# Atlin TGI Part II: Preliminary Results from the Atlin Targeted Geoscience Initiative, Nakina Area, Northwest British Columbia

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***KEYWORDS:*** *Regional geology, aeromagnetic, mineral potential, resource, volcanogenic massive sulphide, geochemistry, fossil, geochronology, Cache Creek Terrane, Atlin, Nakina, oceanic arc, seamount, mélange, accretionary complex.*

## INTRODUCTION

In 1898, Fritz Miller and his partner Kenneth McLaren discovered rich placers near the town site of Atlin (Bilsland, 1952). Since that time, placer mining and vein lode exploration have been an important economic force in the region, and economic vitality has been largely determined by the price of gold. Economic diversification in the mining sector has not materialized, as exploration for commodities other than gold has been comparatively minimal, despite prospective geological environments in the area.

In 1999, the Atlin area was selected, along with several others across Canada, under the federally funded Targeted Geoscience Initiative (TGI), as one of those most likely to benefit from a modernized geoscience database. The Atlin TGI was launched in 2000 with a regional aeromagnetic survey of the entire Atlin map sheet, about 14000 square kilometres (Dumont *et al.*, 2001a; b; c and 13 others). In 2001, a regional geological mapping program was launched under the TGI with joint federal, provincial, and university support. Scientists from the British Columbia Geological Survey Branch, Canadian and European universities, and the Geological Survey of Canada have contributed to this mapping effort. The first published results are presented here together with a synopsis of aeromagnetic survey results. These results show that the area harbours potential for mineralization other than placer gold. For example, new mapping has revealed an extensive magnetite exhalite, as well as submarine felsic volcanic rocks, both of which are known to occur in the neighbourhood of polymetallic massive sulphide accumulations.

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## LOCATION, ACCESS AND PHYSIOGRAPHY

Regional geologic mapping at 1:50 000 scale was conducted across the southeast corner of the Atlin mapsheet in the Nakina Lake - Nakina River area, NTS mapsheets 104N/1 and 2. NTS mapsheet 104N/3 is scheduled for mapping in 2002. These three mapsheets are herein referred to as the Nakina area. When mapping is completed it will encompass an area between 38 and 115 kilometres southeast of the town site of Atlin (Figure 1).

Access to the Nakina area is most effectively achieved by use of helicopter, available for charter in Atlin. Parts of the area can also be accessed from lakes that are large enough for floatplanes. There are no all-season roads within the area. One road extends to the northern limit of 104N/3, but it requires fording the O'Donnel River during low water and is suitable only for four wheel drive or all-terrain vehicles. The old Telegraph Trail was cut diagonally across the western two thirds of the study area (104N/2 and 3) between 1900 and 1902 (Bilsland, 1952), but it has long since fallen into disuse and is thoroughly overgrown in most places. Likewise, the Taku Trail that joined Atlin with tidewater on Taku Inlet and followed the Silver Salmon River in the Nakina area has overgrown with the ebb of traffic in the post gold rush era.

Once in the Nakina area, travel by foot is easy, particularly on dry south-facing slopes where fir, spruce, aspen and pine forest are open, or where recent forest fire scars have yet to be established with willow, alder and dwarf birch. North-facing or poorly drained slopes can be a challenge, particularly near tree line where they are a tangle of stunted spruce. Precipitous canyons and white water impede travel across the lower Nakina River, Horsefeed Creek and "Paint Creek" (Photo 1; Figure 2; note that informal place names are enclosed in quotes).

From east to west, the area spans parts of the low, swampy Kawdy Plateau and the elevated, deeply dissected Taku Plateau. Most of the area is below tree line, which is around 1400 metres elevation. Mountain peaks are mainly less than 1900 metres elevation, although Paradise peak, just outside the western boundary of the area, is over 2180 metres. Most mountain slopes are easily negotiated.

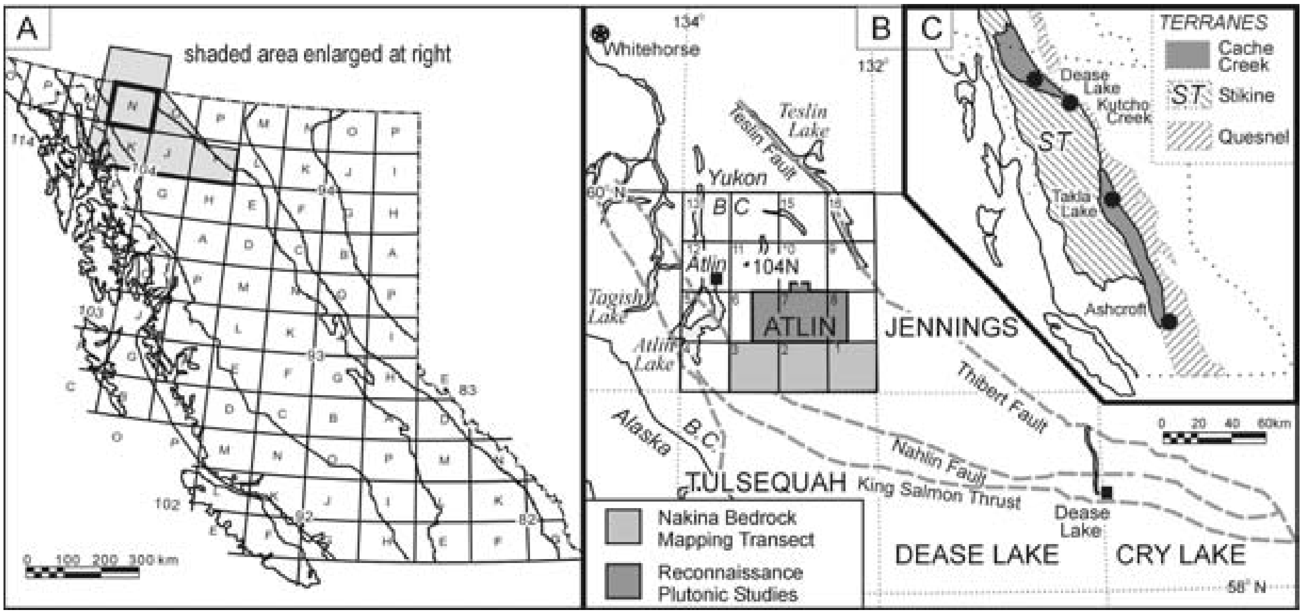


Figure 1. A. Location of the Atlin Integrated Geoscience Project in northwestern British Columbia. Bold outlined box (104N) shows extent of aeromagnetic survey. Regional geologic setting of the Atlin area. B. Regional geological mapping surveys were conducted over the eastern and central Nakina transect (104N/1 and 2). Reconnaissance plutonic studies covered parts of 104N6, 7, 8 and 10. C. Distribution of Cache Creek Terrane in BC and Yukon.

Photo 1. Deeply incised plateau underlain by carbonate of the Horsefeed Formation.

## PREVIOUS WORK

Much of the Atlin area is underlain by oceanic crustal rocks of the Cache Creek Terrane (Coney *et al.*, 1980). Existing regional map coverage is of early to mid 1950's vintage (Aitken, 1959), pre-dating the advent of plate tectonics. Thematic revision mapping in the mid to late 1960's by Monger (1975) covered a significant portion of the central Nakina area. Monger (1975) focused on the Paleozoic stratigraphy, and suggested that the Nahlin mafic and ultramafic rocks may be obducted ocean basin crust.

Terry (1977) argued that the Nahlin body is part of a classical ophiolite, analogous to the Pindos ophiolites of Greece. Ash (1994) drew similar conclusions based on study of the ultramafic rocks near the town site of Atlin. The tectonic history of the Cache Creek Terrane within a Cordilleran context is presented in Mihalynuk *et al.* (1994).

A compilation of Atlin geology was completed as part of a provincial mineral potential evaluation (Mihalynuk *et al.*, 1996). Sources of information drawn upon for the compilation include mineral tenure assessment reports, 1:50 000 scale revision mapping (Lefebure and Gunning, 1988; Bloodgood and Bellefontaine, 1990; Mihalynuk and Smith, 1992) and regional stream sediment survey results. Results of reanalysis of archival Regional Geochemical Survey (RGS) stream sediment samples were recently released for the Atlin area (Jackaman, 2000). Unlike the old RGS data, these new data include a broad suite of elemental determinations including many rare earth elements and gold.

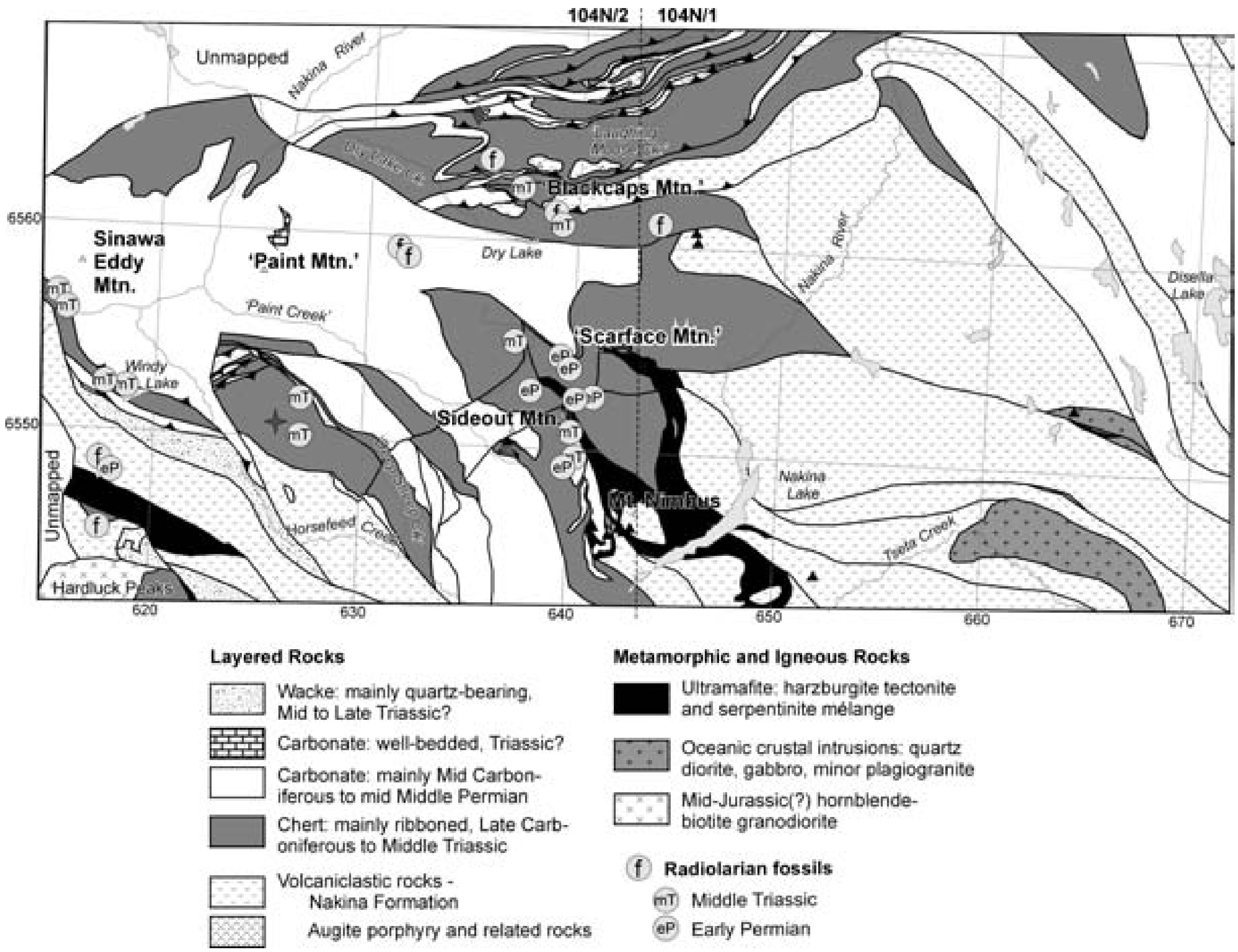


Figure 2. Generalized geology map of the Nakina map area based on fieldwork in 2001.

## REGIONAL GEOLOGY RESULTS

At this reporting, 1:50 000 scale mapping is nearly complete for 104N/1 and about 70% complete for 104N/2. In general, the map area consists of an eastern mafic volcanic-dominated oceanic crustal domain and a western carbonate platform. Between these is a serpentinite mélange belt, and north of these is a heterolithic domain. Harzburgite of the Nahlin ultramafite crops out in south western-most corner of map sheet 104N/2 where it is structurally overlain by a basalt-diorite complex. This complex is separated from the carbonate platform by a beltof structurally intercalated volcaniclastic rocks, chert and wacke that are interpreted as part of an accretionary prism. Regional metamorphic grade is prehnite-pumpellyite facies. Biotite-actinolite grade rocks observed along the eastern margin of the map area may be attributed to contact metamorphism due to nearby intrusions. Thermal upgrading is also observed in the northern map area where it may be due to buried intrusions or an older regional (ocean floor) hydrothermal system.

## NOMENCLATURE OF REGIONAL MAP UNITS

Almost all of the Nakina transect lies within the “southwestern facies belt” of the Cache Creek Terrane (Monger, 1975). Monger (1975) considered the this facies belt as consisting of three formations: thick lenses of Mississippian to Permian Horsefeed Formation carbonate; chert and pelite of the KedahdaFormation that host the carbonate lenses; and mafic volcanic rocks of the Nakina Formation that are intercalated with and underlie the Kedahda Formation. Much of the northern Cache Creek Terrane, especially along its margins, is highly disrupted and most units are bounded by faults. Various lithologies occur as structurally inter-leaved panels, as spectacular mélanges, and as polymictic breccias. Thus, difficulties arise in applying formal rock-stratigraphic nomenclature to the Cache Creek Terrane. Monger (1975, page 2) addressed these issues and elected to apply uniform nomenclature over the entire northern Cache Creek Terrane, conforming as much as possible to original usage (*e.g.* Watson and Mathews, 1944). We continue to use Monger's formation names within the bounds of their stated limitations, acknowledging that formation designations are locally inappropriate (Figure 2). In some areas, new age, geochemical and map data demand that we define separate units. As more such data becomes available, future workers will probably be forced into finer subdivisions, as is done for the accretionary belts of Japan (*e.g.* Isozaki *et al.*, 1990). Indeed, English *et al.* (2002, this volume) argue that volcanic rocks included in the Nakina Formation comprise assemblages that may have formed in disparate tectonic settings, and they have assigned local geographic names to distinct volcanic assemblages.

## *OCEANIC CRUST: INCLUDING NAKINA FORMATION*

Rocks included in the oceanic crustal domain include primitive basalt and ultramafic rocks typical of oceanic crust. However, they lack pillowed flows and sheeted dikes of a classical ophiolite succession (although knockers comprised of dikes within dikes are found in the serpentinite mélange belt). The dominant unit of the oceanic crustal domain is Nakina Formation basaltic volcaniclastic rocks. These rocks are the focus of a paper by J. English *et al.* in this volume, and are dealt with here in only a cursory fashion. Basaltic rocks are interleaved with less abundant diorite, gabbro and rare plagiogranite. Basalt is comprised mainly of lapilli and ash-sized fragments which have been altered, commonly to prehnite, pumpellyite and chlorite. Less common are authigenic carbonate, and in the eastern portions, actinolite. Strongly weathered outcrops are orange, dark brown or olive green. Fresh surfaces are a distinctive mint green colour with grey and pink filaments (fine shear bands with clay and iron oxides). Homogeneous regions of volcanic rock locally form entire mountainsides. Locally this unit contains exotic clasts of diorite, chert, and rare carbonate.

Gabbro and diorite occur as isolated intrusions. Only rarely are tabular intrusive bodies seen cutting the volcaniclastic rocks. Gabbro and diorite are most abundant in the southeast and southwest corners of the map area where they are discontinuously exposed over areas of up to 40 $km^2$. They also occur as knockers in the serpentinite mélange where they range from a metre to hundreds of metres in long dimension. In the poorly exposed eastern map area, the covered spaces between outcrops could be underlain by less resistant units, such as ribbon chert or serpentinite. However, juxtaposition of such contrasting magnetic lithologies should disrupt the magnetic field. As no such disruption is observed (see Aeromagnetic Survey Results below), large bodies are shown on Figure 2.

Gabbro and diorite are medium-grained plagioclase and pyroxene or amphibole-phyric rocks; pyroxene is porphyritic in some samples. Ophitic and diabasic textures are common. Pyroxenes show exsolution lamellae and are probably calcic augite. Plagioclase is variably altered, from fresh to totally turbid; authigenic minerals include white mica, prehnite, quartz and carbonate. Mesoscopic and microscopic strain zones with semi-ductile to brittle deformation are common.

Plagiogranite occurs as a plexus of thin, irregular pegmatitic dikes cutting dioritic rocks in southern 104N/1, and as medium-grained knockers within the serpentinite mélange. Petrographic analysis of the pegmatitic plagiogranite shows that it is composed of fresh plagioclase and hornblende with 10% interstitial quartz and accessory titanite. Weak chlorite alteration affects the edges of some of the hornblende crystals. U-Pb and $^{40}Ar/^{39}Ar$ isotopic age dates are pending.

Tectonized harzburgite forms a 1.5 km thick tabular body with an exposed length of 10 kilometres in southwest 104N/2. Considered part of the Nahlin ultramafite (Terry, 1977), it is a resistant, poorly vegetated, dun-weathering body with strongly foliated zones. Lineated bastite (serpentinized enstatite orthopyroxene) are up to 2cm in long dimension, in a matrix of serpentinized olivine (Photo 2). Subidiomorphic chromite grains occur in streaky clusters several millimetres across. Magnetite is not common. Harzburgite also occurs as knockers, generally less than 2 m in diameter, within the serpentinite mélange belt. A 30 cm thick dunite dike intrudes one knocker, composed primarily of chilled diabase dikes.

## *KEDAHDA FORMATION CHERT SUCCESSIONS*

Chert occurs throughout the map area. It is typically ribboned, black, grey, green or tan - weathering, with similarly coloured fresh surfaces. Outcrops are commonly rusty and rubbly, forming tenuous spires on steep slopes. Locally the chert is massive and blocky-weathering. Massive chert is normally black in colour.

Ribbon chert occurs as irregular 1-15 cm thick chert layers alternating with 0.2 - 2 cm argillaceous layers (Photo 3). Exceptions are common as chert beds can reach a metre or more in thickness; rarely chert beds are continuous and

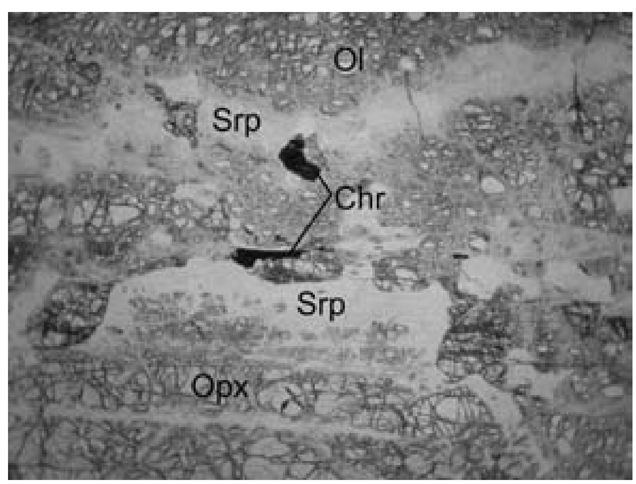

Photo 2. Photomicrograph of serpentinized harzburgite showing orthopyroxene (Opx) and olivine (Ol) now altered to serpentine (Srp). Chromite (Chr) is a common accessory. Long dimension of the photo represents 4 mm.

Photo 3. A representative view of well bedded ribbon chert. Note tight fold hinge (under hammer) plunging towards photographer.

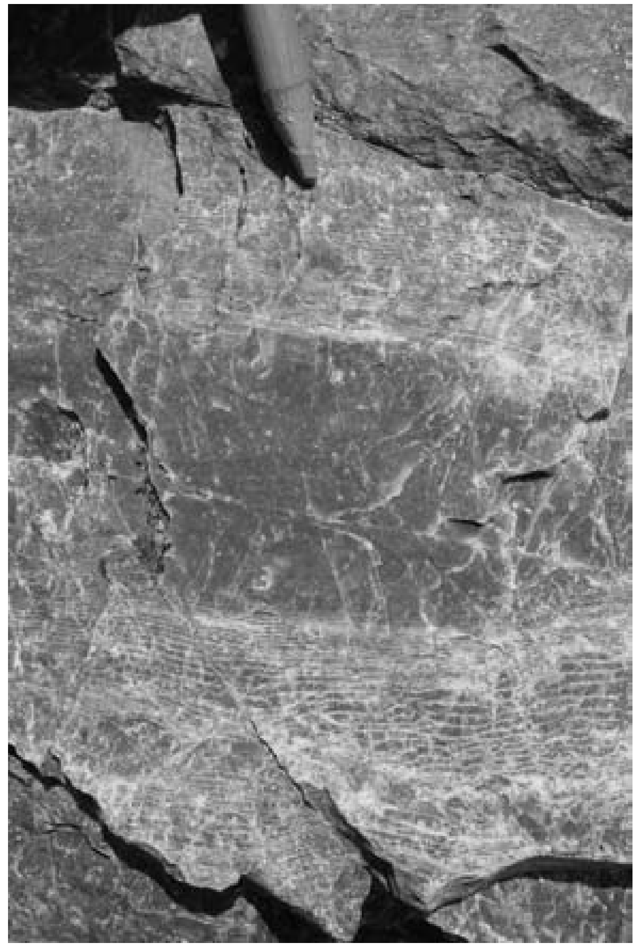

Photo 4. Well laminated chert probably originated as argillite, now silicified.

ruler straight. Massive chert may display fine, millimetre-thick laminae (Photo 4), possibly indicating an argillite progenitor that was subsequently silicified.

Ribbon chert is the dominant lithology in some highly disrupted zones where it is admixed with other lithologies, particularly volcaniclastics. Some of these disrupted zones may be "broken formation", a lithology typical within accretionary prisms.

Radiolaria are common in most ribbon chert, less common in massive chert and uncommon in laminated chert. Preliminary radiolarian identifications indicate ages of Early Permian to Mid Triassic; although ages of Late Carboniferous and Upper Triassic are possible (Table 1). Most radiolaria are of Middle Triassic age and Early Permian chert is also common. Late Permian and Early Triassic forms have not been conclusively identified. Age determinations are based upon field identifications and will be refined further (by F.C. at UCB, Lyon, France).

## *HORSEFEED FORMATION - CLASTIC CARBONATE*

Horsefeed Formation carbonate rocks are located in the eastern, western and northern parts of the map area. In the east (104N/1E), extensively recrystallized carbonate occurs in three poorly exposed, north-northwest-trending belts of carbonate outcrops. In the west (south and central 104N/2), massive to thick-bedded and locally well-bedded and fossiliferous carbonate successions are dissected by the Nakina River and Horsefeed and "Paint" creeks, providing the most complete sections of the Horsefeed Formation. In the north (northwest 104N/1 and northeast 104N/2), fault-bounded panels carry sparsely fossiliferous limestone that is intercalated with volcanic rocks and chert.

Carbonate of the western map area is dominated by massive calcarenite, shallow water fusulinid packstone, turbiditic calcareous sandstone, conglomerate and micrite. One apparently homoclinal, sparsely fossiliferous carbonate section north of upper Horsefeed Creek exceeds 2800m in thickness. However, thrust repetitions that are common elsewhere in the carbonate package may thicken this sec-

## TABLE 1
## PRELIMINARY RADIOLARIAN IDENTIFICATIONS AND AGE DETERMINATIONS PERFORMEDIN THE FIELD

| Sample Number | UTM east | UTM north | ± | Lithology | Preser-vation | Radiolarian taxa | Age |
|---|---|---|---|---|---|---|---|
| FCO01-17-11 | 627845 | 6550565 | | ribbon chert | poor | *Triassocampe* sp. | Middle or Late Triassic |
| FCO01-17-5 | 627465 | 6552526 | 7 | ribbon chert | moderate | *Triassocampe* sp.<br>*Yeharaia* sp. | Middle Triassic |
| FCO01-18-1 | 637094 | 6555462 | 7 | grey ribbon chert | good | *Plafkerium* sp.<br>*Praesarla* sp.<br>*Yeharaia* sp. | Middle Triassic |
| FCO01-23-1a | 631228 | 6560060 | 8 | ribbon chert contact w. breccia | poor | unidentified spumellarians | Phanerozoic |
| FCO01-23-1b | 631228 | 6560060 | 8 | ribbon chert contact w. breccia | poor | *Entactinia* sp.<br>?*Scharfenbergia* sp. | possibly Late Paleozoic |
| FCO01-27-4 | 617145 | 6552880 | | black ribbon chert | moderate | ?*Pseudostylosphaera* sp.<br>*Triassocampe* sp. | Middle or Late Triassic |
| FCO01-27-5 | 619073 | 6551883 | | black ribbon chert | moderate | *Sarla* sp.<br>*Triassocampe* sp.<br>*Yeharaia* sp. | Middle Triassic |
| MMI01-10-2 | 639744 | 6547919 | 6 | ribbon chert | good | *Latentibifistula* sp.<br>*Pseudoalbaillella scalprata* | Early Permian |
| MMI01-10-4 | 640237 | 6548581 | 4 | ribbon chert | fair | ?*Plafkerium* sp.<br>*Pseudostylophaera compacta*<br>*Triassocampe* sp. | Middle Triassic |
| MMI01-10-7 | 640470 | 6548881 | 5 | small clast of red chert | poor | unidentified spumellarians | non diagnostic |
| MMI01-18-3a | 614817 | 6556399 | 8 | ribbon chert | moderate | *Plafkerium* sp.<br>*Praesarla* sp.<br>*Triassocampe* sp.<br>*Yeharaia* sp. | Middle Triassic |
| MMI01-18-3b | 614817 | 6556399 | 8 | ribbon chert | good | *Plafkerium* sp.<br>*Praesarla* sp.<br>*Pseudostylosphaera* sp.<br>*Yeharaia* sp. | Middle Triassic |
| MMI01-18-4b | 614906 | 6556456 | 7 | ribbon chert | moderate | *Yeharaia* sp.<br>*Praesarla* sp. | Middle Triassic |
| MMI01-23-19d | 643810 | 6561084 | | ribbon chert | poor | unidentified spumellarians | non diagnostic |
| MMI01-3-10 | 639743 | 6554556 | 4 | ribbon chert | moderate | *Latentibifistula* sp.<br>*Pseudoalbaillella scalprata*<br>*Pseudoalbaillella* sp. cf. lomentaria | Early Permian |
| MMI01-3-7 | 639819 | 6554835 | 8 | ribbon chert | good | *Pseudoalbaillella scalprata*<br>*Polyfistula* sp.<br>*Quadriremis* sp. | Early Permian |
| MMI01-4-18 | 639980 | 6553130 | | ribbon chert | moderate | *Pseudoalbaillella* sp. cf. *scalprata*<br>*Quadriremis* sp. | Early Permian |
| MMI01-4-4 | 640188 | 6551702 | 7 | ribbon chert | good | *Pseudostylosphaera* sp.<br>*Triassocampe* sp. | Middle Triassic |
| MMI01-5-1 | 641050 | 6553290 | 18 | ribbon chert | moderate | *Albaillella* sp. cf. *sinuata*<br>*Haploaxon* sp.<br>*Latentibifistula kamigoriensis*<br>*Quinqueremis* sp. | Early-Middle Permian |
| MMI01-6-11 | 638253 | 6562083 | 7 | ribbon chert | poor | unidentified spumellarians | non diagnostic |
| MMI01-6-7 | 638650 | 6561050 | 5 | ribbon chert | moderate | *Pseudostylosphaera* sp.<br>*Yeharaia* sp. | Middle Triassic |
| MMI01-6-8 | 638584 | 6561508 | 8 | ribbon chert | poor | *Triactofenestrella* sp.<br>large *Latentifistulidae*<br>spumellarians | Late Paleozoic; Carboniferous or Permian |
| MMI01-7-19 | 635165 | 6563535 | 5 | ribbon chert | poor | arms *Latentifistulidae* (large morphotypes) | Late Paleozoic; Carboniferous or Permian |
| MMI01-7-6a | 636692 | 6562413 | 5 | ribbon chert | moderate | *Triassocampe* sp.<br>*Yeharaia* sp. | Middle Triassic |
| YME01-2-1a | 617234 | 6548431 | | ribbon chert | poor | *Latentifistulidae* | Late Paleozoic; Carboniferous or Permian |
| YME01-2-1b | 617234 | 6548431 | | ribbon chert | moderate | *Latentibifistula kamigoriensis*<br>*Pseudoalbaillella* sp. cf. *lomentaria* | Early Permian |
| YME01-2-9 | 617628 | 6545501 | | ribbon chert | poor | large *Latentifistulidae*<br>*Scharfenbergia* sp. | Late Paleozoic; Carboniferous or Permian |
| YME01-5-27 | 638662 | 6553152 | 8 | ribbon chert | moderate | *Latentibifistula kamigoriensis*<br>*Pseudoalbaillella* sp. cf. *scalprata* | Permian, probably Early |
| YME01-7-6 | 637681 | 6566429 | 6 | ribbon chert | poor | recrystallized spumellarians | non diagnostic |

tion. Without fossil age control, assessment of true stratigraphic thickness will be difficult.

Massive calcarenitic limestone is the most conspicuous unit in 104N/2. It is white to grey with hues of yellow. Outcrops vary from dense, smooth whalebacks to fractured rubbly slopes. A sense of layering can commonly be seen from a distance, although the source of the layering is not always clear. Locally layering can be attributed to bedding, while less commonly it results from jointing. In detail, calcareous grains are comprised of foraminifera, oolites, pelloids, fragments of echinoids, fenestrate bryozoa and algae, fusulinids, and invariably, crinoid ossicles. Rare bryozoan build-ups occur within the massive carbonate. Minor accumulations of alkaline volcanic tuff and flow units within the massive carbonate occur north of Horsefeed Creek headwaters and at “Sideout Mtn.” At these localities the volcanics form a substrate on which coralline reefs nucleated. At “Sideout Mtn.”, a debris-rich back reef and a shelly/algal lagoonal facies are developed. Intense dolomitization has been observed in one locality, north of “Deep Sheep Creek”. The massive unit may have been deposited as shallow water shoals.

Thick-bedded fusulinid packstone is the characteristic unit of the western carbonate. Beds range from decimetres to several metres thick; they generally lack internal structure and rarely have distinct tops and bottoms. Nevertheless, individual beds can be traced for hundreds of metres, recognized by abundant fusulinids commonly comprising more than 80% of the rock. Fusulinids are typically 0.5 to 1 cm in diameter and are commonly best displayed at the soil line or beneath moss, probably due to etching by humic acid. Fusulinid packstone is light grey to cream coloured and is more resistant than other carbonate lithologies. One resistant set of packstone beds, 20-50 m thick, can be traced along the westernmost fault-bounded edge of the main carbonate body in western 104N/2 (Figure 2, Photo 5).

Well-bedded sections within the massive western carbonate are best displayed in the Nakina River canyon, on the flanks of Mt. Sinawa Eddy, east of “Deep Sheep Creek” and south of lower Dry Lake Creek. Of these, the most continuous exposures are on the south and west flanks of Mt. Sinawa Eddy (Photo 6).

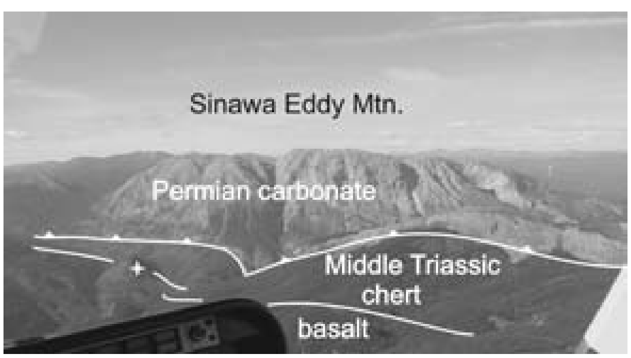


Photo 5. A view to the north of resistant fusulinid packstone beds of Permian age in fault contact with Middle Triassic ribbon chert. Photo 6 is a view of southwestern Sinawa Eddy Mountain, taken from the location denoted by the star.

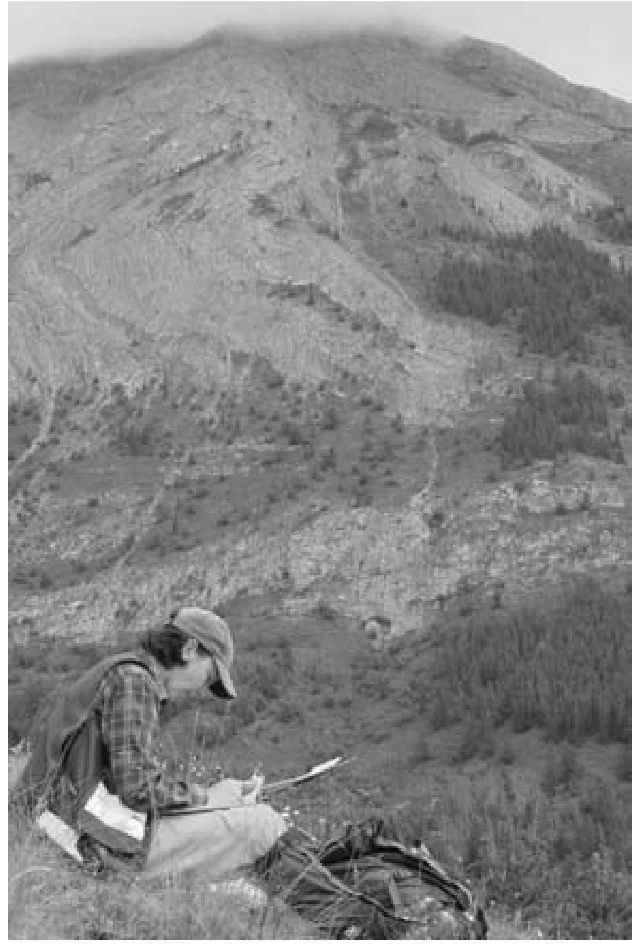

Photo 6. Well-bedded carbonates on Sinawa Eddy Mountain. View is to the northeast.

## *AUGITE PORPHYRY UNIT*

A prominent unit of coarse augite porphyry breccia and ash tuff is repeated by folding and faulting in the “Laughing Moose Creek” area, where it is a key marker unit used to define the fold and thrust belt developed in that area. It forms dark green, locally orange weathering, highly compact, blocky outcrops with joint spacing in excess of 2m. Euhedral augite is conspicuous and crowded in some fragments. A compaction fabric and subparallel tuffaceous layering are common and may reflect rapid deposition and cooling during compaction.

Map patterns indicate thicknesses in excess of 250 m; however, folding probably thickens the unit in these areas. Where both the upper and lower contacts are exposed, the true stratigraphic thickness is between 15 and 80 metres. Basal contacts are with chert. Topographic irregularities and the local development of chert cobble conglomerate at lower contact point to an erosional unconformity. Near its southernmost occurrence, a 3 to >5 m thick lahar sits on the chert (the contact is not well exposed). Farther to the north, along a creek west of “Laughing Moose Creek”, the contact chert unit rests on rhythmically interbedded, turbiditic limestone granule conglomerate and argillaceous chert that is several tens of metres thick. A paleochannel within the rhythmically bedded section is 30 m across, more than 5 m deep, and is filled with coarse debris. Underlying the turbidites is an equal thickness of 5-40 cm thick beds of white chert and tan limestone. Farther west, along the same contact, decimetre-sized blocks of bivalve-bearing limestone occur near the base of the augite porphyry unit. Upper contacts are gradational with overlying tuffaceous carbonate. Local development of red, cross-stratified tuffaceous and calcarenitic sands indicate a subaerial environment. English *et al.* (this volume) show that the unit is subalkaline, and most like mafic volcanics erupted in an ocean island/plateau environment. The persistence of calcareous turbidite units interbedded with chert beneath the augite porphyry unit suggests that an elevated area with carbonate production, perhaps an ocean island, existed nearby prior to eruption of the augite porphyry unit.

## *FELSIC VOLCANIC AND INTERCALATED UNITS*

Alpine ridges between the lower stretches of Horsefeed and "Paint" creeks are underlain primarily by bedded chert of Middle Triassic age (Table 1). Intercalated

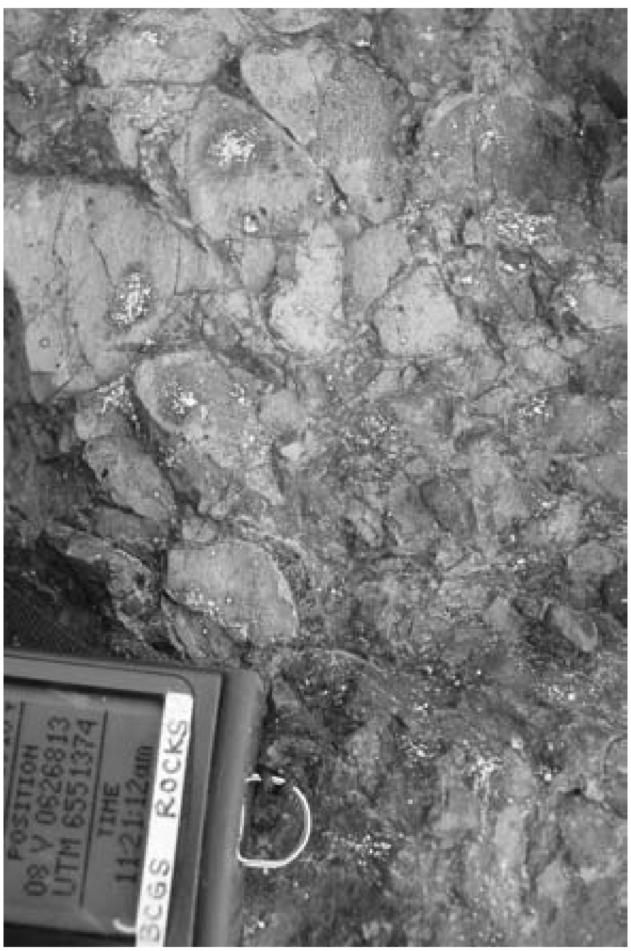


Photo 7. Basaltic pillow breccia within ribbon chert unit.

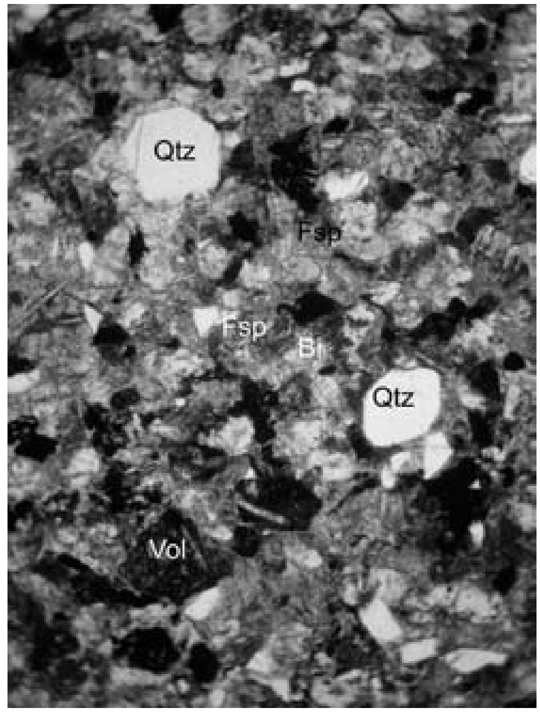


Photo 8. Photomicrograph of volcaniclastic rock within chert succession under plane polarized light. Note subidiomorphic quartz grains (Qtz) admixed with turbid feldspar (Fsp), mafic volcanic grains (Vol) and calcareous bioclasts (Bi). Width of photo represents 1.5 mm.

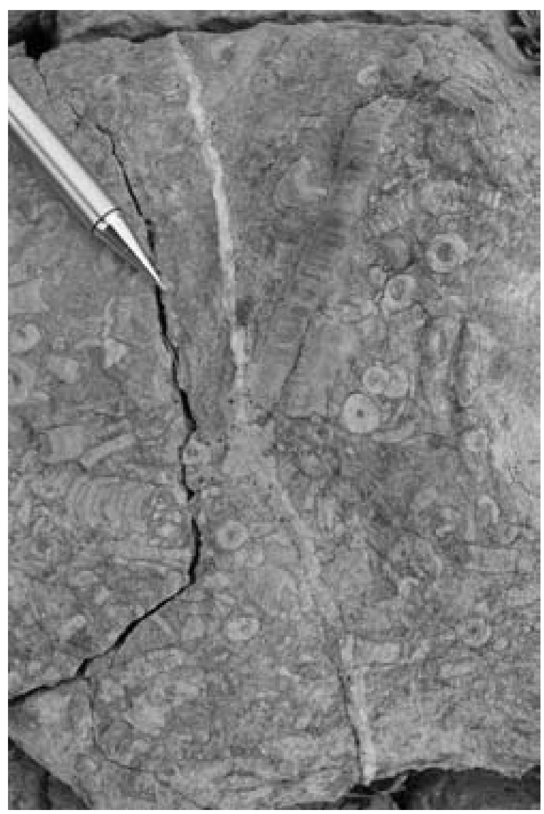

Photo 9. Crinoid and bivalve packstone with quartz-rich tuffaceous interlayers.

with the chert are bimodal volcanics: mafic pillow breccia (Photo 7) and quartz-rich tuff. In both cases the contacts with the chert appear to be primarily depositional. However, the quartz-rich tuffaceous layers grade laterally into shallow-water carbonates in which coarse quartz grains derived from the volcanics are admixed with calcareous fossil debris (Photo 8). The carbonate layer is at most 20 m thick. It is dark grey weathering, fetid and very fossiliferous, containing thick crinoid stems (up to 1.5 cm diameter, Photo 9) and bivalves.

Felsic volcanic rocks are dominantly coarse epiclastics, but breccia-sized trachyte clasts and a possible rhyolite flow were found within the same stratigraphic interval. Due to their economic potential, these felsic volcanics warrant further work to define their thickness and extent (see *Mineral Potential* below).

## *WACKE*

Two types of wacke are common within the map area: those that are mainly siliceous mud matrix, and those that are mainly silt and sand-sized grains. Siliceous mud-rich wacke is brown and less commonly dark grey, black or blue-grey. Locally it grades into chert or volcaniclastics, and commonly contains chert grains and cobbles, volcanic grains and clasts up to lapilli size. Quartz is not common, but does occur in rare clasts of foliated quartz diorite. Because the unit tends to be siliceous and "grades" into chert, the field term "proto-chert" was used to describe all variants.

Wacke that is mainly sand or silt-sized grains is common, but only locally are quartz grains abundant. Clear contact relationships with adjacent strata are only known from the north flank of "Scarface Mountain", on the western ridge of Mount Nimbus, between lower Horsefeed and "Paint" creeks, and on the ridge north of Hardluck Peak. Samples from these localities contain as much as 20% monocrystalline quartz; in rare instances quartz grains comprise more than 30% of the rock. Near "Scarface Mountain" a chert-dominated fault panel contains between 1 and 3 metres of well-bedded, coarse, olive coloured, quartz-rich volcanic sandstone (Photo 10) that caps a section of volcanic flows and reefal carbonate 18m thick. The wacke has been collected for detrital zircon age determination.

West of Mount Nimbus a fault-bounded lens of wacke 5 to more than 20 m thick is sandwiched between fault-bounded panels of mafic volcanic and pure carbonate; each more than 1 km thick. Grains within the wacke are mainly silt-sized (coarser in Photo 11). Thin beds and lamellae have been strongly disrupted by synsedimentary micro-faults. Fault planes are outlined by paper-thin carbonate veinlets. Detrital zircons have been extracted from this unit and are to be dated (F.D. at UBC).

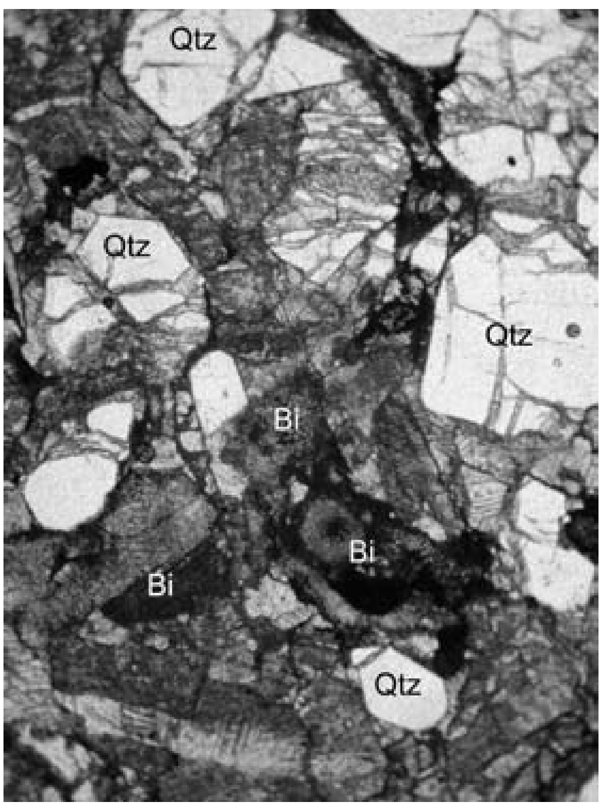

Photo 10. Photomicrograph of quartz-rich volcanic and calcareous bioclast-rich sandstone (sample MMI01-27-7). Note that coarse idiomorphic quartz (Qtz) has not been significantly abraided. Height of photo represents approximately 4mm, Bi = bioclast.

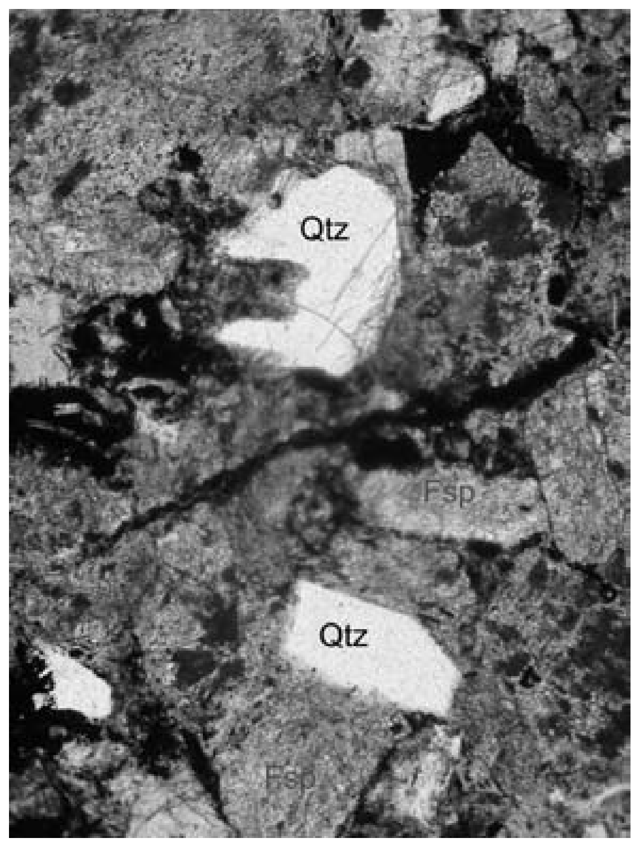

Photo 11. Photomicrograph of quartz-bearing (Qtz) arkose from near Mount Nimbus (sample MMI01-33-1). Height of photo represents approximately 1 mm.

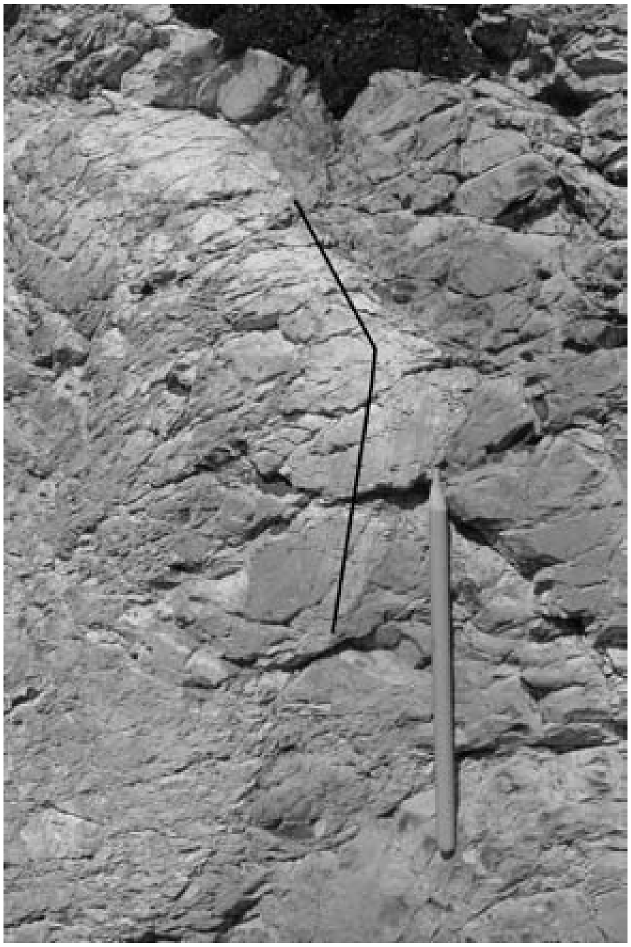

Photo 12. A westerly view of a small-scale reverse fault in quartz-bearing wacke between Horsefeed and “Paint” creeks. A black line approximates the outcrop surface^bedding plane intersection. The pencil crayon points to the clay-lined fault surface. The light-coloured wacke is interpreted to have been thrust in a northerly direction over hemipelagite.

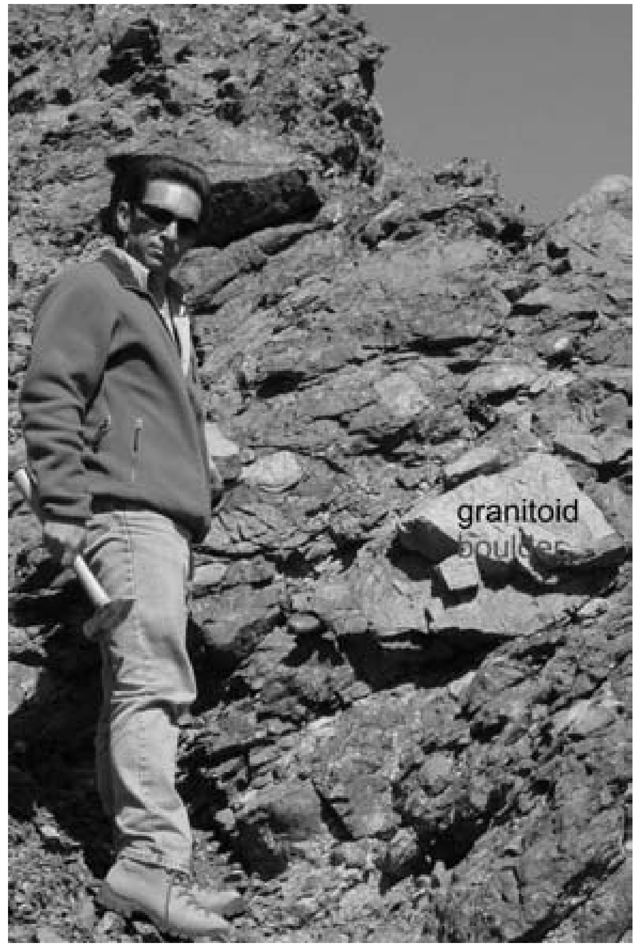


Photo 13. Conglomerate on the ridges north of Hardluck Peaks contains exotic granitic boulders up to 1 m diameter.

Between lower Horsefeed and “Paint” creeks, well-exposed fault-bounded panels of orange-weathering, olive brown to green, quartz-rich wacke are tectonically interleaved with “proto-chert”, ribbon chert and lesser carbonate. Individual panels may range from a few metres to a few hundred metres in thickness. In detail, the panels display abundant evidence for soft-sediment deformation and small-scale reverse faults (Photo 12).

Coarse quartz wacke unconformably overlies mafic volcanic rocks in a well-exposed section on the ridge north of Hardluck Peaks. A red-weathering basal conglomerate containing oxidized cobbles of volcanic rocks grades rapidly upwards into quartz-rich silt, coarse sandstone, and boulder conglomerate containing abundant exotic intrusive clasts up to 1 m diameter, as well as intraclasts up to several metres long. Fusulinid limestone, chert and sparse serpentinite clasts are interpreted to have been derived from the surrounding Cache Creek Terrane lithologies however, no nearby source is apparent for porphyritic and coarse-grained granitic boulders (Photo 13). Carbonate layers up to 5 m thick occur near the middle of the exposed unit. Samples were collected for conodont extraction; however, contamination from older sources is expected. The unit is younger than the Cache Creek lithologies that it contains as clasts, and is older than an unfoliated granodiorite pluton that thermally metamorphoses the unit. Aitken (1959) mapped this unit as wacke of possible Triassic age. Six samples were collected for detrital zircon age determinations in order to better constrain the age of the unit.

## *LATE SYN- TO POST-ACCRETIONARY INTRUSIVE ROCKS*

Intrusive bodies that cut structural fabrics within the Nakina area are known from two localities: on the north flanks of Hardluck Peaks in southwestern-most 104N/2, and on northern Sinawa Eddy Mountain. The body near Hardluck Peaks is herein called the “Hardluck pluton”. It is a blocky, grey-weathering, medium to coarse-grained hornblende biotite granodiorite. Hornblende clots and xenoliths are common. The pluton has steep contacts and a thermal metamorphic halo >100 m thick in which phyllite is locally developed. Within a few metres of the contact, ribbon chert has a sucrosic texture due to recrystallization of quartz. Within 50 cm of the contact the pluton is chilled.

A sample was collected for $^{40}Ar/^{39}Ar$ age determination. Based on comparison with similar dated plutons elsewhere in the Atlin area (Mihalynuk *et al.*, 1992), the pluton is thought to be Middle Jurassic to Eocene age.

On the north flank of Sinawa Eddy Mountain, 3 km north of the peak, a quartz porphyritic rhyolite stock 100 m in diameter is poorly exposed. The rhyolite is flaggy weathering, dusty tan to pale mauve and contains about 10% medium-grained quartz phenocrysts. A similar body has been mapped 1 km to the ENE, based upon the presence of similarly weathering felsenmeer.

## STRUCTURAL STYLES

The degree of structural disruption and complexity of structural relationships within the Nakina area is difficult to convey on a map of 1:50 000 or smaller scale. For this reason, previous maps (*i.e.* Aitken, 1959; Monger, 1975), as well as that shown in Figure 2, under-represent structural complexity. Although a general northwest-striking structural fabric parallels the Nahlin body, there is significant discordance at the mountainside or more detailed scale. Our mapping at 1:20 000 scale, compiled at 1:50 000, and further simplified on Figure 2 (about 1:200 000 if entire page. As is, ~1:335 000) is of sufficient detail to resolve four structural elements not previously shown on maps; (1) a fold and thrust belt, (2) a serpentinite mélange belt, (3) parts of an accretionary prism, and (4) flow around resistant buttresses.

A fold and thrust belt is best defined in the north-central map area near “Laughing Moose Creek” and “Blackcap Mountain”. Shallow to moderately north-dipping shear zones and truncation of hangingwall units are consistent with south verging thrust faults. Radiolarian fossil ages from chert in adjacent structural panels show that older strata are thrust over younger strata (Carboniferous and Permian over Middle Triassic). The fold and thrust belt has not been traced through massive carbonates at Sinawa Eddy Mountain, although at least two thrust faults placing limestone on limestone are recognized there. This together with the abrupt termination of turbidite beds and argillaceous bands strongly suggests a continuation of the belt. A resistant band of Permian fusulinids packstone that marks the western limit of the massive carbonate at Sinawa Eddy Mountain, structurally overlies Middle Triassic chert for 12 km along strike, and appears to extend a further 13 km to the northwest. Steep northeast dips on the fault contact suggest a southwest-verging thrust.

A serpentinite mélange belt extends north from Nakina Lake bifurcates and appears to pinch out south of Dry Lake valley (Figure 2). The belt is up to 4 km thick and contains knockers up to 2.5 km across. Knockers of almost all Cache Creek Terrane lithologies were recognized, but the most abundant are those composed of mafic volcanic rocks and of diorite. Knockers composed of chert and mafic intrusive rocks are of lesser and approximately equal abundance; other knocker types are rare. Where knockers are best exposed, they appear to be subvertical cigar-shaped bodies (Photo 14).

Many of the fault-bounded units in the Nakina area MAY have been first assembled in an accretionary prism. The best evidence of structural panels of sediments that appear to have been interleaved within an accretionary prism comes from between Horsefeed and “Paint” creeks. Here quartz-rich wacke of possible inner trench slope derivation are interleaved with pelagic sediments. Thrust faults apparently verge north-northwest, based upon small-scale low angle fault cut-offs (Photo 12).

Deformation that post-dates original assembly of the lithologic elements recognized in the Nakina area has modified most contacts, tightened folds, and resulted in flow of incompetent lithologies around more resistant buttress-forming lithologies. An example of flow around a buttress was observed 5 km south of Dry Lake where a resistant buttress of carbonate is wrapped by panels of chert admixed with minor amounts of other rock types including mafic volcanics and ultramafite.

Wacke and conglomerate north of Hardluck Peaks forms a 7 km by 1.7 km west-northwest-trending belt that is cut and offset in an apparent dextral sense by a northwest-trending fault. Serpentinite occurs along the fault on the

Photo 14. Resistant knockers in serpentinite mélange are here mainly composed of mafic volcaniclastic and intrusive lithologies. Dashed lines are parallel with long axes of knockers.

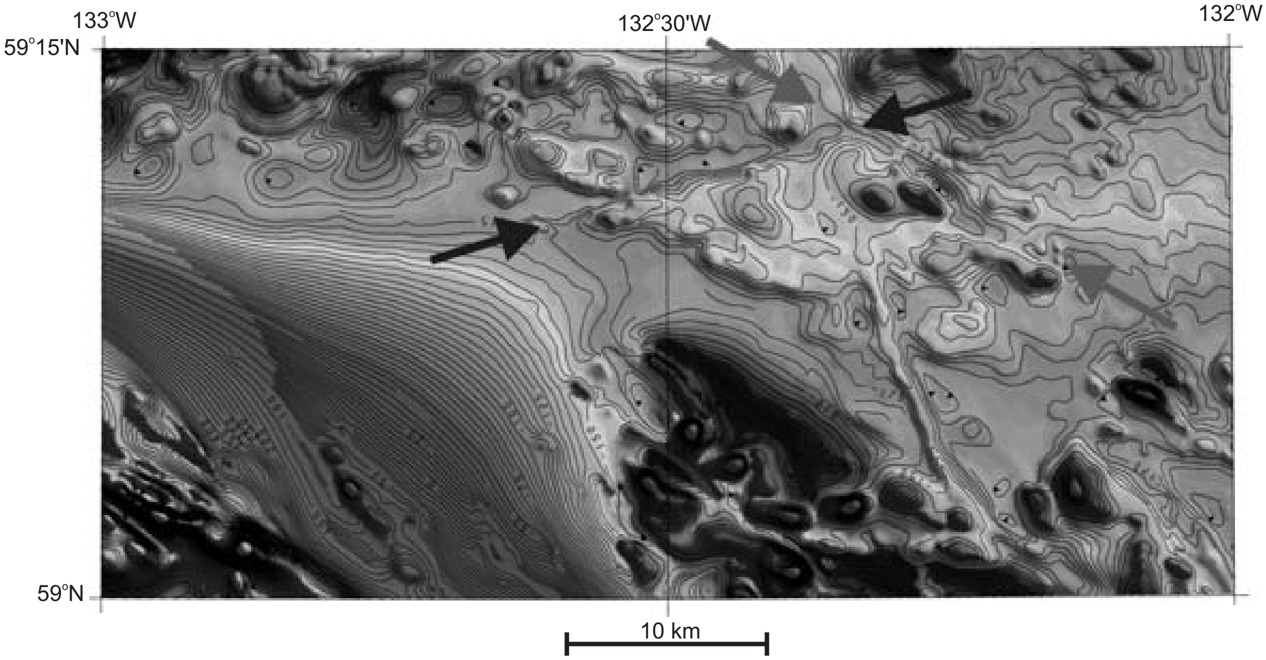


Figure 3. Aeromagnetic results for the Nakina map area, NTS 104N/1 and 2. Arrows show the location of linear negative anomalies as discussed in text. (*See* web page for colour version).

southern margin of the map. The fault appears to terminate in serpentinized harzburgite south of "Windy Lake".

## AEROMAGNETIC SURVEY RESULTS

Magnetic anomaly data covering the 104N/1 and 2 map areas are shown in Figure 3. These data were acquired as part of the high-resolution aeromagnetic survey conducted over the 1:250 000 Atlin map area during the first phase of the Atlin Targeted Geoscience Initiative (Dumont *et al.*, 2001a, b). For a synopsis of the aeromagnetic data that is more thorough than that presented here, please see Lowe and Anderson (2002).

The magnetic field is dominated by a positive (up to 2100 nT) anomaly that extends over the southern two thirds of 104N/2 and continues some 30 km farther to the northwest. The source of the anomaly is interpreted to be serpentinized harzburgite in the northwest-trending Nahlin ultramafic body, because magnetic intensities are largest where these rocks are exposed at surface. In addition, magnetic susceptibility data (Lowe and Anderson, 2002) indicate that serpentinite has significantly higher values than any other Cache Creek Terrane lithology in the area. The spatial extent of the magnetic anomaly suggests that much of the map area to the south of Mt. Sinawa Eddy and "Paint Mtn." is likely underlain, at relatively shallow depths, by serpentinized ultramafic rocks. Such an interpretation requires that the Nahlin ultramafic body dips shallowly to the northeast, although previous workers have interpreted the northeast boundary of the body to be a near-vertical fault (Souther, 1971; Monger, 1975).

Numerous small, sub-oval to elliptical, positive magnetic anomalies punctuate the otherwise low amplitude magnetic field observed in the southern part of 104N/1 (Figure 3). Some of the anomalies correlate with discrete exposures of ultramafic rocks previously mapped in this area (Aitken, 1959; Monger, 1975) and ground investigation of others has led to the discovery of serpentinite mélange in areas previously thought to be underlain by mafic volcanic and associated rocks in the Nakina Formation (*e.g.* serpentinite mélange on Figure 2). The peak amplitudes (typically < 400 nT) and small aerial extent of most of these anomalies indicate that the source bodies unlikely persist to significant depths.

A prominent NNW-trending lineament, characterized by a narrow (<1 km) zone of moderately elevated (35 nT) magnetic anomaly values extends for more than 20 km through the central part of 104N/1. This lineament marks the eastern extent of the chert succession that underlies "Scarface Mtn." (compare Figures 2 and 3). Bedrock exposures in the vicinity of the lineament are not known and ground investigations failed to identify the magnetic source. Possible explanations include a mafic intrusion or secondary magnetization around an unmapped fault zone.

Two other notable lineaments, each approximately 17 km long, are imaged in the northern part of 104N/1. The lineaments are magnetic troughs, one northeast-trending and the other northwest-trending (shown by arrows on Figure 3), that intersect in the Nakina River valley approximately 16 km northeast of Dry Lake (Figure 2). The southern margins of both lineaments correspond to higher magnetic anomaly values where volcaniclastic rocks are exposed in the “Blackcaps Mtn.” area. The northeast-trending lineament parallels the boundary between these volcaniclastic rocks and the weakly magnetic chert succession that underlies much of the area between “Blackcaps Mtn.” and “Laughing Moose Creek”. The northwest-trending lineament parallels the boundary between the volcaniclastic rocks and weakly magnetic carbonate and chert units that underlie much of the northeastern part of the 104N/1 map area.

## MINERAL POTENTIAL

Despite prospective geology, no metallic mineral occurrences area known from within the area mapped. Thus, a principal objective of the Nakina transect mapping was to evaluate the mineral potential of the area, especially for volcanogenic massive sulphide mineralization. Our discovery of a magnetite exhalite unit as well as submarine felsic volcanic rocks underlying parts of drainages with elevated RGS metal values, points to vigorous hydrothermal systems in a setting prospective for a Cyprus-style mineralization, and the right composition of submarine volcanic rocks for Kuroko-style mineralization.

### *MAGNETITE EXHALITE UNIT*

A substantial thickness of magnetite exhalite is located 3.5 km northwest of “Blackcaps Mtn.” in dark green aquagene ash and dust tuff (diamond on Figure 2). Fine-grained magnetite comprises up to 50% of the rock across true thicknesses of at least 5 metres. Geochemical analysis of this unit has returned values of 16% Fe and 900-1200 ppm Ba over 5.3 metres, but background values for base and precious metals. The magnetite layers occur intermittently across a width of 25 m and can be traced for more than 700 metres along strike. Sparse quartz microlites seen in thin section may have been sourced in distal felsic eruptions that were coeval with the more abundant mafic tuff of the exhalite host unit.

RGS results are unavailable for the drainage basin directly underlying the exhalite, but values from the creeks draining areas underlain in part by correlative tuffite are elevated (with respect to the remainder of the Atlin sheet) in Au (41 ppb), As (31 ppm), Cu (64 ppm) and Zn (118 ppm; samples 9215, 9224 in Jackaman, 2000).

### *FELSIC VOLCANICS AND RGS DATA*

Submarine quartz-phyric felsic volcanic rocks with volcanogenic massive sulphide potential were discovered in central 104N/2 (filled square on Figure 2). They appear intercalated with chert that has yielded Middle Triassic radiolaria along strike to the east. RGS data from creeks that drain the area are elevated (with respect to the remainder of the Atlin sheet) in copper (80 ppm), lead (6ppm), molybdenum (6 ppm), zinc (122 ppm), mercury (230 ppm) and gold (10 ppb; samples 9695, 9700, 9895 in Jackaman, 2000).

## SUMMARY AND FUTURE WORK

Regional geological mapping in the Nakina Lake and River sheets (104N/1, 2) reveals a complexity not evident on previously published maps. Recognition of a fold and thrust belt, a serpentinite mélange belt, parts of an accretionary prism and widespread indications of felsic volcanism are among the most significant regional mapping contributions arising from this study. Production of 1:50 000 scale maps will be aided by 80 new radiolarian collections, 50 new collections of Carboniferous to Permian fusulinids and numerous macrofossil collections including Permian ammonoids and corals. Surprisingly, much of the hemipelagic stratigraphy is of Middle Triassic age, younger than expected on the basis of previous fossil age determinations. Oceanic crustal rocks are presumably the basement on which all strata were deposited and should yield some of the oldest ages in the Cache Creek Terrane. They will be dated using a combination of U/Pb and $^{40}Ar/^{39}Ar$ techniques.

Of key importance has been the discovery of submarine felsic volcanic rocks in an area underlain by drainage basins showing anomalous base metal RGS values. Abundant volcanic quartz in detrital sediments from a variety of places across the map area points to widespread felsic volcanism within or on the margins of the ancient Cache Creek ocean basin. The possibility that Cache Creek Terrane felsic or mafic volcanic successions might be associated with exhalites is demonstrated by our discovery of evidence for a vigorous fossil hydrothermal system. This large magnetite exhalite unit, exposed over 25m x 700 m, points to the viability of the Cache Creek Terrane as a host for volcanogenic mineral deposits.


## ACKNOWLEDGEMENTS

We would not have been able to cover the ground without the dollar-stretching, aerial choreography of Norm Graham of Discovery Helicopters in Atlin. Thanks also to the people of Atlin for their generous support of our field program and enthusiastic attendance of our summer geolecture series. Jackie Williams and Alice Carlick kindly provided us with historically correct geographic place names for the Nakina Lake and River map areas. At the time of writing, pending cuts to government funding are anticipated to impact on delivery of some products planned under the Atlin Targeted Geoscience Initiative.


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