMPR Property File)
104M 071 Big Thing (Jessie, Tut1)	Au, Ag, Pb, Zn	Galena, Sphalerite, Chalcopyrite, Arsenopyrite	Boundary Ranges metamorphic suite deformed aquagene tuffs? and sediments	87cm channel sample Ag 51.4g Au 6.5g EMPR AR 15500

cally linked to movement of mineralized fluids within the fault zone.

Geologic environments in the Tagish area are permissive for Carlin-type (E03), and turbidite - hosted gold (I03) deposits, and there is potential for industrial minerals in several deposit types: wollastonite skarn (K09), ultramafic-hosted asbestos (M06), ultramafic-hosted talc-magnesite (M07). No good examples of these deposit types have been discovered to date, perhaps because there has been little or no exploration for them. Further, despite the existence of appropriate geologic settings, no significant massive sulphide-type mineral occurrences have been discovered in the area either.

Widely spaced joint sets of 3 metres or more in some intrusive phases in the Coast plutonic complex indicate dimension stone potential. However, economic viability is limited by access and market proximity.

Epithermal Veins (H05)

A number of models have been developed over the last decade to aid exploration for epithermal veins (*e.g.* Panteleyev,1986). Epithermal gold deposits may occur in almost any type of host rock, although volcanic rocks are most common because of the association of epithermal deposits with felsic volcanic fields. Two main ingredients are large, sustained open fracture systems and extended periods of hydrothermal activity.

Historically the most important mineral occurrences in the Tagish lake area are auriferous veins, particularly those at the Engineer Mine (104M014). Production records at the Engineer Mine are incomplete, but show most of the gold and silver was recovered from 1913 to 1918 and 1925 to 1927. Total production based on existing records was 560000 grams gold and 280 kilograms silver milled with an average recovered grade of 36.00 grams per tonne gold and 17.90 grams per tonne silver. Other claims staked in the area were unsuccessful at finding payloads as rich as those found at the Engineer Mine, and were never put into production. These include the Happy Sullivan, Kirtland, Gleaner Claim Group and Sweepstake (104M 013, 015, 016, and 025). All, including the Engineer gold mine, are collectively referred to as the Engineer Gold Camp.

All vein occurrences belonging to the camp are hosted in Lower Jurassic Laberge Group argillite and wacke and appear to occur adjacent to splays of the crustal-scale Llewellyn Fault zone. In settings like the Bralorne camp, crustal scale faults exert a first order control on the distribution of mesothermal precious metal veins (Kerrich, 1988). In the Tagish area, however, there is little indication of significant offset along splays that control the auriferous veins. The veins display a vertical continuity, although they pinch and swell along strike and dip.

Lode veins at the Engineer display lower silver/gold ratios and higher temperatures and greater depth of formation than veins of typical epithermal deposits. Silver/gold ratios, based upon production figures, range from 0.49 to 0.9, versus a more typical ratio of 15 to 30 for deposits of this type. While the low Ag/Au ratio falls within the range typical of mesothermal deposits, observed textures are more typical of a shallower setting with several veins exhibiting open space textures showing episodic development. Ore-grade vein material at the Engineer is composed of vuggy and drusy millimeter to centimeter quartz crystals, ranging from blue to green to brown (Photo 14-2). Cockscomb and colloidal textures in successive layers of quartz and calcite that mantle angular fragments of wallrock and vein are common. For example, a cross-section of the Happy Sullivan occurrence shows it to be a subvertical vein that is up to 150 centimetres wide with morphologies varying from west to east. Approximately half a meter of pyritized greywacke wall rock is followed by a zone of colloidal to amorphous quartz containing grains and dendritic crystals of gold, often surrounded by a thin layer of calcite. This is followed by a 5 to 8 centimeter zone of quartz and feldspar (adularia?) with up to 5 percent disseminated sulphides, primarily pyrite. The contact between these two zones consists of vuggy quartz on a millimeter scale. Next is a relatively massive, fractured and vuggy quartz vein up to 60 centimeters wide, in which sulphide mineralization is negligible, followed by a second quartz vein up to 90 centimeters wide with 5 to 10 percent fine-grained, disseminated arsenopyrite. The eastern margin of the vein is sheared (Tully, 1979).

Available geochemical data show elevated values of antimony, mercury, arsenic and tellurium in the Engineer camp. This element suite is an ambiguous exploration tool because it characterizes both epithermal and

Photo 14-2. A sample of greasy grey quartz vein with irregular millimetre-sized gold intergrowths concentrated in bands. Mined during the operation of the Engineer Mine *circa* 1925. Photographed courtesy of Jim Brooks, Atlin.

mesothermal deposits. However, elevated tellurium is not characteristic of other veins in the Tagish Lake area.

Fluid inclusion homogenization temperatures reach 195°C in veins that cut Laberge Group siliciclastics (Table 14-4). These veins are more than 800 metres below the base of the Sloko volcanics that are presumed to be roughly coeval with mineralization. More than 1 kilometre of Sloko strata probably overlay the deposit during its formation. Thus, both the temperature and depth of formation stretch the limits for epithermal deposits. Most epithermal deposits that have been mined to considerable depth display an increase in base metals. Not so for veins at the Engineer mine which probably formed at the deep limit of classical epithermal systems: base metals are conspicuously sparse (Table14-2). Veins of the Engineer gold camp are probably most accurately classified as transitional meso/epithermal: low sulphidation type.

Ratios of Ag/Au at the Engineer mine are similar to those of the Skukum gold deposit in the Yukon. However, Skukum is hosted in Sloko volcanic strata and the fluid inclusion trapping temperatures, oxygen and hydrogen isotopic ratios, estimated depth of formation and ore textures displayed by the Skukum deposit (Hart and Radloff, 1990) are typical of epithermal deposits.

A correlation between Eocene Sloko volcanic centres and economic epithermal gold mineralization is demonstrated by both the Engineer and Skukum deposits. Newly recognized Sloko volcanic centres in the Tagish area, like Teepee Peak and Mount Switzer, also have potential to host such mineralization. Visible gold in skarn mineralization at the TP-main occurrence (104M 048) confirms this metallogenic association. Preserved Sloko strata and thick rhyolite dykes near Mount Fetterly represent another potential mineralizing centre. A western strand of the Nahlin fault that cuts volcanics at Mt. Fetterly could have focused hydrothermal fluid flow. Stocks between Engineer Mountain, Mount Fetterly and Mount Cameron are shown as Late Cretaceous in age on Figure GM97-1, however, only one is dated (K-Ar, hornblende, 83 ±3 Ma), and some of the others could be of Sloko age with potential for associated gold mineralization. A small pluton of Sloko age that cuts major Jurassic faults south of Mount Switzer has similar mineral potential.

Gold quartz veins (mesothermal, I01)

Deposit models for mesothermal veins have received considerable attention worldwide because of the historical importance of shear-hosted gold veins in greenstone belts. As mentioned previously, crustal scale faults typically exhibit a first order regional control on the distribution of mesothermal precious metal vein deposits. Shear zones characterized by transitional brittle to ductile rheologic behavior (Kerrich,1989) are particularly important. Ore shoots typically occur along secondary or tertiary structures related to the main shear zone. The Llewellyn Fault zone exhibits transitional characteristics and veins such as those at the Bighorn mine, UM, and MM05-1 (104M 007, 084, and 088) are thought to be located along second or third-order structures related to the Llewellyn Fault zone. Fluid inclusion homogenization temperatures from samples of veins at the Bighorn mine average more than 250 °C (Table 14-4). Average salt content of the trapped fluid is estimated from melting temperatures to be more than 13 weight percent, based upon the freezing point depression relationship of Potter *et al.* (1978). Veins at the Bighorn Mine are podiform, sheared and concordant (or nearly so) with enclosing schists of transitional greenschist-amphibolite grade. Depth and temperature of formation are typical of mesothermal gold quartz veins (200 - 400°C), although, the fluid inclusions are apparently more saline and CO2 -poor than the fluids from which most gold quartz veins are believed to have formed.

Listwanite-associated gold-quartz veins have been rigorously documented in the Atlin area by Ash and Arksey (1990a). Several prospective geological environments exist in the Tagish area but mineral occurrences of this type west of the Atlin placer camp were essentially unknown until 1990 when the UM showing was recorded by Cyprus Gold (Canada) Limited (Cuttle, 1990) between Teepee Peak and Fantail Lake. The UM vein is up to 2.20 metres wide and dips steeply. It is reportedly located along a faulted contact between a tabular peridotite-dunite body and Boundary Ranges chlorite schists. The UM is perhaps the best example of a possible mesothermal gold quartz vein occurrence in the Tagish area. Features characteristic of the deposit type include its genetic association with a strong fault that extends at least 11 kilometres, strong quartz - ferroan carbonate - mariposite alteration of mafic to ultramafic host rocks that are cut by abundant quartz veins, and distinctive orange-brown limonite weathering. Unlike most mesothermal gold-quartz veins, however, it has a moderately high silver/gold ratio of 12 (based upon an average of 15 chip samples). Silver/gold ratios of typical gold-quartz veins are less than 1 and commonly less than 0.1.

The potential for deposits of this type in the Tagish area is largely untested. Primary targets are mafic and ultramafic rocks of greenschist grade, particularly where cut by secondary or tertiary shears related to the Llewellyn or other crustal scale faults.

Polymetallic veins (I05)

Like classical polymetallic vein systems, Tagish Lake area polymetallic veins occur in regions of high permeability that result from the development of fabric in metamorphic rocks or fracturing associated with faulting. Thus, they are predominantly but not exclusively hosted in medium to high-grade metamorphic rocks.

Table 14-3. Tagish area mineral occurrences: A comparison of geochemical signature

*Commodities**	K	Rb	Cs	U	Nb	Ta	Ba	Mn	Fe	Co	Cu	Mo	W	Re	Ag	Au	Zn	Hg	Tl	Sn	Pb	As	Sb	Bi	Te	Se	F	NH_3
Deposit Type/Character																												
VEINS, STOCKWORK, BRECCIA																												
GOLD QUARTZ VEINS I01	♦						♦				♦		♦		♦	♦	♦	♦			♦	♦	♦	♦	♦		♦	
Lawsan											X				X	X	X	X			X	X	X					
UM Vein															X	X						X						
POLYMETALLIC VEINS I05							♦				♦				♦	♦	♦				♦	♦	♦	♦	♦		♦	
Galena-rich																												
Gridiron															X	X		X				X	X					
Spokane											X				X	X	X	X			X	X	X					
Ben-Pond															X	X		X				X	X					
Ben-Camp											X				X	X	X	X			X	X	X					
Nelson Lake											X	X			X	X	X	X			X	X	X					
Rupert Group											X				X	X	X	X			X	X	X					
White Moose Group											X				X	X	X	X			X	X	X					
Gaug-1									X		X				X													
Steep Group											X				X	X	X				X							
Ben Creek															X	X	X				X		X					
Moon Lake											X				X	X	X				X		X					
Arsenopyrite-rich																												
Ben-Four															X	X												
Crine veins											X				X	X	X	X			X	X	X					
Gaug-2											X				X	X	X	X			X	X	X					
Catfish-Middle Ridge											X				X	X					X		X					
Catfish-South Mt											X				X	X	X				X							
Ben-Five											X				X	X	X				X							
Chalcopyrite-rich																												
Silver Queen-North											X				X	X		X			X	X	X					
Brown											X				X	X	X				X							
Great Northern															X	X						X	X					
Paddy															X	X												
Pike											X				X	X												
Silver-Queen											X				X													
Catfish												X			X	X	X			X	X		X					
Kim											X				X	X	X											
STIBNITE VEINS I09													♦		♦	♦	♦	♦			♦	♦	♦					
Ben-Six											X				X	X	X				X							
Lakefront											X				X	X	X	X			X	X	X					
EPITHERMAL																												
EPITHERMAL Au-Ag H05							♦	♦			♦		♦		♦	♦	♦	♦			♦	♦	♦	♦	♦	♦	♦	
Happy Sullivan															X	X												
Engineer mine															X	X							X		X			
Kirkland Group															X	X												
Gleaner Group															X	X									X			
Sweepstake																X												
Ben-Southeast											X				X	X					X							
Ben-Northeast															X	X												
Bald Peak															X	X						X	X					
PORPHYRY																												
PORPHYRY MOLYBDENUM L05	♦	♦	♦	♦	♦	♦		♦	♦	♦	♦	♦	♦	♦			♦			♦	♦						♦	
Net-3												X	X		X													
MAGMATIC																												
BASALTIC COPPER M01										♦	♦				♦													
Edgar Lake											X				X	X	X	X			X	X	X					
Copper Island											X																	
SKARN																												
COPPER SKARN K01										♦	♦	♦	♦		♦	♦	♦					♦	♦	♦				
Mill											X				X	X	X	X			X	X	X					
IRON SKARN K03									♦	♦	♦									♦								
TP-Central									X	X	X				X	X	X	X			X	X						
TP-Camp									X	X	X				X	X	X	X			X	X						
TP-Main									X	X	X				X	X	X	X			X	X						
Selly											X										X							
MARINE VOLCANIC ASSOCIATION																												
KUROKO MASSIVE SULPHIDE G06																												
Big Thing	X						X				X				X	X	X	X				X						
Anyox-Rodeo-M (?Besshi G04)										X	X																	
PLACER																												
SURFICIAL PLACERS C01									♦						♦	♦		♦				♦	♦					
Graham Creek																X												

* in addition to those elements listed here, heavy minerals magnetite, chromite, ilmenite, hematite, and pyrite may also be useful indicators.

♦ = pathfinder element

X= geochemical analysis available for mineral occurrence shows elevated values

Table 14-4. Fluid inclusion microthermometry from Engineer and Bighorn mines.

Sample No.	Location	Th	Tm	Wt. % NaCleq
MMI88-63-5	Engineer Mine	195.4	-0.2	0.35
	(Double Decker vein)	171.4	-0.0	
KMO88-28-3	Bighorn Mine	256.3	-14.0	17.9
		253.7		
		273.9	-8.1	11.8
		220.6	-5.6	8.7
		259.4		

Th = homogenization temperature

Tm = melting temperature

Wt. % NaCleq = weight percent total salts as NaCl

Most are also associated with calcalkaline, granite to diorite intrusions, dikes and dike swarms. Typical veins are discordant, steeply dipping and occur in clusters or sub-parallel sets which in many cases follow specific structural trends in the host rock. At nearly all occurrences the ore minerals are mainly confined within the veins, but mineralization may also be disseminated in the adjacent wall rocks. Polymetallic veins are more abundant than other vein types recognized in the Tagish Lake area, accounting for two thirds of all vein occurrences and half of all recorded mineral occurrences.

Numerous auriferous polymetallic veins have been discovered in the project area over the last century. Of these, the Spokane and Ben-My-Chree occurrences (104M 006, 011) are minor past producers. Over 31 kilograms of gold were recovered from 7 tonnes of ore mined at Ben-My-Chree, and "$2000.00 or more" of gold was recovered from the Spokane occurrence according to the 1933 Department of Mines Annual Report. Recently discovered polymetallic vein occurrences include the Crine veins near Teepee Peak; the Kim, Middle Ridge, and South Mountain veins near Tutshi Lake; veins between Hale and White Moose Mountains; and the Brown vein on lower Wann River (104M081, 063, 074, 075, 008, 026).

Sulphide mineralogy of the polymetallic veins varies between and within vein systems. It is as much a reflection of mineral zoning within the veins as it is of different metal source areas. Most veins consist of vuggy and drusy quartz that is typically iron-oxide stained (both galena- and arsenopyrite-rich veins). Where the veins are thickest, they are typically banded. Late chalcedonic veins locally crosscut mineralized veins (*e.g.* the Pike showing;104M 062).

Structural control of polymetallic veins in the Tagish area appears to vary with the host rock lithology. In metamorphic host rocks, mineralized veins tend to be discordant and oriented parallel to dominant joint or fracture sets such as at the Crine, Catfish (Middle Ridge) and South Mountain occurrences. The original Crine vein showing, discovered by our crews during Geological Survey Branch mapping on the eastern flank of Teepee Peak, received considerable attention with exploratory drilling in 1989 and 1990. It is near-vertical, and tabular to podiform, with maximum widths of up to 4 metres. It has been traced for 650 metres. In contrast, veins and veinlets at the Brown occurrence generally parallel the foliation in a tectonic mixture of altered Late Triassic granodiorite, lesser Boundary Ranges chlorite-actinolite schist, and Stuhini Group volcanics within the Llewellyn fault zone (Mihalynuk and Mountjoy, 1990). There, an adit has been driven about 10 metres, parallel to the foliation and oblique to the main fault trace, to expose an anastomosing network of irregular quartz veins and veinlets that range from less than 1 to 35 centimeters wide. A road cut above and perpendicular to the adit uncovered a series of malachite, and azurite-coated veins and veinlets that extend 35 or more metres on either side of the adit. Mineralization consists of tetrahedrite, chalcopyrite, molybdenite, pyrite, sphalerite and galena.

Veins at the Ben-southeast occurrence (104M 046) are hosted in volcanic strata of probable Jurassic age, whereas veins at the Kim and Catfish occurrences cut across the contact between metamorphic and Cretaceous plutonic rocks. Mineralization occurs as either disseminations within fracture and shear zones or in veins with cockscomb and vuggy textures.

The age of mineralization of polymetallic veins in the Tagish area is uncertain, but based on the wide range of host lithologies, it probably varies. Most appear to be linked to magmatic events concomitant with the development of the Late Cretaceous to Eocene Coast Plutonic Complex. Lead-lead data from the Crine vein suggest a Cretaceous age with isotopic characteristics similar to those of veins related to Cretaceous Plutonic intrusions (Godwin, written comm, 1990).

The widespread occurrence of auriferous polymetallic veins in the Tagish area is an indication that zones of abundant veining could exist. Such zones might be amenable to bulk mining techniques and are possible exploration targets. So far, however, only isolated mineralized vein sets have been reported.

Stibnite Veins (I09)

Stibnite veins and stibnite-bearing quartz and/or carbonate veins occur along or near shear zones in sedimentary or metasedimentary rocks. This is precisely the environment of formation of the three occurrences with stibnite veins in the Tagish area: Lakefront, Golden Bee2, and Cowboy (104M 005, 076, and 086). The latter deposit occurs at the sheared contact between actinolitic schist (metawacke?) and Laberge Group wacke; the other two occur within the Laberge Group succession. All are adjacent to the Llewellyn fault or its splays. The veins are concordant to discordant and attain thicknesses of up to 1.2 metres. Gangue mineralogy is mainly quartz and lesser carbonate, although fragments of country rock are common.

Only the Lakefront showing has a history of past production. Approximately 40 tonnes of ore was recovered, but detailed records are lacking.

Antimony is a relatively low priced commodity. It is produced where small, high grade deposits can be economically hand sorted as a result of inexpensive labour, mainly in China, Turkey and Bolivia. Before deposits in the Canada can be extracted profitably, they, need to be either of very high grade and unusually large, or rich in precious metals so antimony can be produced as a byproduct. Elevated gold is reported from stibnite vein occurrences in the Tagish area, but the gold is spotty and, so far, limited to values around 2 g/t.

Copper skarn (K01).

Copper skarn mineralization has historically been prominent just to the north in the Whitehorse copper belt of the Yukon. In the Tagish area, near Tutshi Lake, auriferous copper skarn mineralization was encountered in a drill program conducted by United Keno Hill Mines Ltd. in the summer of 1989. Drilling intersected several extensive zones of massive sulphide which replace conglomerate clasts and matrix within a unit stratigraphically underlying the “Sinwa” limestone of the Upper Triassic Stuhini Group. The massive sulphide mineralization consists of chalcopyrite, pyrite, and pyrrhotite. The zone is strongly fractured and brecciated with extensive epidote and chlorite alteration. Geochemical results from drill core returned 2.06 grams per tonne gold, 41.14 grams per tonne silver and 1.58 percent copper over 1.40 metres. Several small intrusive apophyses have been mapped in the vicinity of the drill holes (too small to show on Figure GM97-1) and drill core revealed numerous felsic dikes at depth.

Copper skarn mineralization at the Mill showing is located at the same stratigraphic interval as other deposits in the Whitehorse copper belt. It’s occurrence in northernmost British Columbia suggests that the Whitehorse copper belt extends 20 kilometres further south than its present known limit.

Fe skarn (K03)

Iron skarns were once a principal source of iron, but due to their relatively small size and irregular form, they have been replaced worldwide by iron formations. Iron skarns can, however, contain appreciable amounts of gold or have an association with peripheral gold deposits. Such is the case for iron skarns in the Tagish area that are clustered on Teepee Peak at the Main, Central, Camp and Selly showings. All are hosted in Boundary Ranges metamorphic suite marbles, along contacts with Coast Belt granitoid intrusions. To date the Main showing on Teepee Peak has the highest proven potential for further development. It has visible gold in several outcrops and assays up to 22.66 g/t Au over 4.85 metres. Cobalt is also elevated with assays of up to 3.91% over 3.55 metres (Lhotka and Olsen, 1983). Silver generally assays less than 10 g/t.

First order estimates of the conditions of skarn formation based on petrologic and structural criteria (Mountjoy, 1989) indicate lithostatic and fluid pressures of about 1.5 kilobars. Temperatures are estimated at 325 to 450ºC for skarn formation and less than 440ºC for gold, cobalt and arsenic mineralization based on the above pressure and using phase relationships in the simplified chemical system $CaO\text{-}MgO\text{-}Al_2O_3\text{-}SiO_2\text{-}H_2O\text{-}CO_2$. These temperatures and pressures are very similar to those estimated from preliminary fluid inclusion results (Ettlinger, 1989, written communication). The proportion of CO_2 in the fluid phase (XCO_2) is estimated to be between 0.03 to 0.07 at 1 kilobar pressure in the garnet-diopside-actinolite skarn zone. Fluid inclusion data from other skarns have shown XCO_2 values to be consistently less than 0.10. Gold mineralization appears to be associated with late stage retrograde alteration of diopside to actinolite.

Skarn mineralization at TP main occurs as east-dipping stratabound lenses near the apex of the steep ridge of western Teepee Peak. Unfortunately most of the prospective down-plunge extension of this body has, at this locality been carved away by ice that once occupied the near-vertical cirque east of the showing. Similar geological environments on both the southern and northern flanks of Teepee Peak also have potential for gold-bearing skarn .

Porphyry molybdenum (L05)

Most molybdenum production in Canada is from either porphyry molybdenum deposits that average about 100 million tonnes with a grade of 0.1 to 0.2% Mo, or as a secondary product from copper-molybdenum porphyry deposits. Porphyry molybdenum deposits display a strong geochemical signature, both in rocks adjacent to the deposits (Mo, W, Cu and F) and peripherally (Pb, Zn, Ag). Typical, strong dispersion of molybdenum into stream sediments and water can be effectively utilized in exploration for these deposits.

Porphyritic quartz monzonite and monzonite most commonly host porphyry molybdenum deposits, although subvolcanic granite to granodiorite intrusions are also known host rocks. Thus, intrusions of monzonite composition along the eastern margin of the Coast belt may have some potential, as do multiphase hypabyssal Coast Belt intrusives and satellite bodies that intrude the Whitehorse Trough strata. The Net-3 and the Molly Claim Groups (104M059, 051) are examples of molybdenum occurrences within quartz-monzonitic to granodioritc intrusions.

Mineralization at the Net-3 was discovered during a regional uranium exploration program in the late 1970's. It comprises veins and veinlets of native silver, molybdenum and scheelite along an intensely altered fracture zone. Just south of the map area, a considerable exploration effort was focused on the Molly Atlin claim group located at Willison Bay. Molybdenite and minor chalcopyrite, tetrahedrite, magnetite, stibnite and galena mineralization occur in three styles: concentrated along fractures in biotite granodiorite in the vicinity of late alaskite intrusions and in fractures in alaskite and felsite dikes; as rosettes, coarse patches or fine disseminations in quartz and quartz-carbonate veins; and at brecciated contacts between intrusive phases. Phyllic and argillic alteration is intense. Mineralization appears to be related to late hydrothermal stages of the alkali granite intrusive (Wilton, 1970).

Given that economic molybdenum deposits are huge and geochemically conspicuous, and that the region has been explored for this type of deposit in the past, it is not likely that an outcropping deposit is present within the map area. Undiscovered deposits of this type may, however, exist in the near subsurface.

Basaltic copper (M01)

During the early 1900's native copper showings were located in the Tagish Lake area. Best known are the Copper Island and Edgar Lake showings (104M020, 018). Trenching and adit work was conducted at these occurrences shortly after their discovery but economic concentrations were never found and the claims were abandoned. Both showings consist of native copper hosted in calcite veins along fractures in mafic volcanics of the Upper Triassic Stuhini Group. While economic mineralization of this type remains undiscovered in the project area, several similar deposits of limited economic viability have been discovered to the west in the Triassic part of the Wrangellia terrane in Alaska and Yukon (Kirkham and Sinclair, 1984).

One unusual occurrence that may also belong to this deposit class is the Anyox-Rodeo (104M017, *see* next section). It is a copper-nickel-platinum-palladium massive sulphide lens hosted within Boundary Ranges chlorite-actinolite schist near its contact with Upper Triassic Stuhini volcanics. Fractured actinolite porphyroblasts up to 3 centimeters long are accompanied by interstitial or fracture-filling pentlandite, pyrrhotite, chalcopyrite and pyrite (Mihalynuk and Mountjoy, 1990). Gold, platinum and palladium values are not remarkable (Table AD2).

Marine volcanic association (G04/06)

In the Tagish area, submarine volcanic rocks range from pre-Mississippian to Jurassic in age and occur in all the lithostratigraphic terranes. However, only two massive sulphide deposits associated with probable submarine volcanic rocks are known, the Big Thing and the Anyox-Rodeo (104M071 and 017). Both are outcrop-sized massive sulphide lenses in Boundary Ranges metamorphic suite rocks. Although host rocks have volcanic protoliths, evidence of volcanogenic origins for the sulphides is not certain. Mineralogy and geochemistry of the Big Thing is like that of Kuroko massive sulphide Cu-Pb-Zn deposits (G06), but the structural lens is isolated by shear zones and a thick, proximal felsic volcanic succession is lacking.

Mineralization at the Anyox-Rodeo includes pyrite-pyrrhotite-pentlandite and chalcopyrite. Elevated platinum group elements have been reported, but were not substantiated by the geochemical analyses of this study (Table AD2). Chlorite schist of presumed altered pillow basalt origin hosts the sulphide lens which is elevated in cobalt (0.12%), nickel (0.60%), and copper (0.15%). These features are suggestive of a Besshi deposit model (G04), however, nickel is normally less abundant than cobalt in this type of deposit.

Boundary Ranges metamorphic suite rocks appear to offer a high potential for discovery of volcanic associated deposits based upon the Big Thing and Anyox Rodeo mineral occurrences. Also, age data and correlations suggest that the suite is a metamorphosed equivalent of the Stikine Assemblage (*see* Chapter 3) which hosts the Tulsequah Chief volcanogenic massive sulphide deposit located approximately 60 kilometers southeast of the Tagish area (Smith and Mihalynuk, 1992).The Tulsequah Chief deposit is located immediately east of the southward projection of the Llewellyn fault zone, and past motion on the fault may have transported the offset portion of the deposit into the Tagish area.

Placer Showings

Placer claims on Graham Creek cover the westernmost known occurrence of placer gold in the Tagish and

Atlin Lakes area. Property exploration and development to date have not yielded the substantial returns of placers in the Atlin Gold Camp. Extensive geochemical analysis of water samples from Graham Creek and tributaries has consistently yielded values of 1 to 7 parts per trillion (B. Ballantyne, Geological Survey of Canada, written communication, 1989). These values are anomalous with respect to surrounding drainage basins. Nickel tellurides, chromite and gold grains (with electrum) have been recorded from heavy mineral separates (see Hall *et al*., 1986). Silt samples locally yield anomalous arsenic and lead values, but these are not necessarily accompanied by anomalous gold. According to Ballantyne, these geochemical observations can be explained by the occurrence of a hydrothermal system (such as the system that produced the silica-flooded rhyolite breccia in Graham Creek) rooted in mafic and ultramafic lithologies such as those of the Graham Creek igneous suite (Mihalynuk et al., 1989a). Upstream from the placer claims, rocks of the Peninsula Mountain volcanic suite are only weakly anomalous in gold (Table DD).

Dimension stone

The economic viability of dimension stone production depends largely upon market forces and transportation costs. While the Tagish area is far from a large dimension stone market, its northern part is dissected by the Klondike Highway, and tidewater access (and therefore inexpensive transportation) is within 100 kilometres at Skagway, Alaska.

Pink, tan and grey quartz monzonite and granodiorite of the Coast Complex are ice scoured and locally display expansive outcrops with joint spacing greater than 1 and up to 3m. Unfortunately, most such occurrences noted during the course of the Tagish study are not easily accessible from the Klondike Highway. Handsome hornblendite is exposed south of Teepee Peak in glaciated outcrops. Slab and polish tests, however, show it to be unsuitable due to high fracture density and easily weathered sulphides. Deep grey-brown pyroxenite dikes up to 20m thick also occur at Teepee Peak. These dikes are very dense and compact and would be suitable for dimension stone production. Unfortunately, even though Teepee Peak is within 10 kilometres of the Klondike Highway, there is no road access at present and this situation is unlikely to change in near future. Lack of secondary roads in general, will limit prospecting for easily developed dimension stone to the corridor along the Klondike Highway.

Exploration Guidelines

Three general observations apply to mineral occurrences in the Tagish Lake area.

(1) While many mineral occurrence types are found in the area 42 percent are hosted in metamorphic lithologies and all have an element of structural control (Table 14-2). The most prospective veins known within the metamorphic suite tend to be late and discordant. The surface expressions of such veins may be recessive gossanous zones which can be difficult to spot since the host rocks are commonly rusty weathering and contain abundant, white, barren metamorphic quartz sweats that tend to distract the eye.

(2) A MINFILE survey of the 104M and 104K map sheets shows that , where data are available, over 50 percent of the showings are associated with shear zones (Mihalynuk and Rouse, 1988a). The importance of fault zones as structural conduits for metal-bearing fluids is key. There is a strong correlation, for example, between the Llewellyn fault zone and the location of most of the occurrences in the area. Late and extensive vein systems at the Venus and Engineer mines are mesothermal to epithermal fissure-filling veins within Montana Mountain volcanics and Laberge argillites respectively. They are adjacent to traces of the Llewellyn and Nahlin fault zones. Evidence of shearing along vein margins is abundant at the Venus mine, while at the Engineer mine, most pay veins are related to dilatent zones adjacent to splays of the Llewellyn fault system with little textural evidence of significant fault motion.

(3) Relatively little is known about the absolute age of epigenetic mineralization. Two ages are indicated by data available from the project area: Early to Middle Cretaceous and Late Cretaceous to Eocene. A general assumption based on the Pb-Pb age of the Crine veins and other vein deposits immediately to the north in the Yukon, is that most mineralization is Late Cretaceous to Early Tertiary and related to intrusions of a similar age. One pulse of metal-bearing fluid migration along the Llewellyn fault zone probably occurred in the Early to Middle Cretaceous time as evidenced by the K-Ar age determination on coarse sericite at the Brown occurrence.

Geochemical Guides

One approach to systematic exploration in the Tagish Lake area, is to rely heavily on the use of geochemical data. A preliminary tabulation of mineral occurrences grouped by deposit type with expected elevated element abundances and specific pathfinder elements is given in Table 14-3. Data for this table has been compiled from a various sources found in assessment reports as well as lithogeochemistry published by the Geological Survey Branch during the course of this study. Perhaps the greatest utility of Table 14-3 is in demonstrating the disparity between what elements *were* analyzed versus the spectrum of elements that would provide useful geochemical guides and *should be* analyzed. This is well demonstrated in the case of polymetallic, epithermal and mesothermal veins. Elements that may provide more accurate identification are tellurium and fluorine for polymetallic veins, manganese, tungsten and zinc for epithermal veins and copper, zinc and arsenic for mesothermal veins.

One possible use of the data in Table 14-3 is in mineral zonation studies. For example, polymetallic veins (I05; Table 14-3) generally display geochemical zoning with copper and gold towards the high temperature centre and zinc, lead and silver towards the cooler peripheries (Cox and Singer, 1986). Table 14-3 shows the White Moose Group veins, Ben-My-Chree, Nelson Lake, and Paddy showings are anomalous in gold and copper while the Catfish-Middle Ridge and South Mountain, Ben-Five showings are anomalous in zinc, lead and silver. An implication of this data is that the untested, deeper portions of the base metal enriched systems could have higher gold values. Application of Table 14-3 data to mineral zoning in other occurrence types may be similarly instructive; however, the data base is in many instances insufficient to define anomalies. Nevertheless it provides a useful starting point for geochemical exploration.

Regional stream silt or moss mat geochemistry can be useful in tracking down exposed mineralization or, in some instances, alteration halos. Based upon regional stream sediments collected during this study, the geochemical response of the Llewellyn fault zone is one of clearly correlated anomalous gold and arsenic values (Figure 14-1b, c). However, as the main strand of the Llewellyn fault passes from the highlands in the Tutshi Lake area to the lowlands in the south, this geochemical expression is lost. Another feature of Figure 14-1 that is noteworthy is the geochemical expression of the potential southern extension of the Whitehorse copper belt skarn mineralization. A zone of anomalous gold values corresponds with the intruded contact between the Laberge and Stuhini Groups.

Mineral Potential Synopsis

A number of geologic tracts in the area have moderate to high mineral potential, particularly for precious metals. Ten of the most prospective, easily defined tracts are presented here:

(1) Veins adjacent to the Llewellyn fault zone. The most prospective veins are those hosted by Laberge Group strata and associated with fault splays, fault-related folds, and dioritic intrusions and volcanics adjacent to the splays. Obvious examples are auriferous quartz-carbonate veins at the old Engineer mine; at least one vein is developed in the core of a fold. Fault splays genetically related to the veins need not display evidence of regionally significant offset.

(2) Quartz veins in the Boundary Ranges metamorphic suite rocks. Exploration for occurrences of this type should focus on late crosscutting metal-bearing veins rather than the abundant, concordant quartz sweats which are generally barren.

(3) Quartz - carbonate - clay - altered shear zones. Several altered shear zones within and adjacent to the Llewellyn fault zone are known to be anomalous in gold (*e.g.* Mihalynuk and Rouse, 1988a, b; Mihalynuk *et al.,* 1989b). One sample from a brecciated and silicified zone along the Nahlin fault contained moderately elevated gold values; other samples were barren. Structurally-controlled, calcareous sediment-hosted disseminated Au-Ag deposits of the Carlin type may occur in such environments. They are recognized mainly in passive continental margin successions which are affected by much younger deformation and intrusions, but are also known to occur in arc settings (Lefebure and Höy, 1996). Two settings are most prospective in the Tagish area: extensively faulted and intruded Sinwa Formation and underlying, fine-grained calcareous sediments; and well-bedded, fine-grained calcareous strata within the Laberge Group, especially where it is near the Llewellyn fault or its subsidiary splays.

(4) Contacts between Boundary Ranges metamorphic suite and Eocene volcanic or subvolcanic intrusive rocks, for example, the volcanic rocks at Teepee Peak and Mount Switzer. Skarn development and/or polymetallic replacement in Boundary Ranges suite marbles are good exploration targets.

(5) Contacts between Stuhini Group and Laberge Group where adjacent to Cretaceous plutons. For example, copper skarn mineralization is recognized in the subsurface conglomerates that overlie the Sinwa Formation at the Mill property. This may be the southern limit of the Whitehorse copper belt, a string of deposits formed within and adjacent to Sinwa carbonates as far north as Whitehorse.

(6) Quartz-carbonate ± mariposite alteration of mafic and ultramafic bodies. Potential for lode gold quartz veins of the mesothermal Motherload type is greatest adjacent to crustal scale faults like the Llewellyn and Nahlin faults. However, despite concerted efforts, no developed prospects of this type occur within the map area.

(7) Manto-style mineralization in calcsilicate rocks of the Florence Range metamorphic suite. For example, at the Jackie showing, faults and dikes control the distribution of silver-zinc-lead mineralization near the contact between marble and mica schist of the Florence Range suite. Mineralization of this type may also occur near the Nelson Lake occurrence (104M019) west of southern Nelson Lake, where calcsilicate float derived from the Florence Range suite contains up to 5 per cent sphalerite and galena.

(8) Volcanogenic massive sulphide within the Boundary Ranges metamorphic suite. For example, the Big Thing occurrence near the southeast end of Tagish Lake (104M071) may be an isolated lens of Kuroko-type

volcanogenic massive sulphide mineralization. Boundary Ranges suite rocks are correlated with the Stikine Assemblage which hosts massive sulphide deposits 60km southeast of the Tagish area (Tulsequah Chief and Big Bull).

(9) Copper gold porphyry mineralization in alkalic phases of the Stikine plutonic suite. Mapping at the margins of these bodies reveals striking textural and structural similarities to border phases of the Hogem and Copper Mountain bodies, both of which host copper porphyry deposits. However, no obvious correlation exists between elevated regional geochemical copper values and these plutons.

(10) Shallow submarine hot spring Au-Ag deposits. A prime example is the Eskay Creek mine which is hosted within strata that have age equivalents in the Whitehorse Trough. Volcanic units within the trough that are coeval (or possibly coeval) with Eskay volcanism include the well dated 185 Ma Nordenskiöld dacite, and the Lower to Middle Jurassic volcanic package. Unfortunately, magmatic centres and prospective hydrothermal alteration systems have yet to be identified within the Whitehorse Trough.

Coal Potential

Carbonized plant fragments are common at some horizons within the Laberge Group, rare at the bottoms of flows within the Table Mountain volcanic suite, and occur locally within epiclastic strata of the Sloko Group. Appreciable layers of carbonized plant material were only observed at two localities; both within the Tutshi Lake map area. They are within sedimentary interbeds in sections dominated by Lower to Middle Jurassic volcanic ash and lapilli tuff on either side of Moon Creek. In neither case do the coal layers exceed 15 centimetres in thickness and ash content was estimated at 30 to 50 percent. Neither appear suitable for exploitation due to their poor quality, and limited thickness and strike length. Both occurrences are on rugged ridges and their host rocks are of limited aerial extent.

Hydrocarbon Potential

Requirements for a productive hydrocarbon play are: suitable source rock, adequate reservoir porosity, migration and collection beneath an impervious trap rock or structure, and an appropriate level of organic metamorphism (kerogen to hydrocarbon transformation). Hydrocarbon potential in deformed basins in the Cordillera is limited primarily by two factors: pervasive fabrics are developed which limit the efficacy of traps, and heat generated by structural thickening and magmatism increase the level of organic metamorphism beyond the limits of hydrocarbon generation. Organic metamorphism is a function of both temperature and exposure time. However, the effect of temperature is dominant to the extent that it is the exponential of time (Gretener and Curtis, 1982). At temperatures less than 50°C the reaction proceeds so slowly that even time spans of 500 m.y. have little effect. At temperatures greater than 130°C the reaction rate is so fast that conversion is completed and hydrocarbon degradation commences in an "instant" of geological time (Figure 14-3). In the Whitehorse Trough, both heat and fabric development have acted with deleterious effect on hydrocarbon preservation.

Estimations of oil and gas resource potential of the Whitehorse Trough are reported in Hannigan *et al.* (1995) who identified the Jurassic "Whitehorse Takwahoni Structural Gas Play", "Whitehorse Inklin Structural Gas Play" and the Triassic "Whitehorse Lewes River Structural Gas Play". They also identified the "Whitehorse-Taku fractured carbonate play" hosted in Horsefeed Formation carbonate of the Cache Creek terrane. Estimates of potential in these "plays" are based primarily on reservoir modeling that employed multi-parameter probability distributions. The modeling is flawed because it made no realistic estimates of "Reservoir Temperature". However, as pointed out in Chapter 9, thermal maturation data from which estimates of the level of organic metamorphism can be made, are numerous. Sources of such information include: fission track studies, descriptions of thermal metamorphic aureoles around plutons, investigations of authigenic mineralogy, discordant emplacement and cooling ages from K-Ar and 40Ar-39Ar isotopic studies, demagnetization affecting paleomagnetic studies, estimates of crustal thickening, and contemporary heat flow measurements. Unfortunately, most of these paleo-temperature estimates point to levels of organic metamorphism within the Whitehorse Trough that exceed the window for hydrocarbon generation (Figure 14-3). However, as pointed out in Chapter 9, parts of the

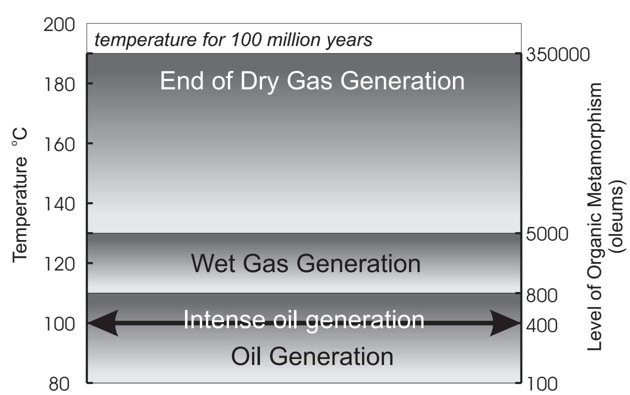


Figure 14-3. Temperature-time plot showing the level of organic maturation and limits for dry gas generation (after Gretener, 1981).

Whitehorse trough between Atlin Lake and Dease Lake may have escaped these temperatures.

Rocks included in the “Whitehorse-Taku Fractured Carbonate Gas Play” form a belt that extends from the BC-YT border near Atlin Lake to the French Range west of Dease Lake. In northern half of this belt, in the Tagish area, the belt contains large intrusions like the Fourth of July batholith, which cut potential source and reservoir rocks. All conodonts collected from this part of the belt have CAIs of 4.5 to 7 (normally 5-6), corresponding to chlorite and garnet zone metamorphism. Authigenic metamorphic mineral distribution in the Tagish area is shown in Figure 3-5. Thermal conditions exceed dry gas generation (Figure 14-3).Portions of the central “Whitehorse-Taku Fractured Carbonate Gas Play” between Dease and Atlin Lakes may be less deformed and or thermally metamorphosed, like the Jurassic Whitehorse Trough. However, thermal data from these areas is generally lacking.

Chapter 15 Geologic History

Rocks of the Tagish Lake area record a long and complex geologic history. Sedimentation, volcanism, intrusion, deformation, metamorphism, mineralization, uplift and erosional events of various ages and extents were interwoven to produce the landscape seen today. Not all rocks of the same age are affected equally, and in a reaffirmation of the Terrane concept, Paleozoic rocks of the Yukon-Tanana and Cache Creek Terranes display disparate histories. On the other hand, Mesozoic strata conventionally thought to define the Stikine Terrane (ST; Stuhini and Laberge Groups) record a younger deformational history that shares some deformational events with the older terranes. Perhaps these Mesozoic strata should not be considered the Stikine Terrane fingerprint (see Chapter 8). To complicate matters further, the geologic histories recorded in the area vary not only *between* Terranes, but also according to structural level *within* Terranes. For example, brittle to ductile fabrics recorded within the Llewellyn-Tally-Ho fault system display this structural dichotomy well (see Chapter 13 and below). A synopsis of this geologic tapestry is shown schematically in the time-space-event chart of Figure TC-1 (in pocket).

Little data within the map area constrains the pre-Mesozoic history. Lisel Currie at Carleton University initiated a doctoral study under the auspices of this project with the goal of unraveling this early history. The Tagish area study focused on the Mesozoic and younger events which can be resolved by contemporary field mapping techniques.

The discussion that follows presents a west to east time-slice approach in describing the geologic history and explains footnote references on Figure TC-1. In order to limit discussion of Cordilleran-wide implications of the local geologic history presented here, a model-dependent approach is taken. The evolutionary model for the architecture of the northern Canadian Cordillera largely follows that detailed in Mihalynuk *et al.* (1994c). According to this model, oroclinal processes dominated the Mesozoic evolution of the Tagish area. A synopsis of this model is presented in Figure 15-1e to f. An extension of the model to incorporate the possible pre-Devonian origins of the Nisling assemblage is presented in Figure 15-1a. Stage names and absolute time scale references, adapted from Harland *et al.* (1990), are shown on Figure TC-1.

Pre-Devonian

The oldest strata in the map area are protoliths of the Florence Range metamorphic suite (Currie, 1990; part of the Nisling assemblage, Mortensen, 1992). These were probably deposited in a passive continental margin setting (Wheeler and McFeely, 1991) during Upper Proterozoic to Cambrian time. A predominance of quartz-rich clastic rocks suggests derivation from cratonic sources to the east, a contention supported (but not proven) by detrital zircon studies (Gehrels *et al.*, 1991a, b; Mortensen, 1992). Detrital zircon U-Pb upper intercept ages are 2.17 to 2.2 Ga (Gehrels *et al.*, 1989; Aleinikoff *et al.*, 1981), and Nd and Sm-Nd model ages are between 2.09 and 2.4 Ga (Aleinikoff *et al.*, 1990; McCulloch and Wasserburg, 1978; Samson *et al.*, 1989). Thick carbonate layers are extensive, but there are no coexisting evaporites; this suggests deposition in a relatively shallow, open sea, but probably not in a sabkah-type environment such as is generally associated with intracontinental rift settings. Metamorphism destroyed any stromatolitic or delicate clastic structures that may once have been present. Hornblende-rich gneisses probably represent mafic dikes, sills and/or flows related to rifting or later magmatic events, however, geochemical data needed to test this suggestion are lacking.

Regional Relations and Problems

A lack of confirmed pre-Devonian oceanic crustal rocks supports the interpretaion that deposition was on attenuated, but not isolated fragments of ensimatic crust (Figure 15-1a), analogous to the model proposed by Struik (1987). Pre-Devonian strata probably have miogeoclinal correlatives on cratonic North America: Upper Proterozoic quartz-rich clastic sediments, limestone, mafic flows and tuffs of the Windermere supergroup (Tempelman-Kluit, 1976); Eocambrian quarto-feldspathic grits and upper limestone of the Gog Group; and Cambrian to Devonian passive continental margin strata exposed in the Rocky Mountains. There are, to date, no direct indications of rocks as old as the middle Proterozoic Purcell Supergroup in the Tagish area. An indirect indication of protolith ages near the youngest limit of known Purcell strata is an 1150 Ma Rb-Sr model age (Werner, 1977), but lithologies of the samples analyzed are unlike those of the Purcell. This problem is not resolved; both oceanic crust and Purcell protoliths are notoriously difficult to date and, as a result,

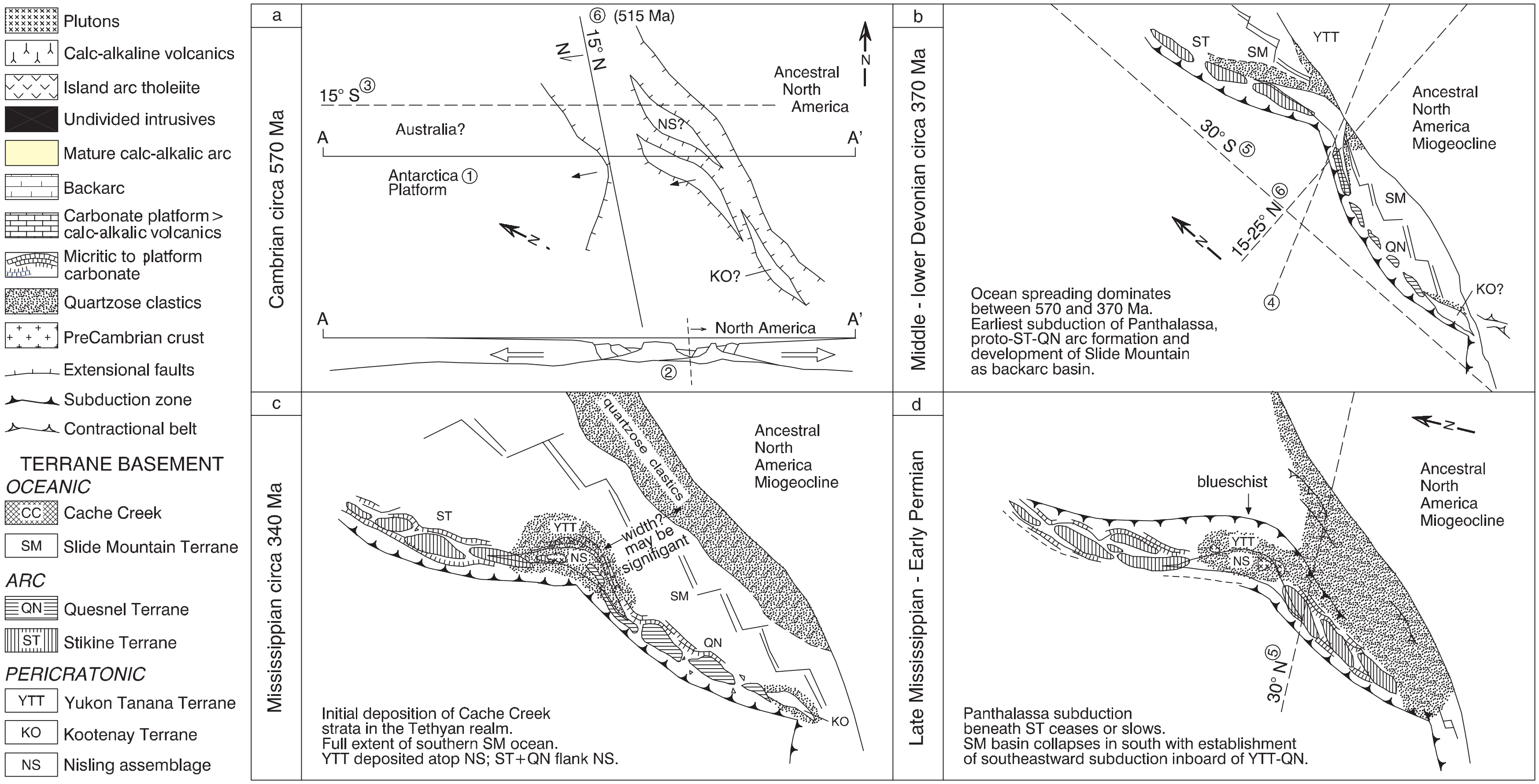
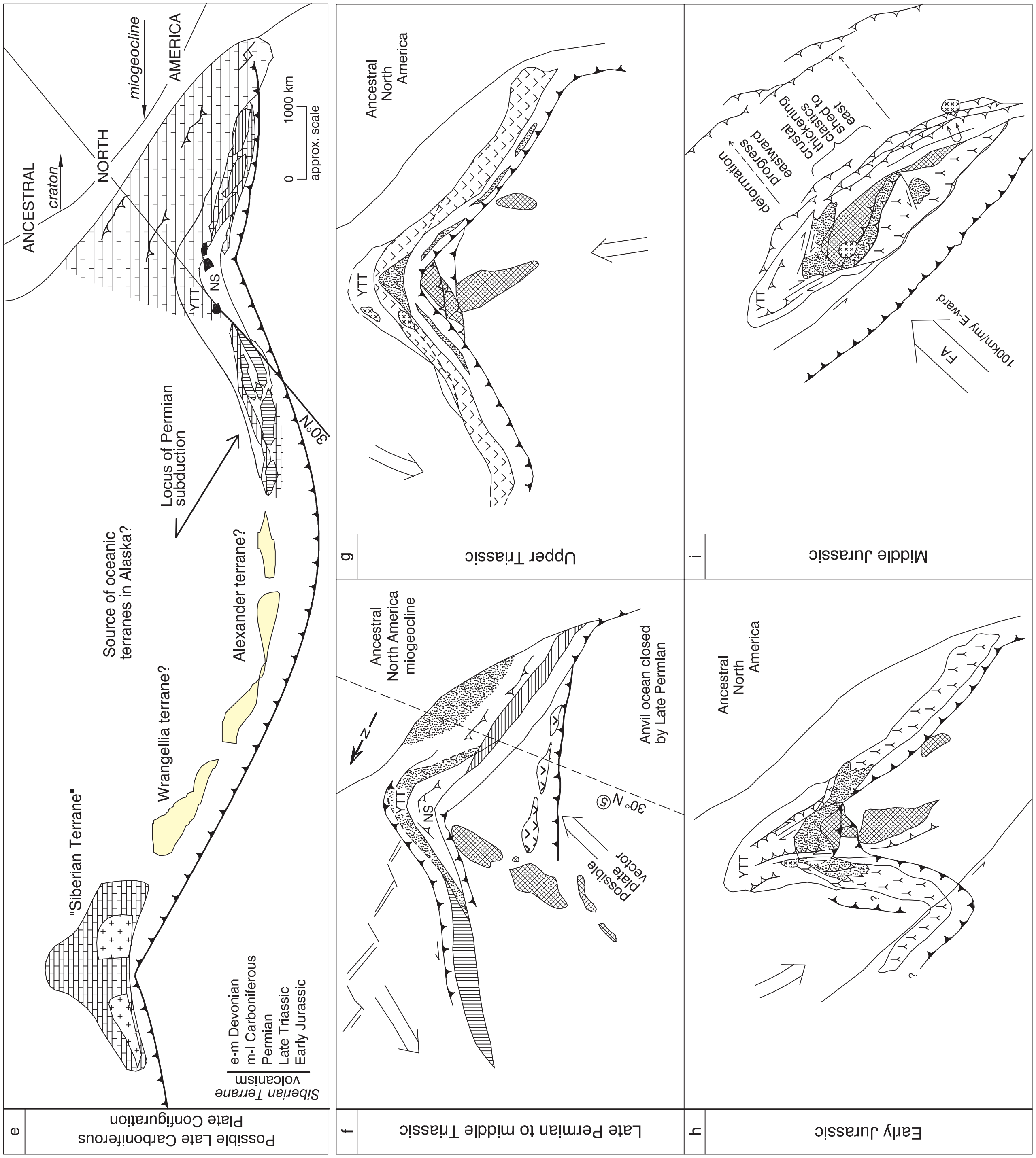


Figure 15-1. Tectonic model time slices depicting the evolution of the Intermontane arc complex. See text for details.



SOURCES OF DATA

① Moores (1991)

② Struik (1987)

③ Dalziel (1991)

④ Van der Voo (1988)

⑤ Scotese et al (1979)

⑥ Scotese (1987)

may not yet have been recognized. Isotopic dating of detrital zircons is another approach to the protolith age problem. So far, however, none of the detrital zircon studies have isolated rocks that consistently yield zircons exclusively older than 1 Ga, the young limit of Purcell strata deposition.

Details of the pre-Devonian period are obscured by later deformation, metamorphism and intrusion. Only vestiges of this potentially long history have been recognized in the Tagish area, and those mainly through indirect isotopic dating techniques. Mortensen (1992) and Currie (1992) dated orthogneiss bodies within these old strata that are of Late Devonian and Early Mississippian age and establish a minimum age for deposition of the host rock protoliths. Further isotopic and perhaps geochemical characterization and careful search and study of relict protolith textures are required in order to distinguish component parts of Nisling assemblage rocks and enable correlation with strata deposited on the craton.

Mineral potential considerations

Correlative para-autochthonous strata of the North American miogeocline host economically important, and in some instances huge, sedimentary exhalative lead, zinc, silver deposits. Examples of these include the world class Sullivan (middle Proterozoic), Faro (Cambro - Ordovician) and Howard's Pass (Early Silurian) deposits. To date only minor indications of lead-zinc-silver mineralization have been found within the Nisling assemblage (near the Nelson Lake occurrence 104M019) and Boundary Ranges suite rocks of the Tagish area (*e.g.* Big Thing, 104M071), and neither of these are classified as sedimentary exhalative. The Tagish area has not been seriously prospected for this type of deposit but comprehensive regional geochemical data to help delineate prospective regions have recently become available (Jackaman and Matysek, 1993) and this offers an exploration opportunity.

Devono-Mississippian

Strata of this age are represented by the Boundary Ranges metamorphic suite, orthogneiss bodies within the older Nisling assemblage, and Early Mississippian oceanic crustal rocks within the Cache Creek Terrane.

Hallmarks of the Stikine Terrane in this time interval are Middle to Late Devonian carbonates and compositionally variable volcanic rocks (Anderson, 1989; Figure 15-1b), and widespread, Late? Mississippian micritic to platformal carbonates (Monger, 1977a; Figure 15-1c). These rocks were in part deposited flanking a fragment of old miogeocline, the Nisling assemblage, and may be partly incorporated in the Yukon-Tanana Terrane as the Boundary Ranges suite (Figure 15-1b, and following).

The oldest dated elements of the Cache Creek Terrane are Lower Mississippian carbonates of the "western facies belt" of the Atlin Terrane (Monger, 1975). These rocks were presumably deposited on an igneous oceanic crustal package now represented in part by basalts of the Nakina Formation and tectonized ultramafites (Monger, 1975). Not all parts of Nakina Formation shown on Figure GM97-1 are demonstrably correlative. Age data are almost completely lacking and some of the mafic and ultramafic units could be fragments of younger oceanic crustal material.

Regional relations and problems

Much of the margin of ancestral North America seems to have been affected by Devonian extension. During this event a continental sliver that appears to have been separated from ancestral North America formed in part the nucleus upon which an extraordinarily long-lived arc system developed. This feature is here termed the Intermontane arc complex (IAC).

Although the period is apparently dominated by extension, local compressional events are documented (*e.g.* Smith *et al.*, 1993). Devono-Mississippian metaplutonic, metavolcanic and intercalated basinal strata form a 340 to 370 million year old, continuous belt that extends 5000 km along the length of the Cordillera (Rubin *et al.*, 1990). Currie (1994) reports that a granitic dike of Early Mississippian age cuts the Boundary Ranges suite in the Hoboe Creek valley just outside of the map area (104M/1). Coeval felsic volcanic strata of apparent arc origin are reported in southern YTT (Mortensen, 1992). During this time, many granitoids were emplaced within the pericratonic strata (Mortenson, 1992) of the Kootenay and Yukon-Tanana Terranes.

Slide Mountain Terrane strata throughout central British Columbia and northwards to the Yukon probably developed in an extensional, back arc setting (Figure 15-1b, c; *cf.* Ferri, 1997). Syndepositional extension is recorded: grabens with clastic infillings, growth faults, exhalative deposits, rift-type alkalic volcanics (Nelson and Bradford, 1989) and intercalated felsic tuffs (Ferri and Melville, 1994) are examples. Miogeoclinal rocks are apparently affected by this same extensional event (Mortensen, 1982; Gordey *et al.,* 1991) but lack a tuffaceous component. Several authors suggest that this lithologic arrangement indicates back-arc spreading (Ferri, 1997, and references therein). Local impingement of the arc on the North American miogeocline may explain predominantly compressional structures in areas such as the Kootenay arc of southeast British Columbia.

Boundary Ranges metamorphic suite rocks apparently correlate with parts of the Stikine Terrane. This is an extension of earlier ideas presented by Tempelman-Kluit (1976, 1979). Mortensen (1992) explicitly suggested such a correlation, and Currie (1992) presented isotopic age data that strengthened this correlation in the Tagish area.

A problem with the proposed correlation is that carbonates, which are a conspicuous and commonly dominant constituent of the Stikine Terrane stratigraphy, are not as abundant within the Boundary Ranges suite. Difficulties also arise in distinguishing Stikine assemblage from non-Stikine parts of the Yukon-Tanana Terrane where the two have been juxtaposed then deformed and metamorphosed. In the Iskut area, McClelland (1992) reports Paleozoic Stikine strata resting unconformably on quartz-rich strata that probably correlate with older parts of the Yukon-Tanana Terrane. A similar relationship is reported in the Tulsequah area (Mihalynuk *et al.*, 1994a). If this apparent relationship is correct then this is probably the oldest observed stratigraphic tie between the two terranes. It also supports isotopic data such as evolved Nd values (Jackson *et al.,* 1991b) and old, inherited zircons (*e.g.* Sherlock *et al.*, 1994) that indicate a spatially restricted older crustal component deep within the basement of northern Stikinia. Later, pre-Triassic deformation and metamorphism may have interleaved these strata to produce a composite terrane, the Yukon-Tanana Terrane. In light of this possibility, a more complete understanding of the evolution and composition of the Yukon-Tanana Terrane will require much more detailed geochronometric and isotopic characterization. Currently, one of the most productive avenues of inquiry is comparison of units that are less complexly metamorphosed, have relatively clear contact relations, and have been more fully characterized from an isotopic and geochemical standpoint, as for example, the work of J. Mortensen and others in the Yukon. Some sections of potentially correlative Yukon strata contain Paleozoic fossils (*cf.* Mortensen, 1992; Hart and Radloff, 1990) whereas most other sections are unfossiliferous.

Mineral potential considerations

As for pre-Devonian strata, Devono-Mississippian strata correlative with those of the North American miogeocline host a spectrum of sedimentary-exhalative deposits. Cordilleran examples of these include the Stronsay, Jason and Tom deposits of the Earn Formation. Apparent restriction of this type of deposit to extensional environments in miogeoclinal and intracratonic basin settings (MacIntyre, 1992) may limit the possibility of finding deposits within accreted terranes west of the Cassiar platform. Instead, volcanogenic massive sulphide deposits of Kuroko, Cypress and Besshi type are most important. For example, within Early Mississippian rocks of Stikinia, a variety of Kuroko-style deposits in the Tulsequah camp are now clearly established as syngenetic (Sherlock *et al.*, 1994). In the Yukon, recently discovered volcanogenic deposits that are of this age include the Kudz Ze Kayah, Wolverine and Fyre Lake deposits, all within the Yukon-Tanana Terrane

Numerous small podiform chromitite±nickel occurrences occur in ultramafic ophiolitic rocks of the Cache Creek Terrane, however, none discovered to date have been large enough to be of economic interest.

Pennsylvanian to Permian

Rocks of Pennsylvanian to Permian age are present in the map area, but their distribution is generally poorly constrained, except in the Cache Creek Terrane, where carbonate and pelagic sediments have yielded fossils representing most of the stages of these periods (Monger, 1975). The Early Permian is represented by the Wann River gneiss, which is believed to be metamorphosed mafic volcanic tuffs (Currie, 1994). However, the Mid-Permian volcanic and intrusive rocks which are part of an important magmatic pulse in the Yukon-Tanana Terrane of the Yukon, have yet to be recognized with certainty in the map area.

During the Pennsylvanian to Permian time interval the North American margin was probably oriented northeast-southwest with geologic elements in the Tagish area at about 30°N based on constraints provided by the paleotectonic reconstructions of Scotese *et al.* (1979).

Cache Creek sedimentation of this age is thought to have occurred mainly on well-oxygenated carbonate banks and shoals and locally restricted lagoons atop seamounts or oceanic plateaux (Monger *et al.*, 1991). Chert and argillite were deposited on the flanks of the plateaux or on the adjacent abyssal plain. Yabeina fusilinids of Permian age indicate that carbonate deposition occurred within the Tethyan realm (Monger *et al.*, 1972). Potentially uninterrupted fossiliferous carbonate and chert deposition occurred in a tectonically quiescent paleogeographic setting. Stratigraphic and fossil data indicate carbonate accumulation kept pace with slowly subsiding seamounts or plateaux (Monger, 1975). Consistent with this paleogeographic interpretation are rare earth element (REE) data from Cache Creek Terrane basalts that are either of MORB or ocean island character (C.H. Ash, personal communication, 1996). Near Graham Creek, the most westerly, and possibly the youngest oceanic crustal slivers include gabbro, disrupted basalt and serpentinized harzburgite tectonite. REE analyses of the Graham Creek basalts yield typical MORB patterns (Mihalynuk, *et al.*, 1991; see Chapter 6). Typical ophiolitic basalts do not have MORB REE signatures; they commonly display a supra-subduction zone signature. Thus, a geochemically isolated mid-oceanic ridge not coupled to a destructive plate margin is implied.

Tectonic settings are highly variable during this time interval. A period of magmatic quiescence spanned the Middle to Late Pennsylvanian. Limited Pennsylvanian and extensive Permian carbonate and quartz-rich or graphitic clastic sediments are depositionally interlayered with well-dated volcanic rocks in the Yukon-Tanana Terrane (Mortensen, 1992). Pelagic sedimentation dominated the Pennsylvanian to Permian deposition in the Slide Mountain basin and Quesnellia, although, in Quesnellia, small volumes of arc volcanics were deposited locally.

Early in this time interval, the Slide Mountain back arc basin continued to form behind an east-directed Quesnellian subduction zone. However, during earliest Permian time the subduction zone jumped to the foreland side of the Intermontane Arc Complex initiating consumption of the Slide Mountain basin (deformation within the Slide Mountain Terrane must have occurred by Early Permian because Harms (1986) describes a thrust plane that is cut by a 276 ± 16 Ma tonalite). Near the cusp of the arc complex, Permian subduction-related rocks with blueschist facies assemblages where emplaced along the inboard edge (Erdmer and Armstrong, 1988). Magmatism above a south-dipping Permian subduction zone was widespread in the Yukon-Tanana Terrane (Mortensen, 1992). Interpreted subduction polarity is based upon the position of the Permian magmatic front relative to the position of the high pressure rocks in the Yukon-Tanana Terrane that are dated at between 267 and 243 Ma (Erdmer and Armstrong, 1988).

A short, intraoceanic arc segment that may have been established on the Cache Creek oceanic crust in mid-Permian time is recorded by bimodal volcanism in both the French Range and Kutcho Formations, and in the Peninsula Mountain volcanic strata. In composition and setting these have analogues in the modern Izu-Bonin-Marianas forearc (*e.g.* Bloomer *et al.*, 1995).

Mineral potential considerations

The only significant mineralizing event of this age in the Intermontane Arc Complex is the kuroko-style Kutcho Creek volcanogenic massive sulphide deposit. Zinc-lead-copper deposits in the Baldy and Bronson areas within metamorphic strata of the Yukon-Tanana Terrane in the Yukon may also be of this age.

Lower to Middle Triassic

Like the Pennsylvanian, few Lower to Middle Triassic rocks occur in the map area except within the Cache Creek Terrane. It also appears to be a time of subduction zone reconfiguration around the Intermontane Arc Complex (Figure 15-1f). Following the initial stage of collapse of the Slide Mountain basin due to east-verging contraction (Nelson, 1993) the subduction zone was reestablished outboard of the Intermontane Arc Complex by Upper Triassic time (Figure 15-1e).

Middle Triassic (Ladinian) strata are common in the eastern Cache Creek Terrane (Jackson, 1992) and Mihalynuk and Mountjoy (1990) mapped deformed Middle to Upper Triassic chert interbedded with quartz-rich wackeof the Peninsula Mountain suite. Chert and argillite of Lower to Middle Triassic age are regionally exposed in northern Stikinia in the Iskut area (Logan and Drobe, 1993; Logan *et al*., 1994), and Middle Triassic pelagic sediments are reported in the Quesnel Terrane in central and northern British Columbia (*see* Ferri, 1997). In the Yukon-Tanana Terrane, this time probably marks the end of a stage of ductile deformation that accompanied collision of the Cache Creek plateau with the Intermontane Arc Complex which caused initiation of rotation of Stikine Terrane and formation of the Intermontane Arc Complex orocline.

Mineral potential considerations

There is a little evidence for significant mineralization of this age.

Upper Triassic

Rocks in the Tagish area preserve a Late Triassic record that crosses terranes. This time slice is critical to our understanding of the Intermontane Arc Complex evolution. This time saw vigorous arc volcanism and plutonism in Stikinia that began in the Carnian and continued into the Late Norian. It is a time of loose terrane linkages: Nisling Assemblage with Stikine Terrane (Tempelman-Kluit, 1976; Bultman, 1979; Jackson *et al.*, 1991b); Stikine Terrane with Cache Creek Terrane (Monger *et al.*, 1992; Jackson, 1992); Cache Creek terrane with Quesnellia in southern British Columbia (Monger, 1984) and data in central and northern British Columbia that suggest probable Quesnellia - Slide Mountain ties (*e.g.* Ferri, 1997). Late Triassic magmatic rocks within the Intermontane Arc Complex host a variety of mineral deposits.

Arc strata of the Stuhini Group began to accumulate as early as the Carnian. These were deposited in a mainly submarine environment and were dominated by bladed plagioclase and pyroxene-phyric pillow basalts and breccias and intercalated volcaniclastics, fetid carbonate and silty turbidites. The comagmatic, granitic to granodioritic Willison Bay pluton intruded to shallow levels and was chilled against these early Stuhini strata and a slightly older, comagmatic, foliated hornblende-pyroxene-rich gabbro. Both the gabbro and Willison Bay granite probably intruded along an old strand of the present Llewellyn fault. A moderate to locally strong synkinematic fabric in the gabbro may provide the oldest preserved evidence for movement along the Llewellyn fault. Although, emplacement of the intrusions may have been facilitated by the fault, the shape of the Willison Bay body does not show elongation parallel with the fault and it may have been dissected by post-emplacement motion on the fault.

Dissection and exhumation of the Willison plutonic assemblage, and development of an extensive granite boulder conglomerate, which in part non-conformably overlies the pluton, demonstrates rapid uplift of the volcanic-plutonic arc complex. A return to fine clastic deposition and extrusion of pillow basalts records submergence of this part of the arc once again. Over 2000 metres of such submarine deposits accumulated. They consist of silty turbidites containing Carnian *Halobia* and pillow basalts with interpillow micrite from which Carnian conodonts have been recovered (Table AB2). A distinctive phreatomagmatic unit, which is overlain by quartz-rich epiclastic strata, hematitic tuff and intercalated carbonate marks a return to shallow water deposition. Capping the section are fossil poor, black to white, well to poorly-bedded carbonates of the Upper Norian Sinwa Formation.

Similar arc construction occurred in other parts of Stikinia and Quesnellia during this interval. In the Tulsequah area, Stuhini Group strata are particularly well exposed and are overlain by the type section of the Sinwa Formation. Details of arc architecture vary from place to place, since facies changes are common and rapid. In general, however, there is little difference between Upper Triassic sequences in the Quesnel and Stikine terrane segments of the Intermontane arc complex. Indeed, depositional character changes more along the strike of each of these arc segments than between the two. For example, both segments display a south to north transition from dominantly subalkaline volcanics to dominantly arc-derived clastics. This is illustrated in Stikinia by the transition from Stuhini Group volcanics in British Columbia to Lewes River Group clastics in the Yukon, and in Quesnellia by the transition from Nicola-Takla Group volcanics in southern and central British Columbia to Shonektaw Formation volcanics and finally Nazcha Formation arc apron clastics near the Yukon border (Gabrielse, 1969).

Within the Cache Creek Terrane Upper Triassic strata mark a change from dominantly pelagic to dominantly hemipelagic sedimentation. Abundant coarse clastics interbedded with chert provide clear evidence of the influence of extrabasinal sedimentary provenance. Granules to cobbles include quartz grains and plutonic clasts that are derived from Stuhini Group volcanics and comagmatic plutons of Stikinia (Jackson, 1992) and Shonektaw volcanic rocks of Quesnellia (Monger *et al.*, 1991).

Evolution of the Intermontane Arc Complex at this time is interpreted to be dominated by continued closure of the Cache Creek ocean through oroclinal bending of the Quesnell-Stikine arc complex (Figure 15-1g). Structural and stratigraphic relations of rocks in the eastern and western parts of the Cache Creek Terrane suggest that they formed parts of a south-facing accretionary prism. Sediments ponded between the leading edges of thrust slices that constitute the accretionary prism may have been caught up in late movement that resulted in closely-spaced domains with contrasting structural styles, like those seen in the Graham Creek area. Deposition behind the forearc ridge probably occurred as a series of high-gradient submarine fans in an environment that persisted into the Jurassic and resulted in the reflection of east-flowing Laberge Group turbidites.

Mineral potential considerations

Upper Triassic rocks within the Stikine and Quesnell terranes host a variety of important deposit types. In the Late Triassic the most important of these are alkaline copper-gold porphyry deposits such as those at Copper Mountain, Afton and Mount Milligan and Cu-Mo±Au porphyry deposits like Brenda, Highland Valley and Stikine Copper. Volcanogenic massive sulphide deposits of this age include the Beshi-type Granduc deposit in Stikinia. No Upper Triassic deposits are known in the northern Cache Creek Terrane, and the restricted distribution of Upper Triassic Stuhini strata in the map area limit the potential for deposits of this age.

Lower Jurassic

Laberge Group clastic sedimentation spans most of the Lower Jurassic and is widespread in both the Cache Creek and Stikine Terranes in the Tagish area. These sediments mark a period of Stuhini arc dissection that occurs south of an interpreted oroclinal hinge zone within the Intermontane Arc Complex. Away from the hinge zone, in the Stikine and Quesnel segments, continued subduction of the Cache Creek Terrane (Figure 15-1g) resulted in a very voluminous pulse of calcalkaline magmatism: the Hazelton Group. Near the end of the Lower Jurassic, Quesnellia was emplaced against the margin of North America. Incipient emplacement of Quesnellia is well dated as 186 Ma (Early Jurassic) and rocks along the contact were metamorphosed and cooled by 181 Ma (Nixon *et al.*, 1993).

Laberge Group strata presumably were deposited upon the Stuhini Group, yet no unequivocal contact with good age control has been found. North of Tutshi Lake, an apparently conformable contact exists between Sinwa Formation carbonates, that generally cap the Stuhini Group, and overlying argillite. This argillite is thought to be part of the lower Laberge Group, but no fossils have been recovered from it. Unfortunately, road construction obliterated the exposures reported by Mihalynuk and Rouse (1988a) in which the Sinwa-argillite contact was exposed. At most other localities a limestone cobble to boulder conglomerate occurs at the contact and oldest fossils above the contact are Sinemurian. This suggests that the contact is generally an erosional unconformity.

Laberge Group strata were deposited as a series of high-gradient submarine fans (Dickie, 1989), probably in a forearc environment. In general, the strata coarsen upwards from dominantly argillite and siltstone of Sinemurian age at the base to wacke of Toarcian age at the top. Conglomerate sheets and lenses that occur at all stratigraphic positions contain Norian limestone cobbles as well as boulders of probable Upper Triassic granodiorite that resemble the Willison body. Local hornblende-rich sedimentary horizons may record unroofing of hornblende quartz diorite and granodiorite intrusions of the nearly coeval Aishihik plutonic suite and coeval volcanic rocks.

On the east side of the Whitehorse Trough, Laberge strata appear to grade imperceptibly downwards into wacke of Middle to Upper Triassic age. They probably onlapped a forearc ridge, and in places extended onto the fragmented oceanic plateau of the Cache Creek Terrane. Abundant slumps and intraformational conglomerate, as well as development of angular unconformities point to synsedimentary deformation at least as old as Sinemurian.

Intermediate to felsic volcanic flows and tuffs are believed to sit with stratigraphic continuity atop the Laberge strata, (Mihalynuk and Rouse, 1988a). Several hundred metres above the base of this unit is a thick conglomeratic horizon comprised of cobbles that are most likely derived from the Laberge Group. Considering that the youngest fossils obtained from the Laberge Group of the Tagish area are Toarcian, and that the volcanic strata appear to have been deposited rapidly, the volcanics are interpreted to be of Toarcian age. If this is true, then part of the Laberge basin was uplifted during the Toarcian to supply detritus for a conglomerate deposited atop it. Basin cannibalization may mark initiation of Whitehorse Trough collapse, interpreted as recording impingement of the inner and outer limbs of the Intermontane Arc Complex orocline. Interestingly, this timing corresponds to a sinistral, top-down-to-the-southwest fabric (Mihalynuk and Mountjoy, 1990) that was pervasively developed in the 185 ± 1 Ma (Currie, 1991) Hale Mountain granodiorite prior to the onset of brittle, dextral deformation at around 179 Ma (Table AA1) and peak metamorphism in the Florence Range metamorphic suite at around 177 Ma (Currie, 1994). Broadly synchronous ductile sinistral fabrics occur in the Tally-Ho shear zone in the Yukon (Hart and Radloff, 1990). Southwest-vergent motion of on the King Salmon thrust (*e.g.* Thorstad and Gabrielse, 1986) facilitated emplacement of the Cache Creek Terrane and formation of the clastic foredeep of the proto-Bowser Basin beginning in latest Toarcian to Aalenian time (Ricketts *et al.*, 1992).

Southwest-verging thrusts in front of the Cache Creek allochthon carried the western margin of the Laberge basin (and possibly parts of the basin floor and margin that consist of Peninsula Mountain volcanics and Graham Creek rocks) up and over Stuhini Group rocks and previously deformed Boundary Ranges and possibly Florence Ranges metamorphic strata (see Figure 13-8). Most of this overthrusting must have been restricted to the area south of Fantail Lake. Neither the 187 Ma hornblendite at Teepee Peak nor the Boundary Ranges rocks in its thermal metamorphic halo appear to have been significantly involved in this event, in contrast to the strongly deformed 185 Ma Hale Mountain body a few tens of kilometres to the south. It appears that the Lower Jurassic overthrust may have been restricted to shallow crustal levels, mainly within the Laberge Group near the British Columbia - Yukon border. Thicker stacking, or stacking that involved deeper stratigraphic levels, might correspond to the limits of high pressure kyanite-bearing amphibolite-grade schists and gneisses of the Florence Range metamorphic suite, and may be genetically related. One possibility is that an accommodation zone between the King Salmon thrust and the Llewellyn fault may represent exposure of deep level rocks in the zone of transfer from overthrust to tear fault. Assuming that the King Salmon thrust follows the Sinwa Formation as it does in the Tulsequah area, it would merge with the Llewellyn Fault near the Engineer Mine. High pressure rocks of the Florence Range suite are limited to positions south of this juncture (see Structure for a complete discussion).

Mineral potential considerations

Assemblages of Early Jurassic age within the Intermontane Arc Complex are generally endowed with a broad range of arc-related mineral occurrences. Rocks of this age within the map area are, however, dominated by coarse, marine clastics of the Laberge Group. Since no syngenetic mineral occurrences are known within these rocks, they are not favourable exploration targets. Minor indications of synsedimentary volcanism do, however, point to potential for shallow hydrothermal deposits of Eskay type. There may be fault-related veins of this age, but none have been dated.

Middle to Upper Jurassic

Quesnel, Stikine and Cache Creek terranes were distinct tectonic elements separated by subduction or collision zones until Middle Jurassic time. The Middle Jurassic was a time of contractional deformation when Cordilleran terranes were assembled into their present relative longitudinal positions due to oroclinal collapse (Figure 15-1i). Quesnellia was thrust over the North American continental margin and the Cache Creek Terrane was emplaced over eastern Stikine Terrane. Sedimentation in the Cache Creek complex ceased prior to

Toarcian time at this latitude, but in the southern Cordillera it continued into the Bajocian (Cordey *et al.*, 1987). Plutons like the *circa* 177 Ma Bennett batholith (Mortensen and Hart, unpublished *in* Hart, 1995) and satellite bodies of the same age in the northern map area (Paddy Pass pluton, 176 Ma, Tables AA1, AA2) are only weakly foliated. Ductile deformation had all but ceased prior to emplacement of the 172 Ma, post-tectonic Fourth of July batholith, which pins the Cache Creek Terrane (Mihalynuk *et al.*, 1992a). A metamorphic muscovite cooling age from the Boundary Ranges metamorphic suite also reveals a strong $^{40}Ar/^{39}Ar$ plateau at about 172 Ma (Smith and Mihalynuk, 1992).

Dextral motion dominates the major, long-lived structures, such as the Llewellyn and Teslin faults. In the Yukon-Tanana Terrane ductile deformation ceased at about this time, giving way to west-vergent brittle thrusting. A long period of cooling followed.

Within the map area, the Middle Jurassic also marks the termination of Laberge Group sedimentation. Both the Laberge Group and overlying Lower to Middle Jurassic volcanic strata were folded during the final stages of oroclinal collapse. Structural vergence in the deformed Laberge basin is mainly toward the west, but on its east margin vergence is locally eastward. Shortening in excess of 50 percent caused major synclines to be forced up and out of the Graham Inlet section (Figure GM97-1; see also Chapter 13).

In contrast, the Upper Jurassic was a period of relative tectonic quiescence - the beginning of a magmatic lull that persisted about 50 million years, through the Early Cretaceous. Perhaps this lull is equivalent to the time span required to rupture a new subduction zone outboard of the collapsed Intermontane Arc Complex, subduct the slab to a zone of melting below the new continental margin and deliver magma to the upper crust. In the case of the juvenile Izu-Bonin-Mariana arc, it appears that only 15 Ma elapsed between initiation of subduction and construction volcanic edifices that outline the arc (Bloomer *et al.*, 1995), but only thin oceanic crust is involved. Plate velocity vectors for the time interval between 175 and 125 Ma display a strong convergence between North America and the Farallon oceanic plate (Engebretson *et al.*, 1985). If this convergence is correct, a new subduction zone should have been rapidly established. The magmatic lull continues to be an enigma.

Mineral potential considerations

Late to post-orogenic mineralizing fluids related to lode gold mineralization have been well documented within the Atlin camp (Ash and Arksey, 1990a, b; Ash *et al.*, 1992). Mineralization is coeval with the 172 Ma Fourth of July magmatism, which displays a mixed geochemical signature of syn-collisional and volcanic arc characters. No other mineralizing event within the Tagish area of this age are known. Although it is possible that auriferous veins at the Rupert and Ben-My-Chree occurrences are coeval, they are more likely related to metamorphic devolatilization of Early to Middle Jurassic age. Veins at the Engineer Mine could be of this age, but close association with Sloko Group volcanic strata suggests that they are coeval with Early Eocene volcanism. Regionally, significant deposits of this time period, such as the Golden Bear and Eskay Creek gold deposits, are situated in tectonic settings grossly similar to that of the map area.

Cretaceous

A magmatic lull affected most of the northern Cordillera in the Early Cretaceous although the Mount Lawson pluton, with a cooling age of 133 Ma (K-Ar; Bultman, 1979), and a single Early Cretaceous pluton along the shores of south Tagish Lake dated at 127 Ma (U-Pb; Currie, 1994; Table AA5) appear to be exceptions. No strata of this age are known in the Tagish area.

By Late Cretaceous time both magmatism and strike-slip deformation were important. Strike-slip faults did not modify longitudinal terrane relationships significantly, however, their latitudinal positions may have been modified by hundreds of kilometres by mainly northward translation. Significant contractional deformation, like that recorded in the Bowser Basin (Evenchick, 1991, 1992), appears to be lacking in the Tagish area, although minor folding may have accompanied pluton emplacement (*e.g.* west of southern Tutshi Lake).

A widespread Early Cretaceous thermal event (Wilson *et al.*, 1985; Pavlis *et al.*, 1993) which has been attributed to uplift and unroofing of regional core complexes (Pavlis *et al.*, 1993)set cooling ages in the Yukon-Tanana Terrane of Yukon and eastern Alaska. A 132 ±5 Ma K-Ar cooling age from sericite in the Llewellyn fault zone falls within the range of minimum $^{40}Ar/^{39}Ar$ cooling ages from Devono-Mississippian orthogneisses exposed in core complexes in Alaska (Hansen *et al.*, 1989; Hansen, 1990). However, evidence of a core complex in the Tagish area is lacking despite assumptions made early in the project that discovery of such evidence was highly probable.

Mid-Cretaceous magmatism is widespread in the Yukon and includes what may be the world's largest collection of highly radiogenic plutons (Armstrong, 1988). These S-type granites are presumably the product of melting at mid-crustal levels in response to tectonic loading during the Middle Jurassic compressional event. This is well illustrated by intrusions inboard of the eroded edge of the Anvil-Nisutlin allochthon, where the plutons are concentrated in the thickest accumulations of pre-Cretaceous strata. Depositional thickening is particularly well displayed by the Devonian sequence (Fritz, *et al.*, 1991).

Magmatism was renewed with vigor in Late Cretaceous time as a result of subduction beneath the new western Cordilleran margin. The oldest related plutons in the Tagish area are part of the 111 to 109 Ma Whitehorse magmatic epoch that is well dated north of the British Columbia border (Hart, 1994; Table AA5). These plutons are associated with copper ± iron skarns (Tenney, 1980) developed in carbonate of the Upper Triassic Lewes River Group (Stuhini equivalent).

High-level plutons and coeval volcanic rocks with ages of about 83 Ma are the first widespread suite of Cretaceous magmatic rocks in the Tagish area. These intrusions are part of the Windy-Table intrusive suite and include small dioritic plutons that intrude the Whitehorse Trough and miarolitic and porphyritic quartz monzonite and alaskite of the Surprise Lake batholith that intrude western Atlin complex. Geochemically, the Surprise Lake batholith is an A or S-type granite (see section 14-12) with elevated tin, tungsten, fluorine, rubidium and unusual development of wrigglite (tin) skarn (Webster and Ray, 1992), but it lacks muscovite (Mihalynuk *et al.*, 1992a). The batholith displays a slightly elevated initial strontium ratio of 0.706 calculated from a steep, two point isochron that is sensitive to small errors. This ratio may reflect the incorporation of some older, radiogenic crust, perhaps the edge of continental crust in the subsurface. However, when the initial strontium ratio is back calculated from the U-Pb age, it is geologically unreasonable, indicating isotopic disturbance. Thus, the unusual chemistry of the Surprise Lake body may be due to protracted cooling or refusion during a regional hydrothermal event and not crustal contamination (Mihalynuk *et al.*, 1992a; *see* Chapter 12).

Volcanic rocks of this age are tilted and offset across minor and major faults, such as the Llewellyn and Nahlin faults. Closely spaced cleavage or even weak foliation is developed locally. However, no offsets greater than a few kilometres have been demonstrated. Regional cooling of the area between the Llewellyn and Nahlin faults to below 90°C followed this pulse of magmatism with final annealing of apatite fission tracks at about 50 Ma (Donelick, 1988).

Mineral potential considerations

Mainly high angle brittle faults of this age, with or without dextral offset, are common and may have provided conduits for mineralizing fluids. Widespread Late Cretaceous magmatism holds potential for regionally important hydrothermal events, and many of the meso- and epithermal veins and fault-related veins within the Tagish area may be Late Cretaceous or younger. Precious metal gold-silver-base metal sulphide veins of the Venus Mine and arsenical veins of the Ben claim group may be of this age. The setting of the copper-rich calcsilicate skarn at the Mill showing is similar to that of deposits of the Whitehorse Copper belt. It is hosted in Upper Triassic calcareous sediments of the Stuhini Group adjacent to the Late Cretaceous Jack Peak pluton (dated as 89.5 Ma ±2.6 Ma; K-Ar biotite may be reset; Bultman, 1979).

Tertiary

A spectacular widespread period of intermediate to felsic magmatism heralded onset of the Tertiary. Volcanic centres are particularly well displayed, each with intrusive and extrusive components. At 58.5 Ma a weakly foliated felsic volcanic unit was deposited adjacent to the Llewellyn fault near eastern Skelly Lake (Figure 11-1). At 56-55 Ma voluminous outpourings of Sloko Group volcanics blanketed the Tagish area; coeval semi-circular granitic plutons mark volcanic centres or the magmaic roots of Sloko volcanoes in the Coast Belt. At 54-53 Ma calderas along the east side of the Coast Belt were formed, including the Bennett and Skukum complexes. The huge volume of coeval plutonic rocks that dominate the Coast Belt is an anomaly of global scale. Plutonic emplacement in the Coast Belt occurred mainly in belts which young to the west at this latitude (*e.g.* Brew and Morrell, 1983).

Structures of this age are mainly high-angle and brittle. North-northwest to north-northeast-trending dike swarms probably fed the Sloko volcanic fields. Late, northeast to east-west-trending steep structures may in part be synvolcanic block faults that localized deposition of Sloko Group volcanic strata. Some of these faults appear to have focused mineralization - as between Atlin Lake and Tulsequah (Smith and Mihalynuk, 1992) and others are outlined by the loci of shallow, recent earthquakes (*e.g.* Brew *et al.*, 1991) as in the Tulsequah area. However, most faults appear to be later, mainly vertical adjustments across major and minor fault strands (*e.g.* Llewellyn and Nahlin faults) that may have controlled epiclastic deposition. Offsets of this age are generally less than a few hundred metres. The 55 ± 2 Ma Pennington Pluton (Hart, 1994) plugs the main strand of the Llewellyn fault; it is only locally affected by brittle deformation and shows no apparent offset.

Elevated crustal heat flow resulted in static Buchan-style, sillimanite-grade metamorphic overprinting of high P-T metamorphism within the Yukon-Tanana Terrane of the Coast Belt. Cooling to below 90°C mainly occurred in the 20 Ma following this magmatic pulse (50 to 30 Ma; Donelick, 1988).

Mineral potential considerations

Epithermal mineral potential of Sloko and related volcanic systems is well demonstrated by auriferous veins at the Mt. Skukum deposit. Ore formation at the Engineer Mine is probably also of this age. Of historical importance, mineral deposits of this age will remain key exploration targets.

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Appendix A.
Isotopic Age Data

Table AA1. New U-Pb and K-Ar isotopic age data from the Tagish Lake area

BCGS AGE DATA FROM THE TAGISH PROJECT listed by age

Field No.	NTS map zone 8	Easting	Northing	Rock type	Method (Mineral)	Age (Ma)	Map unit old	Map unit new	Reference
Sloko Group									
MMI89-62-5	104M8E	546500	6593300	rhyolite	U/Pb (zrn)	54.1±0.1	muKTv	eESr	8
MMI89-39-6	104M8W	529600	6570900	granite	K/Ar (bt)	55.3±1.8	lKg2	eESg	8
LCU88-45-4	104M10E	521200	6617200	granodiorite-tonalite	K/Ar (bt)	55.3±1.8	KTtp	eESg	9
88MM46-7-2	104M10E	521350	6614600	rhyolite flow	U/Pb (zrn)	55.5±0.14	MVr	eESr	8
MMI89-30-10-1	104M9E	556400	6600300	ignimbrite	U/Pb (zrn)	54.4±1.9	eTs	eESr	8
MMI89-53-6-2	104M8W	538300	6578650	rhyolite flow	U/Pb (zrn)	55.3±0.2	muKTv	eESr	8
MMI89-53-6-2	104M8W	538300	6578650	rhyolite flow	K/Ar (wr)	55.3±0.2	muKTv	eESr	8
Coast Belt Intrusion									
MMI89-67-1	104M15	517450	6625725	rhyolite	U/Pb (zrn)	58.5±1.5	PPm	lKg	8
Windy-Table volcanic suite									
NWI89-17-5	104M9E	555700	6617000	rhyolite ash flow	U/Pb (zrn)	81.3±0.3	muTPv	lKTv	6
Surprise Lake Batholith									
DVL87-051	104N11	597750	6608590	bt granite	U-Pb (zrn)	83.8±5*		lKSlg	6
Fourth of July plutonic suite									
MHG87-64	104N13	59° 55.5'	133° 47.5'	quartz diorite	U-Pb (zrn)	170.4±5.1	mJFJ	mJFJd	6
DVL87-078	104N12	584300	6609800	diorite dike	U-Pb (zrn)	167±	mJFJ	mJFJ	6
DVL87-082	104N12	575575	6608100	quartz syenite	U-Pb (zrn)	171.5±3.4*	mJFJ	mJFJg	6
Bennett plutonic suite (Long Lake suite?)									
KMO89-54-1	104M8W	538700	6581300	pegmatite	U/Pb (zrn)	178.8±0.9	PPmh	eJHp	5
87MM40-4	104M15	504950	6639100	altered granodiorite	U-Pb (zrn spn)	175.8 +5/-3	MTgd	eJgd	3
Stikine plutonic suite									
88MM42-7	104M10E	518175	6619650	hornblendite	K-Ar (hbl)	187±7	JKh	eJh	1
92MM50-1	104M1	553200	6567000	Kfs megacrystic granite	U-Pb (zrn)	216.7±4	uTgd	lTgd	7
MISCELLANEOUS: age reset or very approximate									
MMI89-59-2c	104M8	542675	6590050	granodiorite	K/Ar (ser wr)	132±5	lTgd	lTgd	1
88MM40-6c	104M10E	519775	6621625	Crine vein	Pb/Pb (gn)	Cretaceous	PPm	DTBc	4
87MM34-3	104M15	517700	6630350	hbl lapilli tuff	K-Ar (hbl)	110±4	uTSh	uTSh	2
87MM25-5	104M15	502250	6646800	hornblendite	K-Ar (hbl)	150± 6	PPm	DTBp	1

Age: * = isochron forced through zero

Mineral abbreviations: act = actinolite; amph = amphibole; bt = biotite; gn = galena; hbl = hornblende; pyx = pyroxene;

Argon decay constants: ^{40}K epsilon=0.581 x 10-10 year^{-1}; ^{40}K beta=4.96 x 10-10 year^{-1}; ^{40}K/K = 1.167 x 10^{-4}.

ser = sericite; wr = whole rock, zrn = zircon.

Potassium determined at the University of British Columbia geochronology laboratory; Ages given with 1 sigma error.

Age determination and calculation by:

1 = J. Harakal, University of British Columbia; reported in Table AA3.
2 = J. Harakal and D. Runkle, University of British Columbia; reported in Table AA3.
3 = D.C. Murphy and J.E. Gabites, University of British Columbia; reported in Table AA2.
4 = C.I. Godwin and J.E. Gabites, University of British Columbia; reported in Table AA4.
5 = J.E. Gabites, University of British Columbia; reported in Table AA2.
6 = J.E. Gabites *in* Mihalynuk *et al*., 1992.
7 = J.E. Gabites *in* Mihalynuk *et al*., 1997.
8 = J.E. Gabites *in* Mihalynuk *et al*., 1999.
9 = J. Harakal *in* Mihalynuk *et al*., 1999.

Table AA2. New U-Pb isotope data for samples from the Tagish Lake area

Fraction [1,2]		Wt. mg	U [3] ppm	Pb [3] ppm	$^{206}Pb^{4}/^{204}Pb$	Pb^{5} pg	^{208}Pb % [6]	Isotopic Ratio (± %1σ) $^{206}Pb/^{238}U$	$^{207}Pb/^{235}U$	$^{207}Pb/^{206}Pb$	Apparent Age (Ma, ± 2σ) $^{206}Pb/^{238}U$	$^{207}Pb/^{206}Pb$
87MM40-4												
A	-b+c	0.500	237	7	3876	52	13.1	0.02769 (0.11)	0.1918 (0.16)	0.05023 (0.08)	176.1 (0.4)	205.9 (3.7)
B	-b+c eq	0.500	342	9	1151	254	11.6	0.02703 (0.31)	0.1860 (0.26)	0.04992 (0.36)	171.9 (0.4)	191.3 (10)
C	-b+c l	0.700	388	11	1242	390	11.2	0.02808 (0.14)	0.1930 (0.22)	0.04985 (0.15)	178.5 (0.5)	188.2 (7.1)
D	M1 -b	0.600	515	14	1310	383	12.6	0.02560 (0.08)	0.1756 (0.22)	0.04974 (0.17)	163.0 (0.3)	182.8 (7.9)
G	-c+d	0.123	398	11	2640	32	12.5	0.02752 (0.18)	0.1881 (0.29)	0.04958 (0.19)	175.0 (0.6)	175.5 (9.0)
H	-c+d	0.066	398	12	3742	12	13.4	0.02777 (0.10)	0.1902 (0.21)	0.04968 (0.13)	176.6 (0.3)	180.1 (6.0)
I	-b+c	0.097	272	7	4348	10	13.0	0.02605 (0.23)	0.1783 (0.31)	0.04963 (0.16)	165.8 (0.7)	177.8 (7.3)
J	-b+c	0.125	387	10	2633	30	12.0	0.02550 (0.13)	0.1739 (0.24)	0.04946 (0.14)	162.3 (0.4)	169.7 (6.8)
K	-b+c	0.168	394	11	6036	19	12.5	0.02689 (0.12)	0.1849 (0.20)	0.04989 (0.11)	171.0 (0.4)	189.7 (5.0)
KMO89-54-1		Pegmatite, Hale Mountain Intrusions										
A	+c	0.100	369	10	1046	62	8.8	0.02825 (0.09)	0.1953 (0.24)	0.05014 (0.20)	179.6 (0.4)	201.5 (9.5)
B	M mx	0.200	133	4	219	222	7.4	0.02798 (0.13)	0.1925 (1.4)	0.04990 (1.4)	177.9 (0.5)	190.3 (63)
C	M1mx	0.020	725	21	172	166	7.9	0.02967 (0.23)	0.2077 (1.9)	0.05077 (1.8)	188.5 (0.9)	230.3 (84)
D	N/20 mx	0.086	8133	179	309	3665	1.0	0.02413 (0.27)	0.1677 (0.67)	0.05042 (0.52)	153.7 (0.7)	214.2 (24)
G	M1 c	0.050	7326	169	353	1747	1.2	0.02527 (0.34)	0.1756 (0.66)	0.05041 (0.46)	160.9 (1.1)	213.7 (21)
I	M +c	0.021	5608	125	951	196	.8	0.02453 (0.12)	0.1675 (0.33)	0.04950 (0.23)	156.2 (0.4)	171.8 (11)
J	M -c	0.015	5207	121	716	181	.9	0.02546 (0.19)	0.1760 (0.41)	0.05012 (0.28)	162.1 (0.6)	200.5 (13)
MMI89-67-1		Rhyolite, Skelly Lake (originally mapped as DTrB)										
A	a	0.100	234	3	137	128	16.3	0.01050 (0.31)	0.0690 (1.6)	0.04761 (1.4)	67.4 (0.4)	80.2 (67)
B	-a+c	0.200	546	6	268	280	16.8	0.01013 (0.22)	0.0680 (0.70)	0.04865 (0.57)	65.0 (0.3)	131.0 (27)
C	M -c	0.200	808	8	386	251	19.9	0.00916 (0.40)	0.0600 (0.69)	0.04750 (0.50)	58.7 (0.5)	74.2 (23)
D	M1 -c	0.200	238	3	145	224	18.9	0.00956 (0.39)	0.0626 (1.5)	0.04750 (1.3)	61.4 (0.5)	74.6 (60)
F	-c	0.046	565	6	582	31	16.9	0.01052 (0.17)	0.0734 (0.61)	0.05060 (0.52)	67.5 (0.2)	222.4 (24)
H	M1 c	0.072	625	7	225	134	18.7	0.00988 (0.19)	0.0673 (0.80)	0.04939 (0.66)	63.4 (0.2)	166.4 (31)
I	M1 c	0.041	936	11	407	58	26.9	0.00915 (0.16)	0.0601 (0.56)	0.04763 (0.44)	58.7 (0.2)	81.1 (21)
J	M c	0.017	880	9	264	34	17.8	0.00908 (0.16)	0.0591 (0.79)	0.04721 (0.69)	58.3 (0.2)	59.7 (32)
MMI92-50-1		Hornblende granodiorite, Williston Pluton										
A	+a	0.709	420	14	3193	185	8.2	0.03265 (0.18)	0.227 (0.24)	0.05042 (0.14)	207.1 (0.7)	214.6 (6.4)
B	-b+c	0.491	485	16	10571	45	8.7	0.03286 (0.22)	0.229 (0.22)	0.05054 (0.05)	208.4 (0.9)	220.0 (2.2)
C	-c+d	0.17	552	18	4176	46	9.3	0.03308 (0.27)	0.2308 (0.36)	0.05061 (0.25)	209.8 (1.1)	223.2 (12)
D	-d na	0.278	795	23	3280	122	9.4	0.02884 (0.19)	0.1998 (0.22)	0.05025 (0.08)	183.3 (0.7)	206.4 (3.8)
F	+b	0.182	408	14	2831	55	8.7	0.03362 (0.07)	0.2341 (0.09)	0.05051 (0.06)	213.1 (0.3)	218.7 (2.7)
G	+b tips	0.208	402	13	5027	35	8.3	0.03376 (0.10)	0.2346 (0.13)	0.05039 (0.08)	214.1 (0.4)	213.1 (3.6)

Notes: Analyses by J.E. Gabites, in the Geochronology Laboratory, Department of Earth and Ocean Sciences, U.B.C..

IUGS conventional decay constants (Steiger and Jäger, 1977) are: $^{238}U\lambda=1.55125 \times 10^{-10} a^{-1}$, $^{235}U\lambda=9.8485 \times 10^{-10} a^{-1}$, $^{238}U/^{235}U = 137.88$ atom ratio.

1. Column one gives the label used in the Figure.
2. Zircon fractions are labelled according to magnetic susceptibility and size. Except where noted all fractions are NM2A/1° (non-magnetic at given amperes on magnetic separator, side slope is given in degrees), abraded except where indicated (na). M = M2A/1° , M1 = M1.5A/3° , B = nonsplit magnetically Size fractions are: a 149, b 104, c 74, d 44μm. mx = mixed sizes. The - indicates zircons are smaller than, + larger than the stated size. Eq = elongate, l = elongate crystals.
3. U and Pb concentrations in mineral are corrected for blank U and Pb. Isotopic composition of Pb blank is 206:207:208:204 = 17.299:15.22:35.673:1.00, based on ongoing analyses of total procedural blanks of 10-40 ± 1 pg (Pb) and 3-6 ± 0.5 pg (U) during the time of this study.
4. Initial common Pb is assumed to be Stacey and Kramers (1975) model Pb at the $^{207}Pb/^{206}Pb$ age for each fraction.
5. Radiogenic Pb.
6. Total Common Pb in analysis.
7. Errors are % 1σ except $^{207}Pb/^{206}Pb$ age errors which are 2 σ in Ma.

Table AA3. New K-Ar isotope data for samples from the Tagish Lake area

Field No.	NTS map zone 8	Rock type	Method (Mineral)	%K, n	$^{40*}Ar(10^{-6}cc/g)$	$\%\Sigma Ar^{40*}$	Age (Ma)
88MM42-7	104M10E	hornblendite	K-Ar (hbl)	1.04±0.01, 2	7.982	93.3	187±7
MMI89-59-2c	104M8	granodiorite	K/Ar (ser wr)	3.18±0.04, 2	16.858	94.7	132±5
87MM34-3	104M15	hbl lapilli tuff	K-Ar (hbl)	0.508±0.002, 2	2.243	83.5	110±4
87MM25-5	104M15	hornblendite	K-Ar (hbl)	0.338±0.009, 3	2.057	79.7	150± 6

Analyses by J. Harakal and D. Runkle, UBC Geochronology laboratory

Table AA4. New Pb-Pb isotope data for a sample from the Tagish Lake area

Field No.	NTS map zone 8	Rock type	Method (Mineral)	$\frac{^{206}Pb}{^{204}Pb}$	$\frac{^{207}Pb}{^{204}Pb}$	$\frac{^{208}Pb}{^{204}Pb}$	Age
88MM40-6c	104M10E	Crine vein	Pb/Pb (galena)	19.022	15.620	38.609	Cretaceous

Analysis by C.I. Godwin, UBC Geochronology laboratory

Table AA5. Compilation of isotopic age data for the map area and immediately adjacent areas

OTHER AGE DATES listed first by mapsheet and then by age

Lab/Field No.	NTS map	Easting	Northing	Rock type	Method (Mineral)	Age (Ma)	Map unit old	Map unit new	Reference
104M BENNETT									
Sloko Group volcanics									
03028	104M/14	486500	6650500	partly welded tuff	K-Ar (wr)	51.9±3	ES (Skukum Group)		6
08088	104M/14	485500	6648000	welded ignimbrite	K-Ar (wr)	51.2±3	ES		6
Sloko plutonic suite									
LC89-175c	104M/8	543260	6575550	Quartz monzonite	U-Pb(zrn)	55.7±0.2			16
LC89-75c	104M/8	537250	6578900	hbl diorite	U-Pb(zrn)	55.9±0.2			16
Windy-Table volcanic suite									
T75 305-8	104M/9	59 28	133 57	rhyolite	Rb-Sr (wr)	72.4±2.1	lKTv		7
Surprise Lake plutonic suite									
GSC61-47	104M/11	486500	6597500	granodiorite	K-Ar (bt)	72±8	lKg		3
Coast Plutonic Complex orthogneiss									
Ak-206	104M/11	BC-AK boundary south		non-migmatitic orthogneiss	U-Pb (zrn)	61.7±2[a]			14
Ak-206	104M/11	BC-AK boundary south		non-migmatitic orthogneiss	K-Ar (hbl)	54.7			14
Ak-206	104M/11	BC-AK boundary south		non-migmatitic orthogneiss	K-Ar (bt)	49.4			14
Post tectonic intrusions									
Ak-208	104M/11	Clifton, USA		granite	U-Pb (zrn)	47.8±2[a]			14
Ak-212	104M/11	Summit Lake		tonalite	U-Pb (zrn)	53.9±2[a]			14
Ak-212	104M/11	Summit Lake		tonalite	K-Ar (bt)	52.4			14
T75 310-2	104M/16	537410	6630666	bt granite	K-Ar (bt)	58±1.1			2
GSC 61-39	104M/10	500937	6621506	granodiorite	K-Ar (bt)	56±8**			3
GSC60-26	104M/11	492500	6609500	granite	K-Ar (bt)	62±8**	lKg		3
GSC61-46	104M/11	490000	6603500	granite	K-Ar (bt)	66±8**	lKg		3
GSC60-38	104M/14	499500	6628500	granodiorite	K-Ar (bt)	66±8**	lKgd		3
Ak-207	104M/11	Summit Lake		granite	U-Pb (zrn)	52.3±2[a]			14
Ak-207	104M/11	Summit Lake		granite	K-Ar (bt)	52			14
GSC60-27	104M/14	499000	6634500	granodiorite	K-Ar (bt)	70±8**	lKgd		3
T75 323-3	104M/8	531970	6587000	hbl-quartz diorite	K-Ar (bt)	60.6±1.2		lKg1	2
T74 207-1	104M/8	535275	6585940	unfoliated bt granodiorite	K-Ar (hbl)	66±1.3		lKg1	2
Ak-216	104M/15	Log Cabin		Log Cabin granite	U-Pb (zrn)	72±2[a]			14
Ak-216	104M/15	Log Cabin		Log Cabin granite	K-Ar (hbl)	66.5			14
Ak-216	104M/15	Log Cabin		Log Cabin granite	K-Ar (bt)	63.3			14
T75 102-2	104M/15	512835	6636068	bt granite	K-Ar (bt)	80±1.6			2
T74 223-2	104M/9	546681	6596894	hbl tonalite	K-Ar (hbl)	83±3			2
T75 413-1	104M/16	533196	6627996	bt granite	K-Ar (bt)	84±2.1			2
T74 101-4	104M/15	516292	6642578	bt granite	K-Ar (bt)	92±3		uKg1	2
LC90-261c	104M/1	551075	6561325	granite	U-Pb(zrn)	101.6±0.6			16
LC90-359	104M/1	544950	6564725	bt-hbl granodiorite	U-Pb(zrn)	103±0.7			16
T75 323-2	104M/8	531970	6587000	hbl-quartz diorite	K-Ar (hbl)	120±3		lKg1	2
LC89-31	104M/8	538130	6586250	ms-bt granite	U-Pb(zrn)	127±0.6			16
Mount Lawson tonalite									
T74 228-1	104M/10	526509	6601183	hbl-rich tonalite	K-Ar (hbl)	133±3		eKt1	2
T74 208-1	104M/8	540510	6587230	hbl-bt granodiorite	K-Ar (hbl)	145±4		lKgh	2
Aishihik plutonic suite									
T74 213-1	104M/9	542051	6604573	granodiorite	K-Ar (hbl)	185±5			2
LC90-273	104M/1	549225	6553100	folded tonalite dyke	U-Pb(zrn)	191±1			16
Hale Mountain intrusives									
T75 323-6	104M/8	538890	6588300	plagioclase-hbl gneiss	K-Ar (hbl)	170±3[b]	PPMH	eJAgd	2
LC88-35-1	104M/8	531925	6596500	granodiorite orthogneiss	U-Pb (zrn)	187.7±1.1	PPMH	eJAgd	16
LC88-35-2	104M/8	531925	6596500	granodiorite orthogneiss	U-Pb (spn)	184.5±0.9	PPMH	eJAgd	16

Mount Caplice intrusive complex									
a58BLW77	104M/1	546400	656400	granodiorite	K-Ar (bt)	96±3.4			1
a58BLW77	104M/1	546400	656400	granodiorite	K-Ar (hbl)	97.5±3.4			1
LC90-314	104M/1	547850	6556325	Hoboe quartz syenite	U-Pb (zrn)	189.5±3			16
LC90-343	104M/1	564825	6557750	quartz monzodiorite	U-Pb (zrn)	180.9±3.1			16
LC90-344	104M/1	564825	6557750	quartz monzodiorite	U-Pb (spn)	177.0±0.6			16
a76cLW77	104M/1	544744	6562377	bt-hbl diorite					
b76cLW76	104M/1	544744	6562377	aplite					
a58ALW77	104M/1	544744	6562377	granodiorite	Rb-Sr	234±31			4
a58BLW77	104M/1	544744	6562377	granodiorite					
Stuhini Group volcanic rocks -K-Ar dates reset									
T75 223-1	104M/8	554600	6572710	Stuhini Gp.pyroxene basalt	K-Ar (wr)	74±1.4	uTS	uTSpb	2
T75 223-1	104M/8	554600	6572710	Stuhini Gp.pyroxene basalt	K-Ar (px)	192±11	uTS	uTSpb	2
Stikine Plutonic suite									
T75 130-1	104M/8	550360	6573270	porphyritic granodiorite	K-Ar (hbl)	178±4 reset	uTgd	lTgd	2
T74 108-1	104M/8	551710	6569425	porphyritic granodiorite	K-Ar (hbl)	220±5	uTgd	lTgd	2
Wann River gneiss									
A41D-LW-76	104M/1	541193	6567905	amphibolite	K-Ar (amph)	214±8 reset	PPMF	Pw	1
LC 89-91b	104M/8	536750	6573525	hbl-plag gneiss	U-Pb (zrn)	270±5	PPMw	Pw	16
C34A-LW76	104M/8	544210	6571625	amphibolite	K-Ar (act)	244±16 reset	PPMF	Pw	1
Mississippian orthogneiss									
LC90-304	104M/1	549250	6556150	felsic dyke cuts	U-Pb(zrn)	335±10			16
LC90-267b	104M/1	550425	6552000	pink mylonitic granitic dike	U-Pb(zrn)	352±5.5			16
LC88-28-1	104M/8	531700	6599400	Bighorn orthogneiss	U-Pb(zrn)	366±9			16
Florence Ranges Suite metamorphism									
LC89-84b	104M/8	536000	6570400	Leucosome	U-Pb (zrn)	177±7			16
LC89-84b	104M/8	536000	6570400	Leucosome	U-Pb (zrn)	177.5±1.5			16
LC89-86	104M/8	536330	6571460	calcsilicate	U-Pb(spn)	189.6±1.8			16
LC91-469	104M/8	539325	6573700	bt schist	U-Pb(rut)	142.5±2.5			16
Boundary Ranges Suite metamorphism									
LC91-458b	104M/8	539350	6569275	Wann R gneiss	U-Pb(spn)	205±30			16
LC91-458b	104M/8	536750	6573525	Wann R gneiss	U-Pb(rut)	146.0±1.8			16
b42ALW77	104M/1	541700	6561300	bt-hbl amphibolite	K-Ar (hbl)	144±5	PPMW		1

104N ATLIN

Surprise Lake plutonic suite									
PC 15	104N/11	589834	6619988	quartz monzonite	K-Ar (bt)	63.1±2.2	lKSLb		9
A-KAR-4	104N/11	589834	6619988	mafic quartz monzonite	K-Ar (bt)	70.3±2.4	lKSLb		9
A-KAR-1	104N/11	589834	6619988	quartz monzonite	K-Ar (bt)	71.6±2.2	lKSLb		9
A-KAR-2	104N/11	589834	6619988	granite	K-Ar (bt)	71.4±2.1	lKSLb		9
A-KAR-3	104N/11	589834	6619988	sparse porphyry	K-Ar (bt)	71.6±2.1	lKSLb		9
A-KAR-5	104N/11	589835	6619988	granodiortie	K-Ar (bt)	73.3±2.6	lKSLb		9
18751M	104N/11			coarse alaskite	K-Ar (bt)	75.4±2.5	lKSLb		9
Fourth of July Plutonic suite (in part reset by Surprise Lake batholith)									
A-KAR-5	104N/11	589200	6620800	granodiorite	K-Ar (hbl)	110±4	mJFJb		9
MAB89-016	104N/6	592400	6593700	quartz vein cutting MT	K-Ar (ser)	144±6	Qvn		1
DY-2958	104N/12	579800	6600600	bt granite	K-Ar (bt)	167±3	mJFJ		5
DY-2957	104N/12	579800	6600600	sericite alteration	K-Ar (ser)	160±2	Mo-Py veins		5

105D YUKON

93CH T-11	105			Ta'an plug	K-Ar(bt)	50.6±1.4			17
WHA-1	105			Annie Ned	K-Ar(bt)	51.2±2			8
92CH80-3	105D			andesite dike	K-Ar(wr)	52.1±1.3			17
Sloko volcanic suite									
48, 52, 53, 67, 76, 101, 108	105D	Mt. Skukum		rhyolite plugs	Rb/Sr	53.3±3	ES		11
WHA-4	105D			Jackson Creek granite	K-Ar(bt)	55±1.9	EEq	Tgqm	8
89CH52-1	105D	134° 57.0'	60° 1.5'	Pennington qtz monzonite	K-Ar(hbl)	54.9±1.9	EEqP		13
89CH52-1	105D	134° 57.0'	60° 1.5'	Pennington qtz monzonite	K-Ar(bt)	41.2±2.8	EEqP		17
92CH80-2	105D			rhyolite dike	K-Ar(wr)	56±1.4			17
	105D	Goat-Lakeview Mtns.		andesite	K-Ar(wr)	58.3±2.0			13

Sloko plutonic suite								
Y88-7	105D	135° 30.9'	60° 1.5'	Mt. MacAuley pluton	U-Pb (zrn)	53.7±0.3		17
	105D	east of Mt. McAuley		Mt. MacAuley pluton	K-Ar(bt)	57		13
Y88-6	105D	135° 11.1'	60° 2.9'	Crozier Ck. qtz monzonite	Rb-Sr(wr)	56.4±1.5	LPqCC	13
Y88-6	105D	135° 11.1'	60° 2.9'	Crozier Ck. qtz monzonite	U-Pb (zrn)	56.0±0.3	LPqCC	17
Y88-29A	105D	135° 13.5'	60° 5.0'	Crozier Ck. qtz monzonite	K-Ar(wr)	50.3±1.8	LPqCC	17
Y88-6	105D	135° 11.1'	60° 5.0'	Crozier Ck. qtz monzonite	K-Ar(wr)	51.2±1.8	LPqCC	17
Y88-32	105D	135° 58.5'	60° 48.4'	Annie Ned granite	U-Pb (zrn)	57.1±0.2		17
Zr1	105D			Upper Ibex alaskite	U-Pb (zrn)	58.1+4/-1	EEql	17
	105D			leucogranite	Rb-Sr(wr)	58.5±12	LPq	13
	105D	head of Boudette Ck.		hbl-bt granodiorite	K-Ar(bt)	58.8±3		13
12017	105D/3	492920	6653253	porphyritic rhyolite dike	K-Ar (wr)	51.6±3		6
94028	105D/3	476516	6652615	Hbl-Bt Qtz monzonite	K-Ar(bt)	58.8±3		6
Coast Belt Intrusions								
	105D			Mt. Wheaton	K-Ar	61.7		13
	105D	Grey Ridge		rhyolite dike	K-Ar	64		13
WHA-9	105D	south of Carcross		Carcross pluton	K-Ar (bt)	64.3±2.2	PgC lKqm	8
89CH60-5	105D	134° 54.6'	60° 14.8'	Carcross pluton	K-Ar(hbl)	68.6±2.5		17
	105D	Idaho Hill		rhyolite dike	K-Ar	70		13
Wheaton volcanic/plutonic suite								
WHA-7	105D			Mt. Lorne	K-Ar(bt)	75.3±2.8		8
Y88-14	105D	135° 2.2'	60° 15.4'	Wheaton Valley granodio	U-Pb (zrn)	77.1±0.7	LKgWV	17
Y88-1	105D	135° 0.7'	60° 17.4'	Folle Mountain stock	U-Pb (zrn)	77.5±0.3	LKqF	13
Y88-1	105D	135° 0.7'	60° 17.4'	Folle bt granite	K-Ar(bt)	61.1±2.1		17
	105D			Folle Mountain stock	K-Ar(hbl)	78	LKqF	13
	105D			Perkins Peak plug	Rb-Sr	70-97	LKqP	13
Windy-Table suite								
Y88-33-2	105D	135° 4.2'	60° 21.6'	Red Ridge hbl diorite	K-Ar(hbl)	80.6±2.8		17
	105D	east of Windy Arm		flow-banded rhyolite	U-Pb (zrn)	83.7±0.4	lKM2	13
Montana Mountain suite								
89CH33-3	105D	135° 14.0'	60° 10.3'	Carbon Hill bt granite	K-Ar(bt-chl)	96±15		17
89CH64-1	105D	135° 15.5'	60° 31.1'	Mt. Granger bt granodiorite	K-Ar(bt)	93.3±3.2		17
	105D			Carbon Hill volcanics	K-Ar	105		13
	105D			Carbon Hill rhyolite dike	K-Ar(bt)	106		13
	105D	head of Pooley Creek		intermediate pyroclastic	U-Pb (zrn)	94±1.2	mKM1	13
	105D			Montana Mtn. complex		95	mKM	13
	105D			Montana Mtn. complex	K-Ar	65 reset	mKM	13
Y88-21	105D	134° 42.0'	60° 5.7'	Montana Mtn. qtz monz	U-Pb (zrn)	106.5±0.5	mKqM	17
Y88-21	105D	134° 42.0'	60° 5.7'	Montana Mtn. qtz monz	K-Ar(hbl)	78.3±2.7	mKqM	17
Whitehorse magmatic epoch								
89CH75-1	105D	134° 23.2'	60° 32.1'	Marsh Lk. qtz diorite	K-Ar(hbl)	104±4		17
89CH35-7	105D	135° 13.5'	60° 20.5'	Mt Hodnett pyx diorite	K-Ar(hbl)	106±4	mKdMH?	13
Y88-26	105D	135° 25.6'	60° 35.5'	Ibex River dioirite	U-Pb (zrn)	108.0+1.2/-1.4	mKdW1	17
Y88-26	105D	135° 25.6'	60° 35.5'	Ibex River dioirite	K-Ar(hbl)	110±4	mKdW1	17
Y88-8	105D	135° 24.9'	60° 5.4'	Boudette Ck. pluton	U-Pb (zrn)	108.0+5.1/-1.2		17
Y88-18	105D	135° 11.2'	60° 38.7'	Mount McIntyre pluton	U-Pb (zrn)	108.6+1.2/-0.4	mKqMM	17
WHA6A	105D			Mount McIntyre pluton	K-Ar(hbl)	97.3±3.3		8
Y88-36	105D	135° 20.3'	60° 8.9'	Mount Ward granite	U-Pb (zrn)	109.2±0.4	mKqMW	17
Y88-40	105D	135° 24.0'	60° 10.1'	Berney Ck. pluton	U-Pb (zrn)	110.5+0.4/-0.7		17
	105D			Mount McNeil pluton	U-Pb (zrn)	111±0.6	mKgW2	13
93CH53-3	105D			Cap Ck. pluton	K-Ar(bt)	105±3		17
	105D			Cap Ck. pluton	U-Pb (zrn)	111		17
94CH60-6	105D			Byng Ck. volcanics	K-Ar(wr)	100±2		17
	105D			Byng Ck. volcanics	U-Pb (zrn)	113		17
WHA-5	105D			Whitehorse Plutonic suite	K-Ar(hbl)	105±4		17
WHB-5	105D			Whitehorse Plutonic suite	K-Ar(hbl)	109±4		17
WHB-5	105D			Whitehorse Plutonic suite	K-Ar(bt)	108±4		17
	105D	south of Mt. Ward		Mount Ward granite	U-Pb (zrn)	109+4/-3		13
WHA-8	105D	south of Mt. Ward		Mount Ward granite	K-Ar(hbl)	113±4	mKqMW	8
WHB-1	105D			Whitehorse Plutonic suite	K-Ar(hbl)	116±4	mKgW	8
WHB-1	105D			Whitehorse Plutonic suite	K-Ar(bt)	109±4		17
WHB-1	105D			Whitehorse Plutonic suite	Rb-Sr	116±20		17
Zr3-2,3	105D			Mount Anderson pluton	U-Pb (zrn)	111±3	mKgW1	17

Bennett plutonic suite								
Y88-10	105D	135° 27.5'	60° 21.7'	Alligator Lk. monzodiorite	U-Pb (zrn)	175.3 +1.9/-0.8	EJA	17
Y88-10	105D	135° 27.5'	60° 21.7'	Alligator Lk. monzodiorite	K-Ar (hbl)	128±4		17
Y88-30	105D	135° 12.4'	60° 8.4'	Fenwick Ck. diorite	U-Pb (zrn)	176.4 +1.8/-0.7		17
Y88-30	105D	135° 12.4'	60° 8.4'	Fenwick Ck. diorite	K-Ar (hbl)	136±5		17
Y88-30	105D	135° 12.4'	60° 8.4'	Fenwick Ck. diorite	Rb-Sr	159±6		17
Aishihik magmatic epoch								
92CH85-1	105D			Nordenskiold dacite	K-Ar (hbl)	180±5		17
Stikine plutonic suite								
Y88-33-3	105D	135° 4.2'	60° 21.6'	Red Ridge pluton	U-Pb (zrn)	200.1±0.9		17
Y88-33-4	105D	135° 16.6'	60° 27.3'	Friday Creek Diorite	U-Pb (zrn)	210.4+16/-0.8	LTrFC	17
Zr4-2	105D			Tally-Ho gabbro	U-Pb (zrn)	213.8±0.6	LTrFC	17
Zr4	105D	135° 0.1'	60° 11.9'	Tally-Ho gabbro	K-Ar (hbl)	113±3		17
Zr2	105D			granite	U-Pb (zrn)	220±5	uTgd	10
Cache Creek Terrane								
93CH52-2	105D			Joe Mtn. Fm. (reset)	K-Ar(wr)	51.8±1.6		17
93CH55J	105D			Joe Mtn. Fm. (reset)	K-Ar (hbl)	76.6±2.6		17
93CH T-22	105D			Joe Mtn. Fm. (reset)	K-Ar(wr)	75.1±2.5		17
Clasts in Whitehorse Trough sediments								
WHA11	105D	60° 51.2	135° 26.2	granodiorite boulder	K-Ar (hbl)	144±5	in lJL	8
Y88-44A	105D	Horse Ck.		hbl granodiorite boulder	U-Pb (zrn)	210±8	in lJLi	17
Y88-44B	105D	Horse Ck.		granite boulder	U-Pb (zrn)	210+6/-3	in lJLi	17
Y88-31E	105D	Km 1505 AK Hwy.		granite boulder	U-Pb (zrn)	214.4+8/-6	top of uTL	17
Y88-31A	105D				U-Pb (zrn)	208+10/-3	in uTL	17

Mineral abbreviations: act = actinolite; amph = amphibole; bt = biotite; hbl = hornblende; pyx = pyroxene; ser = sericite; spn = sphene (titanite), wr = whole rock, zrn = zircon.

Reference: 1 = J.E.Harakal, University of British Columbia ; 2 = T. Bultman and D. Seidmann, Yale University; 3 = GSC ; 4 = University of British Columbia [4a J. Harakal, Table AA3; 4b J. Harakal and D. Runkle, Table AA3; 4c D.C. Murphy and J.E. Gabites, Table AA2; 4d J.E. Gabites, Table AA2; 4e J.E. Gabites *in* Mihalynuk *et al* ., 1992; 4f J.E. Gabites *in* Mihalynuk *et al* ., 1997; 4g J.E. Gabites *in* Mihalynuk *et al* ., 1999; 4h J. Harakal in Mihalynuk et al., 1999]; 5 =Geological Survey of Canada, Paper 88-2; 6 =M. Lambert and M. Shafiqullah, Carleton *in* Lambert, 1974; 7 = H. Grond et al., 1982, UBC; 8 = Morrison *et al* ., 1979 [as reported in Hart, 1994]; 9 = Christopher and Pinsent, 1982; 10 = Doherty and Hart, 1988; 11 = Pride and Clark, 1985; 12 = Hart and Pelletier, 1989; 13 = Hart and Radloff, 1990; 14 = Barker et al., 1986; 15 = Anderson, 1989; 16 = Currie, 1994; 17 = Hart, 1995; 18 = Mihalynuk *et al* ., 1999.

K-Ar ages calculated using the decay constants: 4.96/0.581/1.167

* reliability questionalble -very low potassium

** reliability questionable -40Ar/40K <= 0.004

[a] age is average of reported $^{206}Pb/^{238}U$ and $^{207}Pb/^{235}U$ ages, error estimate is reported as "precision".

[b] recalculated

Appendix B.
Fossil Age Data

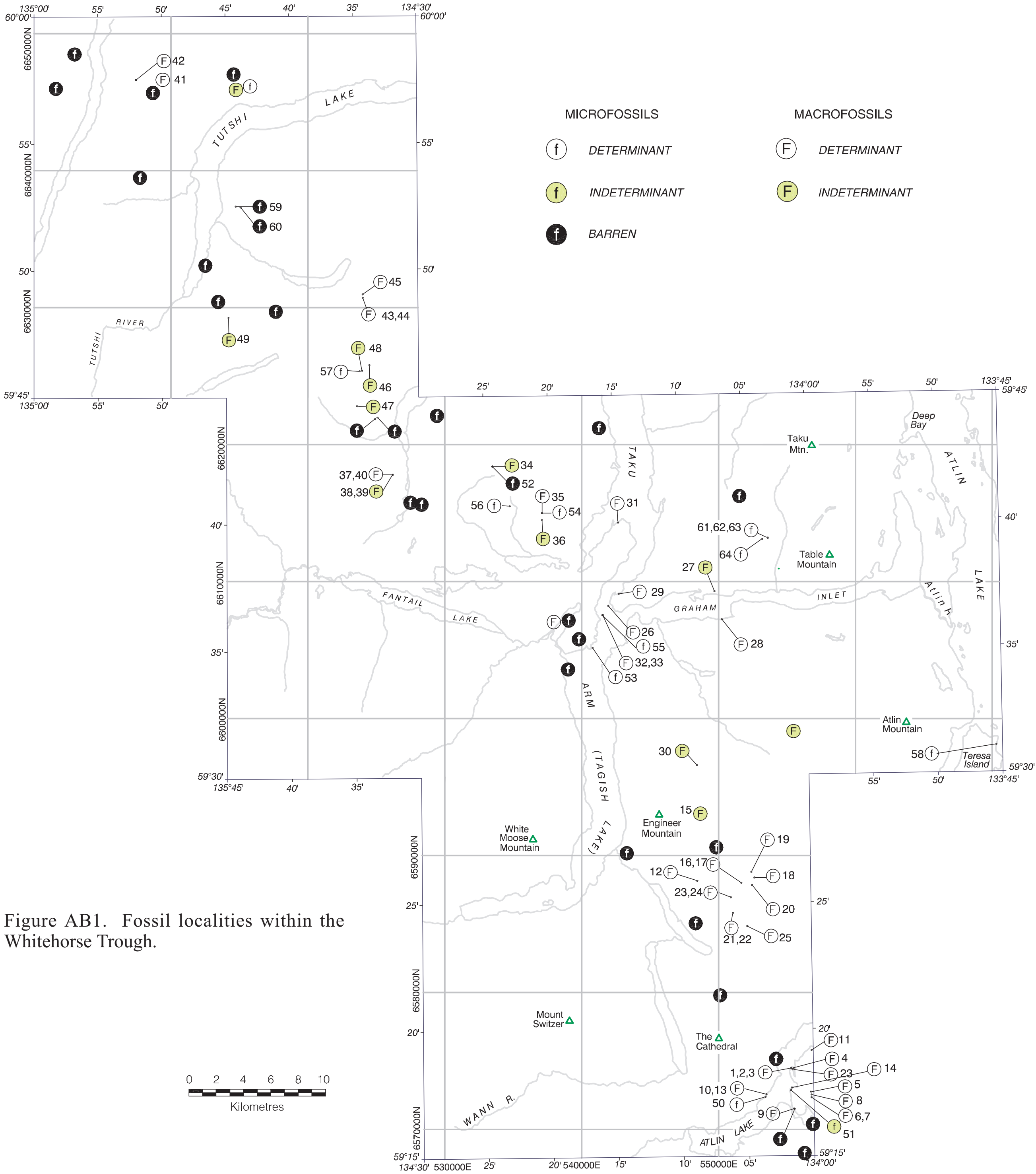


Figure AB1. Fossil localities within the Whitehorse Trough.

Table AB1. Macrofossil collections from the Tagish area

MAP NO.	NTS MAP	GSC NO.	FIELD NO.	UTM EAST	(Zone 8) NORTH	FIELD DESCRIPTION OF FAUNA		AGE	REF.
1	104M8	C-153942	MMI89-5-11a	555400	6574400	ammonites	***Dubariceras* sp.?**	Early Pliensbachian, Freboldi zone	1
2	104M8	C-153942	MMI89-5-11b	555400	6574400	ammonites	***Dubariceras* sp.**		1
3	104M8	C-153942	MMI89-5-11c	555400	6574400	ammonites	***Dubariceras* sp.**		1
4	104M8	C-153944	MMI89-5-12	555500	6574500	ammonites	***Dubariceras* sp.?**	probable Early Pliensbachian, Freboldi zone	1
5	104M8	C-153945	MMI89-7-2	556750	6572750	ammonites	***Metaderoceras* cf. *talkeetnaensis***	Early Pliensbachian, Freboldi or Whiteavesi zone	1
6	104M8	C-153946	MMI89-7-4a	556800	6572350	ammonite (Sinemurian?)	***Dubariceras freboldi***	Early Pliensbachian, Freboldi zone	1
7	104M8	C-153946	MMI89-7-4b	556800	6572350	ammonite (Sinemurian?)	***Dubariceras* cf. *freboldi***		1
8	104M8	C-153947	MMI89-7-3(a,b)	556800	6572550	two specis of ammonites	***Dubariceras silviesi*** ***Dubariceras freboldi***	Early Pliensbachian, Freboldi zone	1
9	104M8	C-153948	MMI89-5-1	555400	6571500	corals and spongiomorphs		indeterminate	3
10	104M8	C-153949	NWI89-4-3c	553500	6572550	bivalves and plants	***Halobia sp.***	Upper Triassic	3
11	104M8	C-153951	KMO89-7-9(1-3)	556800	6575800	appear to be hildoceratids	***Leptaleoceras?***	probable Late Pliensbachian, Kunae zone	1
12	104M8	C-153961	KMO89-35-2-2	548450	6588150	ammonites			
13	104M8	C-153962	MMI89-4-3c	553500	6572550	bivalves and plants	***Halobia* sp.**	Upper Triassic	3
14	104M8	C-153963	MMI89-5-6-2	555350	6573050	ammonite			
15	104M8	C-153968	MMI89-49-3a,b	548650	6593050	2 poor ammonite imprints		indeterminate; unlike any Sinemurian forms	1
16	104M8	C-153969	MMI89-45-13a-kk	551600	6588050	ammonite hildoceratids?, bivalves, coleiod?	***Metaderoceras,*** ***Dubariceras* cf. *talkeetnaensis*** ***Dubariceras* cf. *freboldi*** ***Reynesoceras* sp.**	Early Pliensbachian, Freboldi zone	1
17	104M8	C-153970	MMI89-13-2	551600	6588050	bivalves, ammonite	***Dubariceras freboldi***	Early Pliensbachian, Freboldi zone	1
18	104M8	C-153971	MMI89-44-3(a-f)	552500	6588450	several indeterminate bivalves, ammonite		Sinemurian (suggested by ammonites), probable Early	1
19	104M8	C-153972	MMI89-44-4(a-b)	552400	6588800	poorly preserved ammonites, possibly arietitids	***Asteroceras?***	probable Sinemurian, possible Late Sinemurian	1
20	104M8	C-153973	NWI89-44-1	552450	6587850	ammonite	***Dubariceras* cf. *freboldi***	Early Pliensbachian, Freboldi zone	1
21	104M8	C-153974	DLO89-45-5(a-d)	551050	6585800	5 ammonite frags	***Dubariceras* sp.**	probable Pliensbachian, possible late Early Pliensbachian	1
22	104M8	C-153975	DLO89-45-5-2	551050	6585800	ammonite frag	***Dubariceras?***	possible late Early Pliensbachian	1
23	104M8	C-153976	DLO89-45-1a	550900	6586950	poorly preserved ammonite	***Caenisites?***	Sinemurian, late Early Sinemurian (if Caenisites is correct)	1
24	104M8	C-153976	DLO89-45-1b	550900	6586950	ammonite fragment		possibly arietitid	1
25	104M8	C-153977	DLO89-45-14	552100	6584850	ammonite	***Amaltheus* cf. *A. stokesi***	Late Pliensbachian, Kunae zone	1
26	104M9	C-153924	88CW21-4	541950	6608220	ammonite			
27	104M9E	C-153958	DLO89-13-1	549700	6609300	bivalve?, indet.		indeterminate	2
28	104M9E	C-153959	NWI89-13-10	550200	6607300	belemnite	***Atractites?* sp.**	probable Middle Triassic to Early Jurassic	2
29	104M9E	C-153960	MMI89-14-10(1-7)	542700	6609100	ammonite pieces		probable Middle Triassic to Early Jurassic	2
30	104M9E	C-153979	KMO89-48-5a,b	548425	6596600	2 poorly preserved ammonite frags		indeterminate, possible Sinemurian as suggested by collector, resembles DLO89-45-1b	1

31	104M9W	C-153921	88CW2-2	542650	6614300	ammonite,probably arietid	***Arnioceras* sp.**	Sinemurian	1
32	104M9W	C-153922	88MM4-1-2a-c	541550	6607550	ammonites (arietid?)	***Vermiceras ? Metophioceras?***	Lower Sinemurian	1
33	104M9W	C-153923	88KM4-1-2	541550	6607550	arietid, possibly	***Arnioceras* sp.**	Sinemurian	1
34	104M9W	C-153930	88LC38-4b	533475	6618400	carbonate clast - corals		indeterminate - see Table B2 "Conodonts"	
35	104M9W	C-153936	88MM32-4	537100	6615000	carbonate clast - bivalves		indeterminate - conodonts are Norian (Table B2)	
36	104M9W	C-153941	88MM32-5-2	537100	6614500	carbonate clast - bivalves		indeterminate	
37	104M10E	C-153926	88CW24-9	526200	6617800	bivalves	***Bositra***	probable Toarcian	2
38	104M10E	C-153926	88MM24-9	526200	6617800	ammonite		indeterminate	
39	104M10E	C-153927	88MM24-9a	526200	6617800	ammonite		unknown. Lower Jurassic??	1
40	104M10E	C-153928	88MM24-9b	526200	6617800	bivalves	***Bositra or Posidonia***	most probably Middle to early Upper Toarcian	2
41	104M15	C-153901	87JR23-7	507450	6646625	fragments of ammonites and aptychi	***Haugia?***	late Lower Jurassic or early middle Toarcian; post late Pliensbachian suggested by aptychi	1
42	104M15	C-153903	87MM23-7(a-c)	507475	6646650	ammonites		probable late Middle Toarcian or Early Late Toarcian	1
43	104M15	C-153904	87MM27-6	524005	6630725	bivalves, Trigonia	***Astarte, Pleuromya?* sp.**	perhaps as young as Early Oxfordian	2
44	104M15	C-153905	87MM27-6	524005	6630725	Trigonia, ammonite suture	***Myophorella* sp.**	probable Middle Toarcian or Aalenian	2
45	104M15	C-153909	87MM27-6	524000	6630975	bivalves, Trigonia	***Myophorella* cf. *M. dawsoni***	Middle or Lower Jurassic (Toarcian to Bajocian age)	1
46	104M15	C-153915	87MM47-1	524500	6625800	Daonella? Halobia?		indeterminate	
47	104M15	C-153916	87MM45-2	523600	6622800	bivalves		indeterminate	
48	104M15	C-153917	87JR45-5a	523950	6625400	non-organic?		indeterminate	
49	104M15	C-153982	87PF31-2	514200	6629250	belemnite?		indeterminate	2

REFERENCES:

1 = H.W. Tipper; Geological Survey of Canada, Cordilleran Division;

2 = T.P. Poulton; Geological Survey of Canada, ISPG, Calgary;

3 = E.T. Tozer; Geological Survey of Canada, Eastern Paleontology Division;

Table AB2. Productive microfossil samples from the Tagish area

CONODONTS

Identifications by M.J. Orchard; Geological Survey of Canada, Pacific Section - Vancouver.

NTS MAP	GSC NO.	FIELD NO.	UTM EAST	(Zone 8) NORTH	DESCRIPTION OF FAUNA		AGE
104M8	C-153954	MMI89-4-3	553500	6572000	conodonts (CAI = 6)	***Metapolygnathus* sp.**	Late Triassic (Carnian)
104M8	C-153953	MMI89-5-5	555300	6572900	ichthyoliths		Phanerozoic
104M9W	C-153930	88LC38-4B	533475	6618400	ichthyoliths		Phanerozoic
104M9W	C-153934	88LC3-4 clast	540800	6605150	conodonts (CAI = 4.5-5.5), ichthyoliths	***Epigondolella* ex gr. *bidentata Mosher***	Late Triassic (late Middle to Late Norian)
104M9	C-153936	88MM-32-4 clast	537100	6615000	conodonts (CAI = 4.5-5.5), ichthyoliths	***Epigondolella* ex gr. *bidentata Mosher***	Late Triassic (late Middle to Late Norian)
104M9	C-153938	88MM-4-1A	541500	6607550	ichthyoliths, pellets		Phanerozoic
104M9	C-153939	88KM31-5-2A	534750	6615500	conodonts (CAI = 4.5-5.5), ichthyoliths	***Epigondolella* ex gr. *bidentata Mosher***	Late Triassic (late Middle to Late Norian)
104M15	C-153920	87JR45-5	523775	6625350	conodonts (CAI = 5.5), ramiform elements	***Epigondolella* ex gr. *bidentata Mosher***	Late Triassic (late Middle to Late Norian)
104N/12W	C-168202	89MAB-21	570300	6598150	conodonts (CAI not determined)	***Idiognathodus?* sp.**	Late Carboniferous - Early Permian (Sakmarian)

PALYNOMORPHS

Identifications by A.R. Sweet; Paleontology Subdivision, ISPG.

NTS MAP	GSC NO.	FIELD NO.	UTM EAST	(Zone 8) NORTH	DESCRIPTION OF FAUNA	AGE
104M15	C-153906	MM87-19-3	514728	6637374	contaminated by modern pollen	indeterminate
104M15	C-153907	MM87-19-4	515086	6637314	contaminated by modern pollen	indeterminate

RADIOLARIANS

Identifications by F. Cordey; Geological Survey of Canada, Pacific Section, Vancouver

NTS MAP	GSC NO.	FIELD NO.	UTM EAST	(Zone 8) NORTH	DESCRIPTION OF FAUNA		AGE
104M9E		MMI89-58-4-1A	553600	6613200	Radiolarians	***Triassocampe* sp.**	Middle or Upper Triassic
104M9E		MMI89-58-4-1B	553600	6613200	Radiolarians	***Pseudostylosphaera* sp.**	Middle or Upper Triassic (Lower Ladinian to Upper Carnian)
104M9E		MMI89-58-4-1C	553600	6613200	Radiolarians	***Pseudostylosphaera* sp.**	Middle or Upper Triassic (Lower Ladinian to Upper Carnian)
104M9E		MMI89-58-4-2	532000	6613125	Radiolarians	***Capnodoce* ? sp.**	Triassic (Lower Ladinian to Upper Carnian)
					Radiolarians	***Oertlispongus* ? sp.**	
					Radiolarians	***Pseudostylosphaera* sp.cf. *compacta***	
					Radiolarians	***Pseudostylosphaera* sp.cf. *japonica***	
					Radiolarians	***Pterospongus* ? sp.**	

Appendix C.
Provenance & Paleoflow analysis

Provenance and paleoflow analyses of the Laberge Group were conducted in order to help constrain the tectonic history of the Tagish area. These analyses augment and generally confirm previous basin analysis studies conducted by Wheeler (1961), Bultman (1979), Dickie (1989) and Johannson (1994).

Methods

A suite of 60 Laberge Group samples were gathered from which 26 coarse sandstones were selected for detailed analysis. These represent the regional distribution and time range of the Whitehorse Trough (Figures 9-4, AC1). All samples were thin sectioned, stained for potassium using the standard cobaltinitrite technique and point counted using the Gazzi-Dickenson method. Data from the previous field studies of Bultman (1979) and Dickie (1989) supplement the results of this report; particularly paleocurrent data. Conglomerate provenance data (Bultman, 1979; Dickie, 1989) are compared with wacke provenance data.

Prior to point counting, thin section studies provided identification of constituent types, especially lithic fragments and the amounts and types of matrix and cements. Petrographic observations guided classification of point counting parameters which are listed in Table AC1. These parameters and criteria for their identification are described by Dickinson (1970), Graham (1976), Ingersoll (1978), and Ingersoll and Suczek (1979). For each thin section a minimum of 400 points were counted, using a 1-millimetre grid spacing. The Gazzi-Dickinson method was used to minimize discrepancies introduced by comparing samples of varying grain size (Ingersoll *et al.*, 1984).

Identification of volcanic fragment types was made difficult by devitrification and/or diagenetic alteration. Reliability of identification was maximized by comparing the thin sections with thin sections of possible volcanic source rocks. Despite these difficulties, the trends in clastic detrital modes are considered reliable.

Results of constituent analyses

Relative proportions of sand and sandstone framework components plotted on triangular discrimination diagrams can be effective in resolving provenance terranes in various plate tectonic settings. Constituent axes for various discrimination plots discussed below are shown in Table AC2.

Burial diagenesis had little affect on most grains, although diagenetic alteration was observed in some samples, only the matrix component was significantly altered. Commonly, calcite replaces matrix materials, plagioclase and potassium feldspars are sericitized and plagioclase is saussuritized. Plagioclase is a dominant constituent of all of the samples analyzed. Compositions determined by the A-normal method are commonly andesine, but range to oligoclase. Normal zoning is typical. Results of the framework modal analyses are presented in Figure AC2a-e.

Magmatic arc provenance fields can be divided into undissected, transitional and dissected domains as demonstrated empirically in modern analogues by Dickinson and Suczek (1979). Boundaries of these fields are limited by (F+Q)/L=X ratios as follows: $X<0.75$ for undissected, $0.75<X<1.50$ for transitional, and $X>1.50$ for dissected magmatic arc provenance. Samples plotted in Figures C-2a, b are divided into these fields as indicated by the symbols. In general there is a good correlation between the proportion of quartz or plutonic components and the (F+Q)/L ratio. A direct relationship between age and (F+Q)/L ratio is an expected consequence of continued erosion of the arc source area through time. Only in the

Table AC1. Categories used for point-counts

monocrystalline quartz	(Qm)
polycrystalline quartz;	
stretched metamorphic	(Qps)
polycrystalline quartz;	
recrystallized metamorphic	(Qpr)
plagioclase	(P)
potassium feldspar	(K)
monocrystalline phyllosilicate	(P)
monocrystalline heavy (dense) mineral	(D)
lithic fragments	(L)
volcanic lithic fragment	(Lv)
microlitic acidic volcanics	(Lvm)
trachytic acidic volcanics	(Lvt)
amygdaloidal acidic volcanics	(Lva)
intermediate to basic volcanics	(Lvib)
metamorphic lithic fragment	(Lm)
schists	Lms)
quartz-feldspar aggregates	(Lmq
quartz-feldspar-mica aggregates	(Lqfm)
sedimentary lithic fragments	(Ls)
Fine-grained	
shale and siltstone clasts	(Lsf)
coarse-grained	
(sandstone, granule cong.) clasts	(Lsc)
carbonate grains	(Lsca)
unidentified	(U)
matrix	(M)
cement	(C)

Table AC-2. Axis definitions for sandstone descrimination diagrams

Q=Qm+Qp	where	Q = total quartzose grains
		Qm=monocrystalline grains
		Qp = polycrystalline grains
F = P+K	where	F = total feldspar grains
		P = plagioclase grains
		K=potassium feldspar grains
L=Lm+Lv+Ls	where	Lm = metamorphic grains
		Lv = volcanic grains
		Ls = sedimentary grains
Lt = L+Qp	where	Lt = total labile grains
		L = labile lithic grains

Mount Cameron area are fossil data, stratigraphic control and point count data sufficient to test its application (Figure AC1). Although there is considerable stratigraphic overlap between the fields, there is a good correlation between youngest strata and the highest (F+Q)/L ratio. "Dissected magmatic arc" samples represent the highest stratigraphic position of any sample point counted, while the "undissected" and "transitional" samples lie low in the stratigraphy or in a possibly older fault slice. Although, the number of samples analyzed is insufficient to fully test the applicability of the (F+Q)/L ratio as an indicator of stratigraphic position in lieu of fossil control within the Laberge Group, these preliminary results are promising. However, overlapping strata from various depocentres are likely to yield contradictory results, so unless dissection of the arc source terrain proceeded at a consistent rate along its length, this method will be useful only for individual depocentres.

The quartz-feldspar-labiles (QFL, Figure AC2a) ternary plot of Laberge clastics demonstrates a magmatic arc provenance (Dickinson and Suczek, 1979). This diagram emphasizes chemical and mechanical grain stability with samples 2, 11 and 15 displaying relatively high proportions of recycled or stable acomponents. Up-section, there is a transition from arc to dissected magmatic arc origin. The (F+Q)/L ratios show a trend to increasing proportions of monocrystalline mineral grains derived from plutonic rocks relative to polycrystalline lithic fragments derived from volcanic rocks.

In the QmFLt ternary plot (Figure AC2b), polycrystalline quartz grains (Qp) are removed from the quartz (Q) axis and added to the total labile (Lt) axis. In effect, this plot tests for skewing as a result of fine-grained polycrystalline quartz grains of uncertain origin. For example, the few samples that plot near the "Recycled Orogen" field of the QFL diagram may actually be fine-grained rock fragments not derived from a stable orogen but from devitrified rhyolite for example, in which case an arc source is confirmed. The effect of adding Qp to Lt and removing it from Q is to decrease F+Qm/Lt ratios. The net result produces no shift between magmatic provenance types. Except for the few quartz-rich samples, close correlation of results between Figures C-2a and C-2b illustrates that grain size of the source rocks has little or no influence on the grain stability and thus weathering, gradient and transport mechanism. Thus, a nearby, rapidly eroded source is indicated.

Polycrystalline framework grains are distinguished on the QpLvLs diagram (Figure AC2c; Dickinson and Suczek, 1979). It is particularly useful in distinguishing magmatic arc suites from collisional orogen suites. Plotted data clearly suggest an arc source with samples clustering around the volcanic grain (Lv) pole.

The LmLvLs diagram (Figure AC2d) yields similar results. Substitution of metamorphic grains (Lm) for monocrystalline quartz grains (Qm) shows that either most labile metamorphic grains are winnowed out, leaving only polycrystalline quartz grains to represent the metamorphic source terrane, or that polycrystalline quartz grains are not from metamorphic sources. Perhaps, metamorphic source terrane contributions are insignificant or are overshadowed by a copious supply of volcanic sediment from rapid arc denudation.

Monocrystalline framework components plotted on the QmPK diagram (Figure AC2e) show a clustering of samples around the P axis, consistent with a predominantly volcanic source as indicated by Figure AC2c. Again, systematic increase in the Qm/F ratio points to an increasing importance of plutonic detritus due to uplift and dissection of the magmatic arc.

Paleoflow

Paleoflow information gathered during regional mapping augments the point counting results. Sparse fossil control enables age constraints to be placed on the system. From the combination of such data a picture of Laberge Trough sedimentation and provenance area evolution can be developed. Data are incorporated from Wheeler (1961), Bultman (1979) and Dickie (1989), particularly for areas outside of the map area, in order to create a more regional picture of Laberge Trough evolution.

Paleocurrent data collected were selectively restricted to quantitative and qualitative unidirectional indicators of the current direction during deposition. These indicators consisted of scour or tool marks (Photo 9-10), imbrication (9-11) and ripple or trough cross - stratification (Photo 9-8) in finely laminated, thinly bedded, fine-grained greywackes and argillites. A unidirectional paleoflow measurement was not accepted unless cross-stratification features were exposed in at least two dimensions and unique trough axes or ripple crests could be determined.

Paleocurrent restoration was performed manually on a Lambert equal-area stereonet. Sites of paleocurrent measurement were evaluated to determine the possible extent of post-depositional tectonic influence. Beds and paleocurrent indicators were restored to the most appropriate pre-tectonic position. Restored paleocurrent directions are illustrated in Figure 9-4.

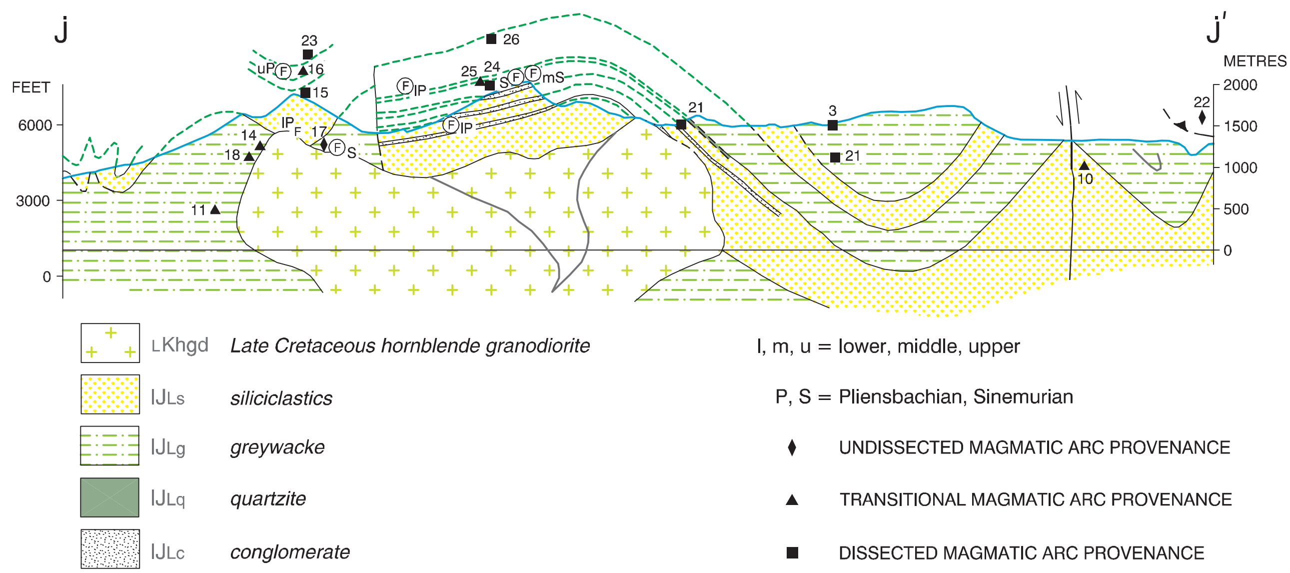


Figure AC1. Location of dated fossils and provenance sample sites on cross section j-j' through Mount Cameron (the cross section is located on Figures 2-1 and GM97-1). Note that Sinemurian to Upper Pliensbachian Laberge Group strata are represented; only Toarcian strata are missing at this locality.

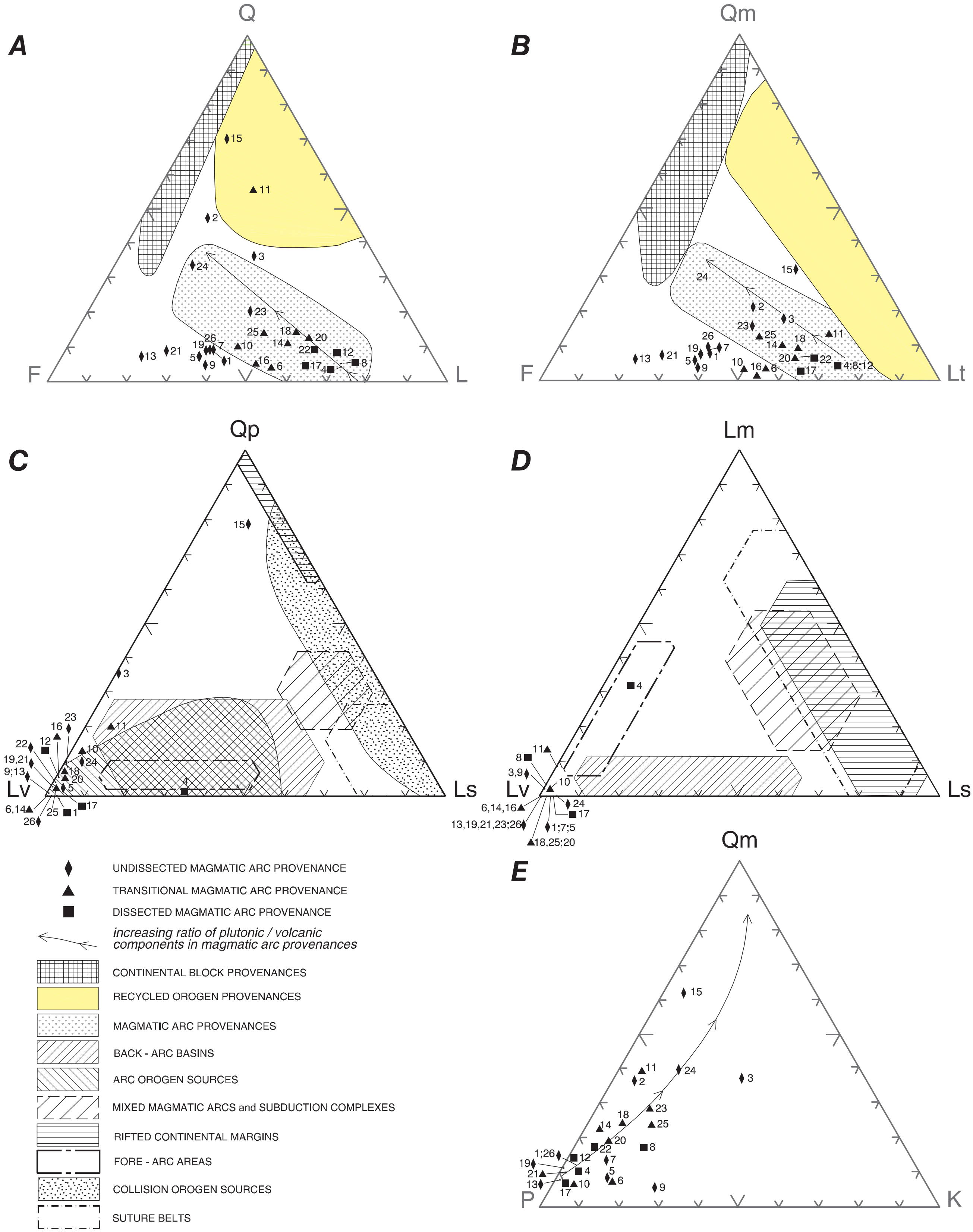
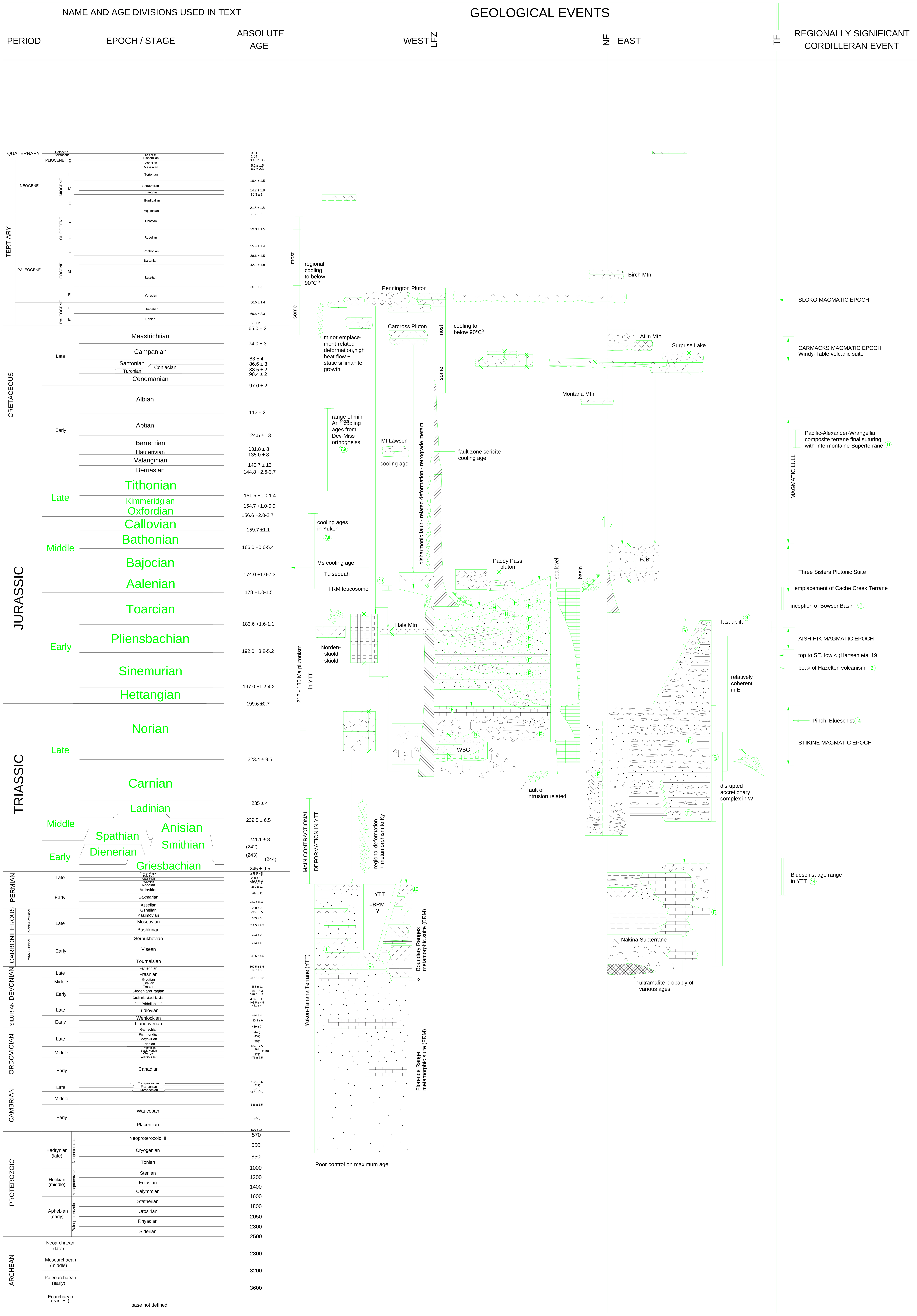


Figure AC2. Provenance plots (see text for explanation).



BC Ministry of Energy and Mines

Geological Survey Branch

FIGURE TC-1

To Accompany Bulletin 105

GEOLOGICAL EVENT SYNOPSIS

LEGEND

- Calc-alkaline volcanics, intermediate
- Calc-alkaline mafic + felsic tuffs (in metamorphic rocks = tuffs +/or flows of unknown chemical affinity) — felsic / mafic
- Subalkaline to shoshonitic
- Subalkaline to shoshonitic pillow basalt
- Ultramafite
- Conglomerate
- Chert breccia
- Siltstone/pelite
- Sandstone or quartz-rich schist/gneiss
- Carbonaceous schist and quartzite
- Pelite/pelitic schist
- Chert
- Limestone/marble
- Wacke
- Undivided plutonic rocks
- Hornblendite and hornblende-pyroxene gabbro
- Orthogneiss

- Llewellyn Fault zone — LFZ
- Nahlin Fault — NF
- Teslin fault — TF
- Fourth of July batholith — FJB
- Surprise Lake batholith — SLB
- Willison Bay granodiorite — WBG

- Best magmatic age estimate + error limits from isotopic data
- Best stratigraphic age estimate + error limits from fossil data
- Age control: certain, probable, uncertain
- Intrusive ties: uncertain, certain
- Stratigraphic ties: uncertain, certain
- Fossil occurrence

- a Shallow water clam beds
- b For discussion of apparent age conflict see Chapter 8
- F1 Monger, 1975
- F2 Cordey, 1990
- F3 Cordey et al., 1991
- F4 Jackson, 1992

Sources of Information

1. Mortensen, 1992
2. Rickets et al., 1992
3. Donelick, 1988
4. Paterson and Harakel, 1974
5. Currie, 1991
6. Tipper, 1984
7. Hansen et al., 1988
8. Foster et al., 1987
9. Hansen, 1990
10. Currie, 1994
11. Currie and Perscanni, 1992
12. Armstrong, 1988
13. Monger, 1975
14. Erdmer and Armstrong, 1988

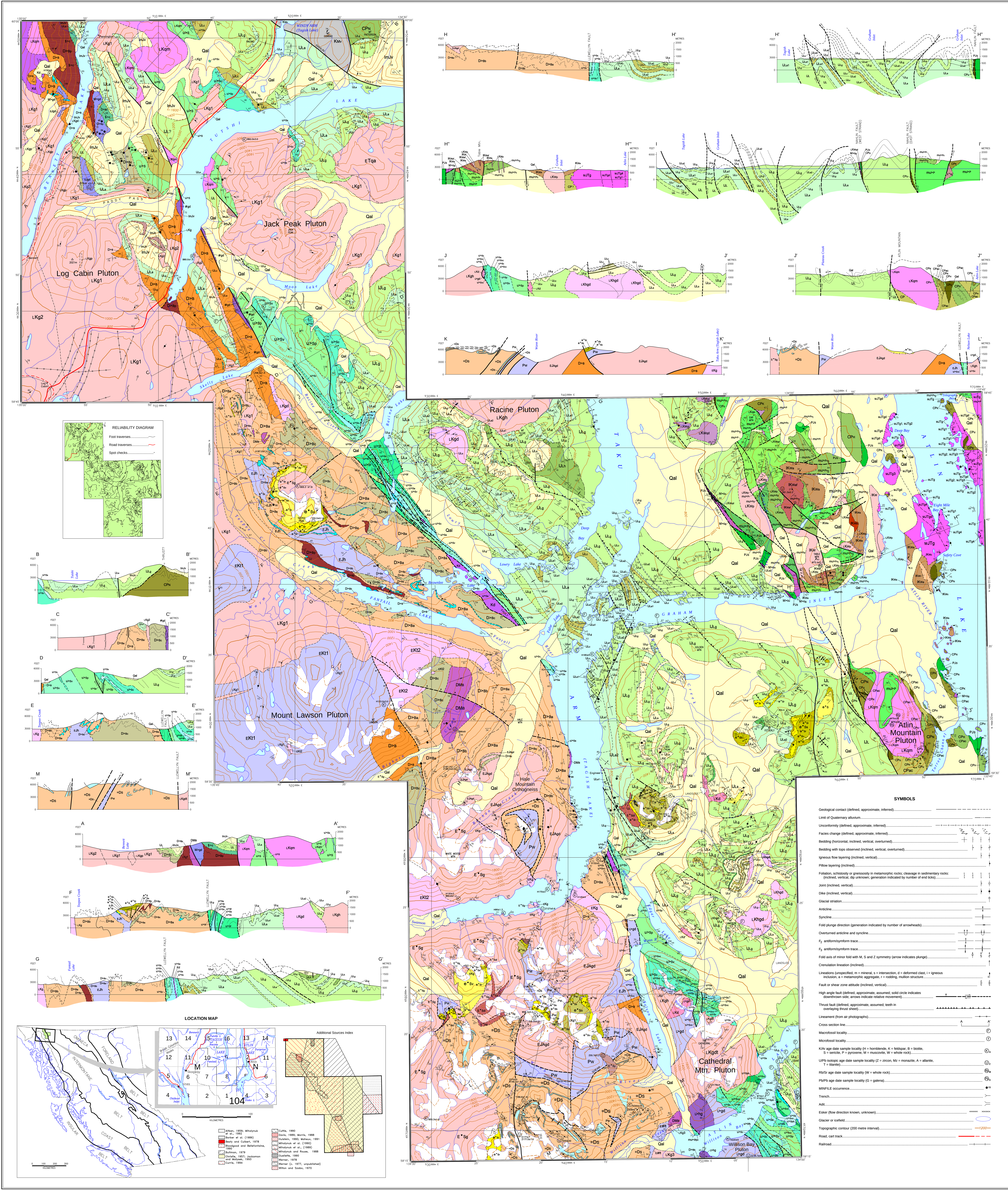
approximate fault offest

sinistral dextral

100 0 100 kilometres

subsidence curves

subarial submarine



Ministry of Energy and Mines
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Geological Survey Branch

Geological Survey Branch

FIGURE GM97-1

To Accompany Bulletin 105

(Updated from Geoscience Map 1997-1)

GEOLOGY OF THE TAGISH LAKE AREA

NTS (104M/8, 9, 10E, 15 & 104N/12W)

Compiled by: M.G. Mihalynuk

Geology by: M.G. Mihalynuk, K.J. Mountjoy, L.D. Currie, M.T. Smith and J.N. Rouse.

SCALE 1:100 000

LEGEND

LAYERED ROCKS

QUATERNARY

Qal — Unconsolidated glacial till and poorly sorted alluvium; sparse gold flakes and nuggets are reported at Graham Creek and Moon Creek.

EOCENE

SLOKO GROUP (c. 55 Ma)

METASEDIMENTARY AND METAVOLCANIC SUITES (continued)

PROTEROZOIC TO ?DEVONIAN NISLING ASSEMBLAGE

=Ds — Florence Range metamorphic suite (undivided): mainly pelitic and semipelitic rocks with carbonate, amphibolite, quartzite and minor calcsilicate and graphite-bearing semipelitic rocks. Metapelites in layers 0.1 to 30 m thick may contain sillimanite and pseudomorphed kyanite. Amphibolite is spatially associated with carbonate in 0.1 to 20 m thick layers.

=Dsq — Impure meta-quartzites: quartz-rich biotite schists texturally indistinguishable from D>Bb typically < 10% biotite and < 20% feldspar.

Marble: carbonate layers up to several hundred metres thick, medium-grained; resistant, white, yellow, orange and tan-weathering (thicknesses may be exaggerated for presentation).

INTRUSIVE ROCKS

REFERENCES AND ADDITIONAL SOURCES