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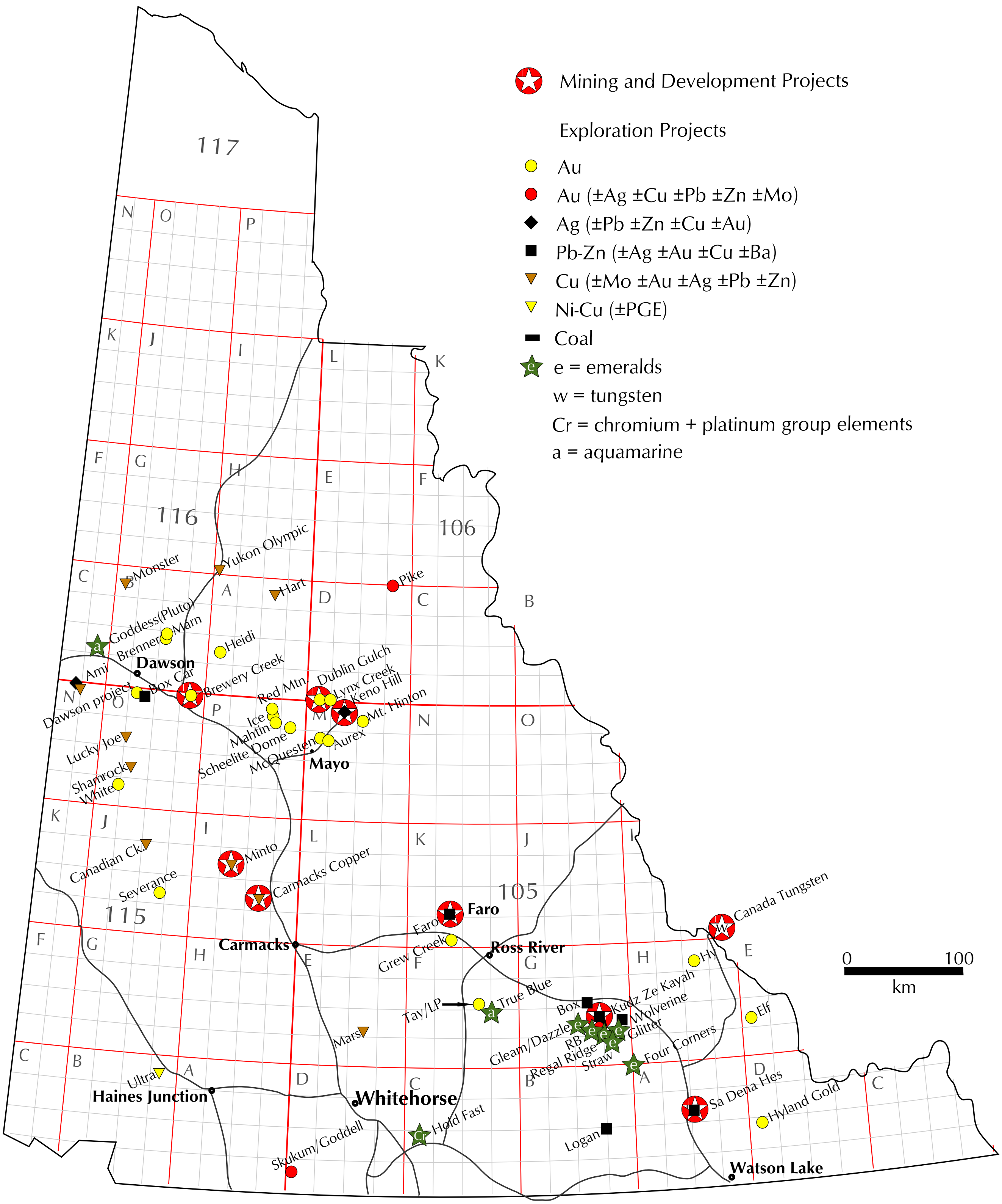

Figure 2. *Location of Yukon development projects (permitted or undergoing permitting) and exploration projects in 2003. Not all active projects are shown on the map. Background of the map showing the National Topographic System (NTS) grid.*

Yukon Mining, Development and Exploration Overview, 2003

Mike Burke[1]
Yukon Geological Survey

Burke, M., 2004. Yukon Mining, Development and Exploration Overview, 2003. *In:* Yukon Exploration and Geology 2003, D.S. Emond and L.L. Lewis (eds.), Yukon Geological Survey, p. 2-26.

ABSTRACT

The search for emeralds and the rise in the price of gold has fueled an increase in mineral exploration expenditures in Yukon. Exploration for base metals was directed mainly toward copper (with significant gold credits), while zinc, lead and nickel received little attention. Expenditures are estimated at over $13 million, up from the $6.9 million spent in 2002. Claim staking remained healthy in 2003, with 2816 claims staked to the end of October, and for the first time in five years, claims in good standing posted an increase to 43 314 claims to the end of October. Unfortunately there has been no hard-rock mining or development taking place.

The largest exploration program in Yukon was the Regal Ridge project of True North Gems in which $2.1 million was dedicated to the evaluation of an emerald occurrence first discovered in 1998. Exploration for additional occurrences of emeralds in a similar geologic setting to Regal Ridge (intrusive-related quartz-beryl veins) was conducted mainly in the surrounding Finlayson Lake district. Several new areas have been identified; the most significant being the True Blue prospect. Deep blue-coloured beryl discovered at the True Blue property has been identified as a unique form of aquamarine and is currently being evaluated to determine if the stones may be a new species of gemstone.

Gold exploration in Yukon focused mainly on intrusion-related gold systems within the Tintina gold province, which comprises several mineral-rich districts that are coincident with extensive regions of mid-Cretaceous plutonism. The geological knowledge of intrusion-related gold systems has advanced dramatically over the last ten years while exploration for gold in these systems has been at historical lows. This has resulted in very few advanced exploration programs that have been able to adequately drill test the numerous targets within the Tintina gold province in Yukon.

The continued strengthening of the gold price, recent discoveries and positive results from current exploration programs all indicate that Yukon is poised for a return to healthy exploration levels.

RÉSUMÉ

La recherche d'émeraudes et la hausse du prix de l'or ont contribué à l'augmentation des dépenses d'exploration minérale au Yukon. L'exploration des métaux communs a été axée sur le cuivre (combinée à des crédits importants pour l'or); le zinc, le plomb et le nickel ont été, pour leur part, des cibles peu prisées. On estime les dépenses à plus de 13 millions de dollars, ce qui est 6,9 millions de dollars de plus qu'en 2002. Les jalonnements de claims ont continué d'être nombreux en 2003, 2816 claims ayant été jalonnés à la fin d'octobre, et pour la première fois en 5 ans, les claims en règle ont atteint le nombre de 43 314 à la fin d'octobre. Malheureusement, il n'y a pas eu d'exploitation ou de mise en valeur de mines de roche dure.

Le plus vaste programme d'exploration au Yukon a été celui de Regal Ridge de la société True North Gems qui a consacré 2,1 millions de dollars à l'évaluation de la minéralisation d'émeraude découverte en 1998. Des travaux d'exploration pour trouver des émeraudes dans un contexte géologique semblable à celui de Regal Ridge (filons de quartz-béryl associés à une intrusion) ont été menés principalement dans les environs du district de Finlayson Lake. Plusieurs nouvelles zones ont été relevées, la plus importante étant celle de True Blue. Le béryl bleu foncé découvert à la propriété de True Blue est en cours d'évaluation pour déterminer si les pierres constituent une nouvelle espèce de pierre précieuse.

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L'exploration de l'or au Yukon a surtout porté sur les systèmes aurifères associés à une intrusion dans la province aurifère de Tintina qui inclut plusieurs districts riches en minéraux qui coïncident avec des grandes régions de plutonisme du Crétacé moyen. La connaissance géologique des systèmes aurifères associés à des intrusions a fait des pas de géant au cours des dix dernières années alors que l'exploration visant à découvrir de l'or dans ces systèmes n'a jamais été aussi faible. C'est pourquoi les programmes d'exploration de pointe ont été peu nombreux à effectuer des forages d'essai dans les nombreuses cibles situées dans la province aurifère de Tintina au Yukon.

Le raffermissement ininterrompu du prix de l'or, les récentes découvertes et les résultats positifs obtenus par les programmes d'exploration indiquent que le Yukon reconnaîtra des activités d'exploration prospères.

INTRODUCTION

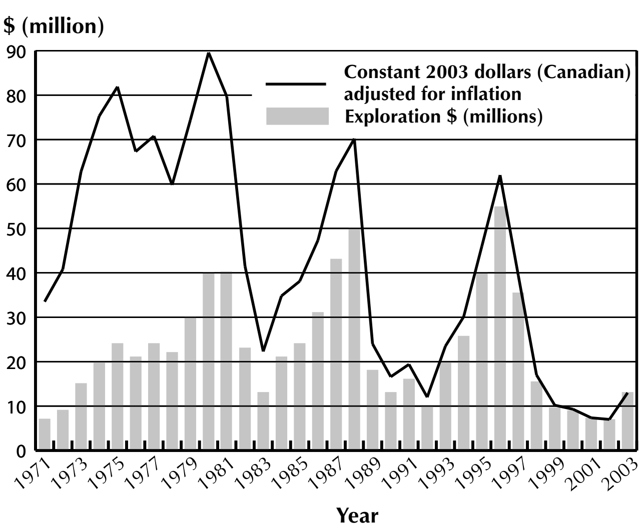
Mineral exploration expenditures in Yukon rose to over $13 million in 2003, nearly double the 2002 total (Fig. 1). The increase in exploration was driven by the rise in the price of gold and the increased activity of companies exploring for emeralds (Fig. 2, page 2). New discoveries continue to be made by companies and prospectors active in Yukon. Hinterland Metals and Firestone Ventures both discovered gold mineralization on their claims while exploring for emeralds in the Finlayson Lake district. Prospector Shawn Ryan rediscovered a high-grade gold vein on his White claims, first noted in an 1897 report by William Ogilvie. True North Gems identified three new emerald-bearing zones on their Regal Ridge property and announced the discovery of a blue-coloured beryl, identified as a unique form of aquamarine, on their True Blue property. The number of projects involving diamond drilling did not increase in 2003, however, the total drilling footage increased by 50% (Appendix 1) illustrating the ability of companies to raise enough funds to complete sizeable exploration programs. No percussion drilling was carried out this year.

Claim staking in 2003 remained healthy with 3571 claims staked, resulting in an increase in the number of claims in good standing to 44 022 (Figs. 3, 4).

The Yukon government continued to support the mineral exploration industry in Yukon by funding the Yukon Mining Incentive Program. In 2003, $987,000 was offered to 61 successful applicants (Galambos, this volume). The function of the program is to provide a portion of the risk capital required to locate and explore for mineral deposits in Yukon. The Yukon government also supports the industry through the Yukon Mineral Exploration Tax Credit, which provides a 25% tax refund on eligible exploration expenditures (effective until March 31, 2004).

Eight Yukon First Nations (Nacho Nyak Dun, Teslin Tlingit Council, Champagne and Aishihik First Nation, Vuntut Gwichin First Nation, Little Salmon/Carmacks First Nation, Selkirk First Nation, Tr'ondëk Hwëch'in and the Ta'an Kwach'an Council) have finalized their land claims in Yukon, and have final and self-government agreements in

Figure 1. *Exploration expenditures 1971- 2003 (estimated). Inflation adjustment calculated using Bank of Canada inflation calculator (www.bankofcanada.ca/en/inflation_calc.htm).*



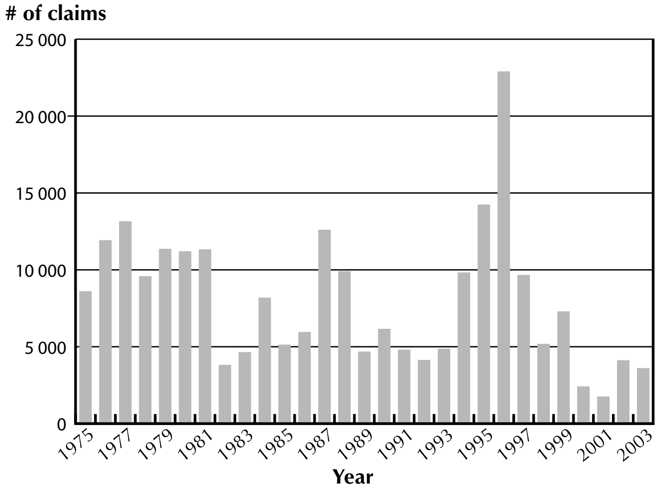


Figure 3. *Claims staked 1975 to 2003.*

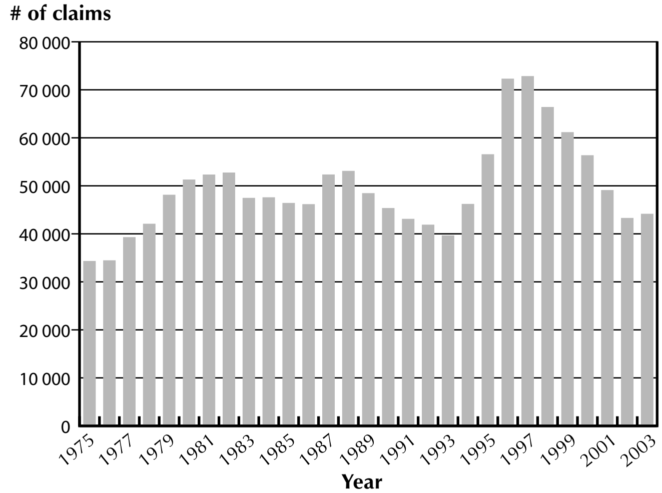


Figure 4. *Claims in good standing 1975 to 2003.*

effect. The Kluane First Nation has finalized its land claims, and its final and self-government agreements will come into effect on February 2, 2004. The Carcross/Tagish First Nation and the Kwanlin Dun First Nation have finalized their land claims, and will vote on ratification of their final and self-government agreements in 2004. The White River First Nation is working on completing the details of its claims so that it may finalize and move towards ratification in 2004. The Liard First Nation and Ross River Dena Council are not presently negotiating their claims with Canada and Yukon, and there is no timetable for reactivating the tripartite negotiation table, however, Yukon has entered into some interim measures agreements with those First Nations to facilitate development in the southeast Yukon.

This overview highlights a number of exploration projects conducted in Yukon during the 2003 field season, and is by no means a comprehensive review of the geology of the properties and of all exploration conducted in Yukon. Detailed property descriptions are commonly available on company websites, in documents filed electronically for the System for Electronic Document Analysis and Retrieval (SEDAR at www.sedar.com). Yukon MINFILE, the Yukon's mineral occurrence database, also contains detailed descriptions of many of the occurrences described herein (Deklerk, 2003); this is available on CD-ROM, and also on the Yukon Geological Survey's website at www.geology.gov.yk.ca. Several projects have not been included because of restrictions on disclosure for publicly traded companies, and for competitive reasons when companies and individuals choose not to openly share exploration results.

PRECIOUS METALS

GOLD

SpectrumGold Inc. (a subsidiary of NovaGold Resources Inc.) completed a major geologic compilation of the **Brewery Creek** mine property (Yukon MINFILE 2003, 116B 160, Deklerk, 2003). The property ceased heap leach production from oxide gold deposits which produced 8 694 695 g (279,541 troy oz) of gold from

1996 to 2002. Approximately 2 million tonnes of capacity remain on the heap leach pad and the Reserve Trend on the property contains indicated resources of 4.51 million g (145,000 troy oz) and inferred resources of 4.45 million g (143,000 troy oz) of oxide material. Previous work focused mainly on the near surface oxide reserves with very few holes testing the potential for deeper sulphide mineral targets. SpectrumGold feels the property's 15-km-long mineralized trend has similar geologic characteristics to NovaGold's 775 million g (25 million oz) Donlin Creek deposit in Alaska. Detailed structural mapping in 2002 and 2003 is helping to develop a more comprehensive structural model that incorporates known ore-controlling structures in the Reserve Trend into a more regionally consistent context. A program to test drill targets is planned for the 2004 season.

Canadian United Minerals restaked the **Marn** deposit (Yukon MINFILE 2003, 116B 147, Deklerk, 2003) as the Prune claims and conducted 22 km of ground-based magnetometer surveys, soil sampling and prospecting. Sulphide skarn minerals in the Marn deposit are mainly pyrrhotite and chalcopyrite (Fig. 5). The surveys produced a 150 by 400 m magnetic anomaly with coincident soil values up to 200 ppm Cu. Prospecting in the valley bottom near a weak magnetometer anomaly uncovered weak skarn mineralization that assayed up to 580 ppb Au, >10 000 ppm As and 0.6% Cu.

Four kilometres to the south of the Marn, Klondike Exploration (Shawn Ryan) conducted a ground-based magnetometer survey and prospecting on the **Brenner** claims which have potential to host similar mineralization to the Marn.

Regent Ventures Inc. upgraded the access road to their **Red Mountain** property (Yukon MINFILE 2003, 115P 006, Deklerk, 2003) near Mayo in central Yukon. This was followed by drilling a single deep diamond drill hole on the Treadwell structure (Fig. 6) at the south end of the property. Diamond drill hole DD03-39 was drilled to a depth of 442.5 m at a dip of -60° to test this structure. A number of quartz-calcite veins and stockwork zones were intersected within the hornfels aureole of a

Figure 5. *Trench on the main Marn Zone.*

Figure 6. *Drilling the Treadwell structure at Red Mountain.*

Cretaceous Tombstone Suite biotite quartz monzonite intrusion, while the intersection from 440 to 441 m depth was in the intrusion itself. The more significant assay results from the drill hole are set out in the following table.

Depth (m) from	Depth (m) to	Interval (m)	Gold (g/t)
109.65	110.45	0.80	2.74
235.00	247.00	12.00	1.01
265.00	267.00	2.00	1.20
288.00	289.00	1.00	1.10
300.45	307.00	6.55	2.12
348.00	349.00	1.00	1.20
384.00	385.10	1.10	2.04
415.00	416.00	1.00	1.65
440.00	441.00	1.00	11.3

ASC Industries Ltd explored the **Ice** property (Yukon MINFILE 2003, 115P 006, Deklerk, 2003) which adjoins the Red Mountain property to the north. The program consisted of 1368.39 m of HQ core drilling in 10 drill holes. The drill program was directed at a number of targets associated with the Cretaceous Red Mountain Stock, a biotite quartz monzonite intrusion of the Tombstone Suite. Drilling tested the northwest-trending Jethro structure which was defined over a strike length of approximately 500 m. It is a well defined, wide and steeply dipping fault zone with only limited surface expression. The Midway zone is located in the middle of the Jethro structure and consists of a 500-m-long, 250- to 500-ppb gold-in-soil anomaly with a 250-m core of greater than 500 ppb Au. A number of surface rock samples within this anomalous zone returned values of greater than 1 g/t Au.

Figure 7. *Faulted quartz monzonite in Hole 8 on the Ice property assayed 1.12 g/t Au from 31.0 to 42.3 m.*

Four diamond drill holes (DD03-04, 06, 08 and 12; Fig. 7) intersected the Jethro structure over a strike length of 500 m. DD03-04 and -06 were drilled at the southeast end of the structure, and DD03-08 and -12 were collared 500 m to the northwest in the Midway zone. DD03-04 intersected a swarm of quartz monzonite sills and hornfelsed siltstone that assayed 311 ppb Au over the entire 171 m length of the hole. Nine intervals of greater than 1 g/t Au were returned in the hole, with the widest intersection returning 1.34 g/t Au over 3.5 m, and the highest grade assaying 4.56 g/t Au over 1.0 m. DD03-08 returned two intersections of 1.12 g/t Au and 1.24 g/t Au over 11.30 and 5.0 m, respectively in biotite quartz monzonite with zones of clay alteration and fault gouge. DD03-12, located 60 m northwest of DD03-08, returned 102 m of 0.88 g/t Au including 2.29 m of 15.35 g/t Au and 16.79 m grading 1.28 g/t Au in clay-altered, sheared, oxidized biotite quartz monzonite.

Klondike Exploration (Shawn Ryan) acquired the **Mahtin** property (Yukon MINFILE 2003, 115P 007, Deklerk, 2003) by staking early in 2003. The claims cover the Cretaceous Sprague Creek stock which intrudes Upper Cambrian-Ordovician limestones of the Rabbitkettle Formation. The property had been previously held since 1994 but had only seen sporadic work, consisting mainly of short property visits. Sheeted quartz-arsenopyrite veins (Fig. 8) occur within the intrusion near the margin; and skarn and mineralized calc-silicate rock is developed in several areas proximal to the intrusion. Ryan conducted a program of geophysics (28 line-km of magnetometer and 9 line-km of Induced Polarization) and geochemistry on a 1 by 2 km grid. Soil sampling outlined an anomalous zone of >40 ppb Au geochemistry, 1 km by approximately 150 m, with peak values in the 400 ppb Au range paralleling the intrusive contact. Geophysics outlined several magnetic highs with high chargeabilities that correspond to areas with skarn in float or subcrop. Grab samples of sheeted quartz-arsenopyrite veins assayed up to 2.8 g/t Au, and skarn/mineralized calc-silicate rock assayed up to 6.5 g/t Au.

Logan Resources conducted a program of geochemistry and geophysics (magnetic and Induced Polarization surveys) on the **Heidi** property (Yukon MINFILE 2003, 116A 037, Deklerk, 2003) northeast of Dawson. The Heidi property is underlain by Neoproterozoic to Lower Cambrian Hyland Group quartzites, sandstone and quartz-pebble conglomerates intruded by Cretaceous biotite-feldspar porphyry dykes. Disseminated to massive sulphide minerals replace calcareous units within the highly folded Hyland Group rocks and occur in quartz-arsenopyrite veins.

Golden Patriot Resources optioned the **Scheelite Dome** property (Yukon MINFILE 2003, 115P 003, Deklerk, 2003) from Copper Ridge Exploration and conducted 7.8 km of line grids, 7.8 km of ground magnetometer and 5.9 km of Induced Polarization surveying, geological mapping and sampling on the Tom Zone, followed by diamond drilling (Fig. 9). Property geology consists of siliciclastic metasedimentary rocks of the Neoproterozoic to Lower Cambrian Hyland Group intruded by the Cretaceous Scheelite Dome intrusion. The Tom Zone is characterized by mineralized calc-silicate skarn hosted within a lens of calcareous rocks and discordant quartz-arsenopyrite veins. Surface sampling of the skarn returned values of up to 32.8 g/t Au. Five holes totaling 310 m were drilled to target skarn and replacement mineralization in the Tom Zone. The final two holes of the program were not completed due to the onset of winter conditions which compromised access to the drill.

Figure 8. *Sheeted quartz-arsenopyrite veins hosted in quartz monzonite on the Mahtin property.*

Figure 9. *Drilling on the Tom Zone on the Scheelite Dome property.*

Highlights from drilling at the Scheelite Dome property.

Hole	Interval (m)	Gold (g/t)
SH03-29	1.22	5.06
SH03-30	6.40	7.09
SH03-32	5.80	2.55
SH03-33	0.61	3.53

Four of the holes intersected gold mineralization and one hole was abandoned before reaching the target depth.

StrataGold Corporation conducted a small program of geology, geochemistry and geophysics (ground magnetic and Induced Polarization surveys) on their **Lynx Creek** property (Yukon MINFILE 2003, 106D 020, Deklerk, 2003) north of Mayo in central Yukon. Gold at Lynx Creek is associated with a small granodiorite stock of the Cretaceous Tombstone Plutonic Suite. Previous work on the property partially outlined a quartz-sulphide mineral vein system hosted within the granodiorite which returned drill intersections up to 3.4 m grading 7.37 g/t Au. StrataGold is evaluating the property for a potential gold deposit proximal to the intrusive stock, and previous drilling returned up to 22.2 m grading 1.4 g/t Au in quartzite.

StrataGold Corporation also conducted an exploration program on the **Aurex** property (Yukon MINFILE 2003, 105M 060, Deklerk, 2003) which lies east of Mayo in central Yukon and is accessed by the Silver Trail Highway. Gold occurs in quartz-sulphide mineral veins and distal pyrrhotite skarn and calc-silicate rocks hosted in Neoproterozoic to Lower Cambrian Hyland Group metasedimentary rocks within the Tombstone strain zone. Skarn has returned values up to 8.87 g/t Au, and veins up to 9.31 g/t Au from surface exposures. StrataGold tested a number of targets on the property with 21 diamond drill holes totaling 2417 m. Drilling began in early November (Fig. 10) and results were not yet available by year-end.

Figure 10. *Winter drilling at StrataGold Resources' Aurex property near Mayo.*

SpectrumGold Inc. (a NovaGold subsidiary) conducted an 18-hole, 3050-m diamond drilling program on the **McQuesten** property (Yukon MINFILE 2003, 105M 029, Deklerk, 2003) optioned from Eagle Plains Resources. The property is adjacent to the Aurex claims. Gold is hosted within calcareous metasedimentary rocks of the Neoproterozoic to Lower Cambian Hyland Group and a quartz monzonite dyke, likely of the Tombstone Plutonic Suite, within the Tombstone strain zone. Gold occurs with disseminated to semi-massive sulphide minerals in skarn and calc-silicate horizons (Fig. 11). Previous drilling and geophysical surveys by Eagle Plains and Newmont have indicated a mineralized system that has at least a 3-km strike length.

Strategic Metals Ltd. tested the **Pike** property (Yukon MINFILE 2003, 106E 040, Deklerk, 2003) with four diamond drill holes totaling 295 m. The claims located north of Mayo in the Wernecke Mountains cover a large Proterozoic 'Wernecke Breccia' which hosts iron-oxide-copper-gold occurrences. A talus slope on the property contains high-grade float

Figure 11. Gold-bearing semi-massive pyrrhotite in core from the McQuesten property.

specimens with native gold, pitchblende and brannerite in quartz. Drilling targeted the apparent source of high-grade, mineralized quartz fragments that contain up to 10 to 30% Au. Anomalous values of copper and gold were intersected by the drilling but nothing approaching the tenor of the mineralization found at surface.

Klondike Gold Corp. renewed its exploration efforts in the historic Dawson mining district by acquiring additional claims in the area and conducting a first-phase program of trenching and bulk sampling on the **Lone Star** and **Buckland** shear zones (Yukon MINFILE 2003, 115O 072, 077, Deklerk, 2003).

Fjordland Exploration Inc. optioned the contiguous **Flume** and **Ten** properties (Yukon MINFILE 2003, 115N 110, 163, Deklerk, 2003) from Phelps Dodge Corporation and Teck Cominco Ltd. The properties are located approximately 75 km south of Dawson City. Mid-Cretaceous biotite quartz monzonite stocks and later quartz-feldspar porphyry dykes intrude Devono-Mississippian schist, gneiss and minor marble of the Yukon-Tanana Terrane. Previous exploration by Phelps Dodge and Teck Cominco outlined gold-bearing veins and stockwork within intrusive and metamorphic rocks, as well as skarn. Previous trenching returned up to 1.6 g/t Au over 25 m including 11.1 g/t Au over 3 m from quartz veins hosted in quartz monzonite. Fjordland conducted a short program of geology and geochemistry on the property, but it was cut short by the onset of winter conditions.

Klondike Exploration (Shawn Ryan) conducted a small program of prospecting and soil geochemistry on the **White** claims (Yukon MINFILE 2003, 115O 011, 012, Deklerk, 2003), approximately 100 km south of Dawson. The claims were previously subjected to small exploration programs by Teck Corporation from 1999 to 2000, which concentrated on the Teacher epithermal gold-silver showing hosted by feldspar porphyritic dykes in the northern part of the claim block. Ryan collected a float specimen of massive white quartz with minor limonite and malachite staining

Figure 12. *Partially exposed high-grade gold-quartz vein in an old hand trench on the White claims.*

which returned just over 50 g/t Au. Follow-up prospecting located a partially exposed quartz vein in what appeared to be a very old hand trench. The vein is exposed for approximately 10 m in strike length and over a 1-m width (Fig. 12). The true thickness of the vein was not determined. Mineralization in the vein consists of trace amounts of galena, tetrahedrite, malachite, limonite and visible gold.

Eagle Plains Resources optioned the **Severance** property (Yukon MINFILE 2003, 115J 003, Deklerk, 2003) located in the Dawson Range approximately 120 km west of Carmacks in south-central Yukon. Results from the property in 2002 outlined a coincident gold-copper-molybdenum-arsenic-in-soil anomaly with gold results up to 2680 ppb. A grab sample of silicified and quartz-veined granodiorite with disseminated pyrite returned 1.2 g/t Au and 0.35% Cu. The 2003 program consisted of prospecting, soil and silt sampling and a small ground electomagnetic survey.

Northgate Exploration funded an exploration program that included two phases of diamond drilling (Fig. 13) on StrataGold Corporation's **Hyland Gold** property (Yukon MINFILE 2003, 095D 011, Deklerk, 2003) located 70 km northeast of Watson Lake in southeastern Yukon. The property is underlain by phyllites, quartzites, quartz-feldspar pebble conglomerate and limestone of the Neoproterozoic to Lower Cambrian Hyland Group. These rocks are folded into an overturned east-verging antiformal structure. No large intrusive bodies are exposed on the property, however, the property is underlain by a prominent magnetic low feature, and a few narrow intrusive dykes are exposed on the claims. Previous percussion drilling on the property was directed at the near-surface iron-oxidized rock which returned values up to 2.65 g/t Au over 16.7 m and 1.19 g/t Au over 129.7 m. Diamond drilling of 12 holes totaling 2417 m tested approximately 2 km of the north-trending Quartz Lake lineament, a prominent topographic lineament which approximates the axial trace of the antiformal structure. All drill holes intersected significant mineralized rock along the west-dipping structurally controlled zone consisting of intense silicification and silica replacement of phyllites and quartzites with 5 to 20% total sulphide minerals. Sulphide minerals consist of pyrite-arsenopyrite with minor chalcopyrite, sphalerite, bismuthinite and tetrahedrite. Several holes intersected additional mineralized rock hosted by a series of hanging wall splays above the main mineralized structure.

Late in the season, approximately 150 km to the north of the Hyland property, Dentonia Resources optioned the **Hy** property (Yukon MINFILE 2003, 105H 102, Deklerk, 2003) from Phelps Dodge Corporation and staked the **Elf** property (Yukon

MINFILE 2003, 095E 052, Deklerk, 2003) which is 70 km south of Hy. The Hy and Elf claims are underlain by the Neoproterozoic to Lower Cambrian Hyland Group metasedimentary rocks, including quartzite, shale, quartz-pebble conglomerate, phyllite and limestone. No intrusive rocks have been identified on the Hy claims but a mid-Cretaceous Selwyn Suite intrusive stock does exist on the Elf. On the Hy, two areas of anomalous gold geochemistry have been previously outlined on the claims, and a chip sample from a quartz vein in phyllite returned 23.05 g/t Au. The Elf claims cover a 1200 by 400 m soil geochemical anomaly with peak values to 677 ppb Au, 639 ppm As and 323 ppb Bi. Dentonia staked additional claims late in 2003 and plans on commencing exploration on both properties in 2004.

Ross River Minerals Inc. conducted a program of geologic mapping, sampling and prospecting on the **Tay-LP** property (Yukon MINFILE 2003, 105F 121, Deklerk, 2003) in south-central Yukon. Semi-massive to massive sulphide mineralized rock consists of replacement-type pyrrhotite +/- pyrite, arsenopyrite and chalcopyrite in calcareous metasedimentary rocks, and similarly mineralized quartz-sulphide mineral veins. Recent interpretations of the glacial history of the property and area have shown up-valley glacial movement (Kennedy and Bond, this volume). This new information should help in interpreting the source areas of extensive mineralized float boulders found on the claims.

Figure 13. *Rob Duncan and Jason Dunning on StrataGold Corporation's Hyland Gold property.*

Highlights from drilling at Hyland Gold property.

	Interval (m)	Gold (g/t)	Silver (g/t)
HY03-01	17.22	1.29	13.85
including	3.82	3.56	49.79
HY03-02	28.0 m (oxide)	0.93	2.75
including,	4.89	1.31	6.96
including,	9.20	1.68	3.37
and	53.11 (sulphide)	1.38	3.54
including	5.54	4.24	4.96
HY03-08	4.10	1.31	1.91
HY03-09	4.73	0.98	19.46
and	12.35	0.98	5.31
HY03-10	6.52	0.63	1.00
and	5.30	0.62	1.52
HY03-11	5.55	0.69	2.96
HY03-12	9.82	0.76	13.35
and	9.63	1.57	43.76

Tagish Lake Gold Corp. continued with the advanced exploration of the **Skukum Creek** (Yukon MINFILE 2003, 105D 022, 025, Deklerk, 2003) gold-silver deposits located in the Wheaton River district south of Whitehorse. At the beginning of the year, Tagish Lake commissioned an independent technical report updating the resources at the Skukum Creek and Goddell Gully deposits. Significantly, at a 5 g/t Au-equivalent cutoff grade, the resources at Skukum Creek increased by 50% to a measured and indicated resource of 800 000 tonnes containing 6.77 g/t Au and 214 g/t Ag, and an inferred resource of 90 000 tonnes grading 6.53 g/t Au and 225 g/t Ag. Utilizing the same 5 g/t Au-equivalent cutoff grade, the following resources were calculated for Goddell Gully: indicated resources of 320 000 tonnes grading 11.02 g/t Au, and inferred resources of 280 000 tonnes grading 9.21 g/t Au, an increase of over 100%. A number of historical drill holes were not available for use in previous estimates because they were not surveyed. Tagish Lake was successful in using a continuous downhole surveying instrument that allowed the holes to be surveyed and included in the latest estimate. Bench-scale testwork conducted on mineralization from the Skukum Creek deposit utilizing extremely fine grinding demonstrated improved gold and silver recoveries. Leaching by cyanidation of the whole ore gave recoveries of over 85% for gold and 44% for silver. Flotation of a bulk sulphide mineral concentrate and fine regrinding of the sulphide mineral concentrate followed by cyanidation resulted in gold recoveries of 90% and silver of 40%.

At the Skukum Creek property, the 1300-m level was extended by 400 m along strike from the deposit to provide access for underground diamond drilling of the Ridge zone. The extension intersected a quartz-sulphide mineral vein (Fig. 14) that is on-strike with zone 2 of the Ridge zone which was intersected 200 metres to the west by surface drilling (8.44 g/t Au, 260 g/t Ag over 11.67 m). Underground chip-sampling of the zone at 3-m intervals over a strike length of 15 m returned a weighted average of 29.39 g/t Au and 280 g/t Ag over an average width of 0.37 m. An additional zone of massive to disseminated pyrrhotite-chalcopyrite-sphalerite not typical of the mineralization at Skukum Creek was intersected in the diamond drill crosscut. Samples from this zone returned 1.0 m of 0.8 g/t Au and 109 g/t Ag; 0.8 m of 4.2 g/t Au and 170 g/t Ag; and 1.5 m grading 21.0 g/t Au and 159 g/t Ag. Underground drilling of the extension vein and the diamond drill crosscut vein to test continuity of the zones with Skukum Creek and the Ridge zone commenced in late November.

Figure 14. *Quartz-sulphide mineral vein exposed in the underground extension at the Skukum Creek property.*

At the Goddell Gully deposit, a review of core from 1997 revealed unsampled mineralization. Sampling of hole 97-56 increased the previously reported intersection of 0.66 m grading 3.57 g/t Au to 19.82 m grading 2.37 g/t Au including 2.91 m at 8.49 g/t Au. Hole 97-56 is located 225 m to the west of the presently outlined resource block that has a

Figure 15. *Intersection from drill hole GG03-1 in the Goddell Gully deposit of Tagish Lake Gold.*

strike length of 450 m, as generated in the resource model. This hole demonstrates the potential of the deposit to continue along strike to the west and indicates that a significant increase in resources is possible. Hole GG03-01 (Fig. 15) was drilled from surface and intersected the mineralized zone approximately 25 m below and 10 m west of hole 97-56. GG03-01 intersected 26.92 m grading 2.46 g/t Au, including 9.01 m grading 5.00 g/t Au. Hole GG03-02 intersected the zone approximately 60 m west of hole 97-56 and returned 1.86 m grading 1.38 g/t Au and, at a second intersection, 2.56 m grading 2.03 g/t Au.

PLATINUM GROUP ELEMENTS

Tom Morgan explored his **Ultra** claims (Yukon MINFILE 2003, 115B 008, Deklerk, 2003; Galambos, this volume) near Haines Junction in southwestern Yukon with geophysical surveys (max-min and magnetometer), blast trenching and sampling. The Frohberg showing on the claims consists of veins of mainly chalcopyrite with minor pyrite and pyrrhotite near the margin of a mafic sill. Sampling by Morgan returned values up to 5.5 g/t Pt, 13.5 g/t Pd, 4% Cu and 1.7% Ni. Geophysical surveys were directed at helping define a source area for several large zinc-copper boulders with volcanogenic massive sulphide mineralized rocks that have assayed up to 5.1% Zn and 2.1% Cu. The survey produced several good conductors.

Gord Mcleod continued to evaluate his **Holdfast** property (Yukon MINFILE 2003, 105C 012, Deklerk, 2003) located approximately 80 km southeast of Whitehorse and 3 km north of the Alaska Highway. Chromite-bearing dunite hosted in an ophiolitic sequence of mafic to ultramafic rocks on the claims returned values (utilizing NiS fusion analysis) of up to 406 ppb Os, 417 ppb Ir, 683 ppb Ru, 70 ppb Rh, 159 ppb Pt and 5 ppb Pd for a total contained PGEs (platinum group elements) of 1740 ppb.

Figure 16. *Kennecott Canada Exploration's Lucky Joe camp.*

BASE METALS

Kennecott Canada Exploration optioned the **Lucky Joe** copper-gold property (Yukon MINFILE 2003, 115O 051, Deklerk, 2003; Fig. 16), located 50 km south of Dawson City, from Copper Ridge Exploration. Kennecott conducted a helicopter-supported regional-scale geological mapping and soil sampling program covering an area roughly 10 km by 40 km. Detailed work, including limited mechanical trenching, was also completed in the areas of known mineralized rock identified in 2002 by Copper Ridge. Chalcopyrite with minor pyrite, pyrrhotite and molybdenite at Lucky Joe are hosted in a blanket-like layer in biotite-muscovite schist and orthogneiss overlain by a magnetite-bearing amphibolite. The 2003 work defined two large parallel geochemical trends. The Lucky Joe trend is 11.3 km long and defined by anomalous copper and gold, with peak values of 3060 ppm Cu and 235 ppb Au, and associated silver and molybdenum. The copper-gold zone extends outward into a lead and zinc halo that together outlines a hydrothermal system over 21 km long and up to 3 km wide. The Ryan's Creek trend parallels the Lucky Joe trend approximately 4 km to the southwest. This trend, defined by anomalous copper and gold geochemistry, is 7.2 km long and has peak values of 4400 ppm Cu and 611 ppb Au. The geologic setting, alteration patterns and geochemistry of the rocks and mineral showings at Lucky Joe have outlined a large hydrothermal system representing a porphyry copper-gold or an iron-oxide-copper-gold (IOGC) mineralizing system.

Shawn Ryan, the underlying vendor on the Lucky Joe property, staked several properties in the vicinity of the Lucky Joe based on similar geology and a similar geophysical expression. Ryan conducted geochemistry and a 25 line-km ground magnetic survey on his Australia property. The surveys revealed a geophysical expression and geochemical signature similar to that of the Lucky Joe property.

Canadian Empire Exploration conducted a program of geophysics on the **Yukon Olympic** property (Yukon MINFILE 2003, 116G 082, Deklerk, 2003), an iron-oxide-copper-gold target optioned from Copper Ridge Exploration. The program included detailed gravity surveys, Induced Polarization and magnetic surveys, and mobile metal ion (MMI) geochemical surveys. The Yukon Olympic property is located just off the Dempster Highway, 130 km north of Dawson City. In Yukon, 'Wernecke Breccias' intruding Proterozoic rocks have many similarities to the giant Olympic Dam deposit in Australia. Wernecke Breccias are the same age as the breccias hosting the Olympic Dam deposit and have many of the same physical and mineralogic characteristics. Recent tectonic reconstructions indicate that Yukon and eastern Australia were part of the same landmass 1.6 billion years ago at the time of breccia formation (Thorkelson et al., 2001). Previous work on the Yukon Olympic has outlined a 2 mGal gravity anomaly flanked by a magnetic anomaly and intermittently outcropping copper-bearing hematite breccia which assayed up to 0.9% Cu.

Monster Copper drilled a single diamond drill hole on the Monster property (Yukon MINFILE 2003, 116B 102, 103, Deklerk, 2003), under option to Orezone Resources, located in the Ogilvie Mountains north of Dawson City. The single hole targeted a gravity anomaly associated with occurrences of copper-gold hosted by hematitic breccia bodies and hydrothermal siderite veining. Drilling intersected intrusive hydrothermal breccia that did not contain any significant mineralized rock.

Copper Ridge Exploration acquired the **Hart River** iron-oxide-copper-gold property (Yukon MINFILE 2003, 116A 009, Deklerk, 2003) in the Hart River area to the east of the Yukon Olympic property (Fig. 17). The claims cover a new occurrence of 'Wernecke Breccia' where preliminary sampling has returned values up to 1.76% Cu in grab samples and 0.83% Cu over 3.2 m in chip sampling. Gold values up to 2.4 g/t have been obtained.

Grid Capital Corp. conducted a five-hole, 800-m diamond drilling program on the **Ami** property (Yukon MINFILE 2003, 115N 039, 040, Deklerk, 2003) located in the Sixtymile River area west of Dawson City. Diamond drilling followed an Induced Polarization survey that produced anomalies coincident with zones of anomalous gold, silver, lead, arsenic, copper and molybdenum soil geochemistry. The property is underlain by a Cretaceous, magnetite-rich, multiphase granitic stock. Mineralization on the property consists of porphyry-style copper-molybdenum and high-grade silver-lead veins. Drilling intersected weakly altered quartz monzonite mineralized with disseminated pyrite, chalcopyrite and molybdenite, however no significant values were returned. One hole targeted a high-grade lead-silver vein and intersected 0.64 m grading 22.1% Pb, 2085.5 g/t Ag and 1.13 g/t Au.

Figure 17. *Hematitic 'Wernecke Breccia' boulder on the Hart River property of Copper Ridge Exploration.*

Wildrose Resources and Sargold Resources completed an exploration program consisting of grid soil sampling on their **Canadian Creek** copper-gold-molybdenum property (Yukon MINFILE 2003, 115J 035, 036, 101, Deklerk, 2003), 150 km south of Dawson. This survey indicates a coherent copper-gold-molybdenum anomaly covering an area of approximately 900 m by 600 m within the bounds of this grid. Soil gold values for the 2003 survey range from 2.0 to 1609.0 ppb, with a mean value of 66.5 ppb; copper ranges from 13.4 to 334.1 ppm with a mean value of 79.6 ppm; and molybdenum ranges from 0.5 to 84.7 ppm with a mean value of 7.8 ppm. The eastern boundary of the grid is approximately 700 m

Figure 18. *Viewing core at the Logan deposit optioned by Expatriate Resources.*

west of the Casino deposit (Yukon MINFILE 2003, 115J 028, Deklerk, 2003) currently owned by Lumina Copper Corp. The Casino deposit has published measured and indicated resources of 103 million tonnes of supergene sulphide material grading 0.35% Cu, 0.32 g/t Au and 0.03% Mo, plus 323 million tonnes of hypogene material grading 0.26% Cu, 0.28 g/t Au and 0.03% Mo (C.M Rebagliati, PEng, and Ross Banner, PEng, Jan. 23, 2003, Qualifying report Casino property, Yukon, prepared for CRS Copper Resources Corp. and First Trimark Ventures Inc. and filed on SEDAR by Lumina Copper Corp. on March 27, 2003).

Expatriate Resources Inc commissioned Hatch Associates Ltd. to undertake preliminary engineering and economic studies into the Yukon Zinc Project. The Yukon Zinc Project consists of the **Wolverine** project (Yukon MINFILE 2003, 105G 072, Deklerk, 2003) located in the Finlayson Lake Massive Sulphide District and the **Logan** deposit (Yukon MINFILE 2003, 105B 099, Deklerk, 2003) located approximately 100 km west of Watson Lake. The combined resources of the two deposits are 18.5 million tonnes containing 1.5 billion kg (3.4 billion lb) Zn, 83 million kg (183 million lb) Cu, 96.6 million kg (213 million lb) Pb, 2.6 billion g (85 million troy oz) Ag and 11 billion g (350,000 troy oz) Au. The project proposes hauling ore from the high-grade Wolverine deposit approximately 200 km to mine and mill facilities at the Logan deposit (Fig. 18). Upon successful completion of the engineering and economic studies, Expatriate is planning extensive exploration, metallurgical, geotechnical and environmental studies at the Logan and Wolverine deposits in 2004.

GEMSTONES

True North Gems Inc conducted an advanced exploration program on their **Regal Ridge** emerald property (Yukon MINFILE 2003, 105G 147, Deklerk, 2003; Neufeld, this volume) located in the Finlayson Lake District of south-central Yukon. Early in the season, True North signed a memorandum of understanding with the Ross River

Figure 19. Portal site at Regal Ridge. The southwest vein is visible in the trench face (dashed line indicates zone).

Dena Council that acknowledged True North's ownership of the Regal Ridge property, and established a framework for creating economic partnerships with the Kaska First Nation in support of mineral exploration. The 2003 program consisted of construction of an airstrip, upgrading of the camp facilities and the sorting plant, diamond drilling, and underground (Fig. 19) and surface bulk-sampling.

The 2003 exploration resulted in the discovery of 3 new emerald-bearing zones, bringing the total number of zones to 13. The area of mineralization was doubled to 1500 m in length, 500 m in width and over 200 m of vertical section. Underground exploration was successful in following a continuous zone of emerald mineralization in the Southwest zone; and the newly discovered Mattscar zone

Figure 20. Surface bulk sampling under close geological control at Regal Ridge.

produced high concentrations of emerald mineralization including coarse gem and near-gem grade rough emerald crystals ranging in size from 1.4 to 9.9 carats.

Underground bulk-sampling produced 2029 tonnes of mineralized material, and surface sampling (Fig. 20) produced an additional 1781.2 tonnes from the Mattscar zone. From the underground bulk sample, a random sample of 272.7 tonnes of material was processed and produced 1429.2 carats of gem quality emeralds and 2938.94 carats of near-gem emeralds. All emeralds sorted measured in excess of 2 mm. From the underground material, a 2.39 carat emerald was cut from a 16.55 carat rough stone. Eight pits were dug on the Mattscar zone. In Pit 1, 192.4 tonnes of material was processed and produced 1206.5 carats of gem quality emeralds and 11 674.85 carats of near-gem quality emeralds were recovered. Detailed information on gem counts are available on the company's website. The company intends to have a representative parcel of finished gem, near-gem and non-gem material for tendered auction in late January, 2004.

True North also conducted testwork utilizing high-intensity magnetic separation and dense media separation in order to determine the feasibility of automating the extraction of emeralds in concentrates. The magnetic separation was highly successful in recovering 95% of the emeralds from initial testing. Results from dense media separation are pending. Automation of the emerald recovery process is a significant factor in reducing the overhead costs of recovering the emeralds from the Regal Ridge Project.

True North Gems also conducted regional exploration on targets defined through evaluation of proprietary information acquired from Archer Cathro and Associates (1981) Limited and research financed by the company from the University of British Columbia. The regional exploration was conducted by Bill Wengzynowski (discoverer of the Regal Ridge emeralds) of Archer Cathro and Associates and Dr. Lee Groat of the University of British Columbia. The regional exploration was successful in discovering at least one significant new gemstone discovery in 2003. Late in the season, True North announced the discovery of the True Blue beryl, a unique form of aquamarine. A mini-bulk sample was collected from the **True Blue** property (Yukon MINFILE 2003, 105F 081, Deklerk, 2003) which yielded 57.9 g of gem-grade blue beryl with individual crystals up to 38 by 11 mm. The blue beryls have an unusually intense saturation of blue colour and may be a new type of gemstone. A suite of faceted stones will be formally characterized by the Gemological Institute of America.

Firestone Ventures Inc. entered into the gemstone hunt by optioning the **Four Corners** property (Yukon MINFILE 2003, 105A 034, Deklerk, 2003) from Strategic Metals Ltd. and the Meg, Rusty, Lion and Straw properties from True North Gems. The Straw property is located 5 km southeast of Regal Ridge and covers a geological setting that is nearly identical to that at Regal Ridge. Geological mapping, geochemistry and prospecting were successful in delineating a zone of abundant black tourmaline within chlorite schist and alteration of the schist to the distinctive 'golden schist' that is associated with emerald mineralization at Regal Ridge. Anomalous beryllium and chromium in soils are also associated with the zone. Beryl mineralization consisting of white to pale green, opaque crystals up to 1.2 by 4 cm were also discovered in a tourmaline-bearing pegmatite dyke (Fig. 21).

On the Four Corners property, anomalous beryllium and chromium geochemistry was outlined in a 200 by 100 m zone, where rusty-weathering golden schist within

Figure 21. Light green, opaque beryl mineralization from the Straw property (indicated by dashed outline). Close to actual size.

the Fire Lake unit and abundant black tourmaline and quartz-tourmaline veins, similar to mineralization and alteration at Regal Ridge, were noted. In another area on the claims, an opaque to translucent, pale blue-green beryl crystal 1.3 by 1.7 cm was discovered in a tourmaline-bearing pegmatite dyke. Firestone also discovered gold mineralization on the claims. Grey-green siliceous boulders were sampled within a 100-m-long talus train. A chip sample from a 70-cm boulder returned 4.28 g/t Au, 2.64 g/t Ag, 513 ppm Ni, 954 ppm Cr, and elevated arsenic and antimony. Anomalous gold-in-soil samples up to 591 ppb were obtained up to a kilometre to the northeast of the talus train.

Hinterland Metals Inc. also conducted exploration in the Finlayson Lake district searching for gemstones on the **Gleam** and **Dazzle** properties (Yukon MINFILE 2003, 105G 030, 031, 120, Deklerk, 2003) optioned from True North Gems. Hinterland conducted geological mapping and stream sediment geochemistry on the properties originally staked due to their similar geologic setting to the Regal Ridge property located 25 km to the southeast. Anomalous beryllium-in-silt samples were obtained from creeks draining the contact of a mid-Cretaceous granite and Fire Lake metavolcanic rocks on the Dazzle property. During the course of exploration, Hinterland discovered gem-quality chrysoprase hosted in a subhorizontal metavolcanic unit of uncertain thickness that is traceable on surface for 1900 ft. Chrysoprase is a green, potentially gem-quality, cryptocrystalline variety of chalcedony that is used to make beads, cabochons and carved figures. Hinterland is encouraged that it may be able to generate an immediate cash-flow from this discovery. Hinterland also discovered a new gold showing during their exploration program. The showing consists of a vertical zone of massive to semi-massive quartz-sulphide mineralized veins hosted within a granitic intrusion (Fig. 22).

Figure 22. Mark Fekete, President, Hinterland Metals at the new gold-silver vein discovery on the Gleam property.

Chip sampling across the zone returned a weighted average of 3.86 g/t Au and 48.1 g/t Ag over 5.0 m.

International Arrimex Resources Inc. conducted emerald exploration on the **Glitter** property optioned from True North Gems. The Glitter claims are located 12 km east of Regal Ridge. Geological mapping, soil sampling and prospecting were successful in outlining two parallel trends of anomalous beryllium, chromium and fluorine in an area hosting favourable geology.

Arcturus Ventures Inc. conducted a short program of geological mapping, soil and silt sampling and prospecting on their **RB**, **First Base** and **Fife** properties (Yukon MINFILE 2003, 105G 126, 142, Deklerk, 2003) located near Regal Ridge. The properties host geology with potential for emeralds but also have excellent potential for volcanogenic massive sulphide deposits similar to the nearby Fyre Lake.

Strategic Metals conducted exploration for coloured gemstones on a number of properties in the Finlayson district, as well as on other properties such as **Northern Dancer**. Northern Dancer (Yukon MINFILE 2003, 105B 039, Deklerk, 2003) is host to abundant blue beryls (aquamarines) associated with pegmatite dykes and quartz veins. Crystals up to 1 cm in diameter have been previously reported. Results from exploration on Strategic's other gemstone properties, beyond a report of mineralogical studies confirming a green chromium-rich beryl from one property, have not been released.

Figure 23. *Light blue beryl crystals in drill core from the Goddess (Pluto) property.*

Aquamarine crystals have also been reported from the **Pluto** property (Yukon MINFILE 2003, 116C 134, Deklerk, 2003) located 50 km northwest of Dawson City. The property was explored by Cominco in the early 1980s for porphyry molybdenum in an early Tertiary quartz porphyry pluton. In drill logs, Cominco geologists noted numerous pegmatites containing blue beryl (Fig. 23) and quartz-tourmaline veins intruding the surrounding ultramafic rocks. The property was restaked by Klondike Exploration (Shawn Ryan) as the Goddess claims.

Patrician Diamonds Inc. revealed in a press release in early November, 2003 that they had been conducting regional till sampling in 2002 and 2003 in Yukon. Sampling in 2002 had yielded four diamonds, the largest measuring 1.04 by 0.80 by 0.72 mm. The samples also contained kimberlitic ilmenites and chromites, plus blue and pink sapphires. A portion of the 2003 sampling that is being processed at the Saskatchewan Research Council laboratories recovered a total of 10 diamonds, G9 pyrope garnets, chrome diopside, Mg-chromite, picroilmenite and forsteritic olivine. The 2003 samples also contained abundant sapphire. Patrician was conducting a staking campaign late in the season covering potential source rocks and geophysical anomalies. Results from a further round of sampling were also pending at year-end.

ACKNOWLEDGEMENTS

This report is based on public information gathered from a variety of sources. It also includes information provided by companies through press releases, property summaries provided to the department by companies and from property visits conducted in the 2003 field season. The cooperation of companies in providing information, as well as their hospitality and access to the property during field tours, are gratefully acknowledged. Editing by Lara Lewis and Diane Emond is greatly appreciated.

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APPENDIX 1: 2003 DRILLING STATISTICS[1]

		DIAMOND DRILL	
PROPERTY	**COMPANY**	**metres**	**# holes**
Ami	Grid Capital Corp.	800	5
Aurex	StrataGold Corp.	3991	25
Goddell Gully	Tagish Lake Gold Corp.	975	3
Grew Creek	Al Carlos	442	7
Hyland Gold	Northgate Exploration/ Stratagold Corp.	2417	12
Ice	ASC Industries Ltd.	1369	10
McQuesten	Spectrum Gold Inc./ Eagle Plains Resources	3050	18
Monster	Monster Copper Resources	194.5	1
Pike	Strategic Metals Ltd.	295	4
Red Mountain	Regent Ventures Inc.	442.5	1
Regal Ridge	True North Gems Inc.	630	14
Scheelite Dome	Copper Ridge Exploration	310	5
Skukum Creek	Tagish Lake Gold Corp.	284	5
TOTAL		15 200	

[1]*Note: No percussion drilling was carried out this year.*

APPENDIX 2: 2003 EXPLORATION PROJECTS

PROPERTY	COMPANY/OWNER	MINING DISTRICT	MINFILE # or (1:50 000 NTS)	WORK TYPE	COMMODITY
1st Base	Arcturus Ventures Inc.	Watson Lake	105G 031	G,GC	Cu-Pb-Zn-Ag-Au
Ami	Grid Capital Corporation	Dawson	115N 039,040	G,GP,DD	Cu-Mo, Ag-Pb-Au
Aurex	StrataGold Corporation	Mayo	105M 060	G,GC,GP,DD	Au
Brewery Creek	Viceroy Resources	Dawson	116B 160	G,Reclamation	Au
Box	Expatriate Resources	Watson Lake	(105G/10)	G,GP	Cu-Pb-Zn-Ag-Au
Box Car	Shawn Ryan	Dawson	115N 071	GC,GP,T	Cu-Pb-Ag-Au
Canadian Creek	Sargold Resources/ Wildrose Resources	Whitehorse	115J 035,036,101	G,GC	Cu-Mo-Au
Canadian Olympic	Copper Ridge Exploration/Canadian Empire Exploration	Dawson	116G 082	G,GC,GP	Cu-Au
Dazzle/Gleam	Hinterland Metals Inc./True North Gems Inc.	Watson Lake	105G 030,031,120	G,GC,P	gemstones, Au
Dawson project	Klondike Gold	Dawson	115O 072,077	GC,T	Au
Finlayson	Entourage Mining/ Expatriate Resources	Watson Lake	105G various	G,GC,P	gemstones
Four Corners	Firestone Ventures/ Strategic Metals Ltd.	Watson Lake	105A 034, etc.	G,GC,P	gemstones, Au
Glitter	International Arimex Resources Inc./True North Gems Inc.	Watson Lake	(105G/8)	G,GC,P	gemstones
Grew Creek	Al Carlos	Whitehorse	105K 009	DD	Au-Ag
Goddell Gully	Tagish Lake Gold Corp.	Whitehorse	105D 025	DD	Au-Ag
Hart River IOCG	Copper Ridge Exploration	Mayo	(116A/15)	G,GC,P	Cu-Au
Heidi	Logan Resources	Dawson	116A 037	G,GC,GP,P	Au
Hold Fast	Gordon McLeod	Whitehorse	105C 012	G,GC	Cr-PGE
Hy/Fer	Dentonia Resources	Watson Lake	105H 102		Ag-Pb-Zn
Hyland Gold	Northgate Exploration/ StrataGold Corp.	Watson Lake	95D 011	G,GC,DD	Au
Ice	ASC Industries Ltd.	Mayo	115P 006	G,GC,GP,DD	Au
Lion	Firestone Ventures Inc./True North Gems Inc.	Watson Lake	(105G/8)	G,GC,P	gemstones
Logan	Expatriate Resources	Watson Lake	105B 099	G	Zn-Pb-Ag
Lucky Joe	Kennecott Canada Exploration/Copper Ridge Exploration	Dawson	115O 051	G,GC,T	Cu-Au

continued...

Abbreviations:

BS – bulk sample
D – development
DD – diamond drilling
ES – environmental studies
F – feasibility
G – geology
GC – geochemistry
GP – geophysics
M – mining
PD – percussion drilling
PF – prefeasibility
R – reconnaissance
T – trenching
U/GD – underground development

APPENDIX 2 (continued): 2003 EXPLORATION PROJECTS

PROPERTY	COMPANY/OWNER	MINING DISTRICT	MINFILE # or (1:50 000 NTS)	WORK TYPE	COMMODITY
Lynx Creek	Expatriate Resources	Mayo	106D 020	G,GC,GP	Au
McQuesten	SpectrumGold Inc./ Eagle Plains Resources	Mayo	105M 029	DD	Au
Mahtin	Shawn Ryan	Mayo	115P 007	G,GC,GP,P	Au
Marn	Canadian United Minerals	Dawson	116B 147	G,GP,P	Au-Cu
Mars	Saturn Ventures Inc.	Whitehorse	105E 002	G,GC	Cu-Au
Meg	Firestone Ventures/ True North Gems Inc.	Watson Lake	(105G/7)	G,GC,P	gemstones
Minto	Minto Resources	Whitehorse	115I 021,022	D	Cu-Ag-Au
Monster	Monster Copper Resources/ Orezone Resources	Dawson	116B 103	DD	Cu-Au
Mt. Hinton	Yukon Gold Corporation	Mayo	105M 052	T	Au
Pike	Strategic Metals Ltd.	Mayo	106E 040	DD	Au
Pluto	Shawn Ryan	Dawson	116C 134	G,GC	gemstones
Red Mountain	Regent Ventures Inc.	Mayo	115P 006	G,GC,GP,DD	Au
Regal Ridge	True North Gems Inc./ Expatriate Resources	Watson Lake	105G 147	G,GC,T,DD,BS	emeralds
Rusty	Firestone Ventures/ True North Gems Inc.	Watson Lake	(105G/7)	G,GC,P	gemstones
Severance	Eagle Plains Resources	Dawson	115J 003	G,GC,GP	Au
Shamrock	Copper Ridge Exploration	Dawson	(115O/6)	GC	Cu-Au
Scheelite (Tom)	Golden Patriot Resources/Copper Ridge Exploration	Mayo	115P 003	G,GP,DD	Au
Skukum Creek	Tagish Lake Gold Corp.	Whitehorse	105D 022,025,158	G,GC,DD	Au-Ag
Straw	Firestone Ventures/ True North Gems Inc.	Watson Lake	(105G/8)	G,GC,P	gemstones
Tay/LP	Ross River Minerals Inc.	Whitehorse	105F 121	G,GC	Au
Ten/Flume	Fjordland Exploration	Dawson	115N 110,163	G,GC	Au
True Blue	True North Gems Inc.	Whitehorse	105F 081	G,GC,P	gemstones
Ultra	Tom Morgan	Whitehorse	115B 008	G,GC	Ni-Cu-PGEs; Zn-Cu-Au-Ag
White	Klondike Exploration	Whitehorse	105O 011,012	G,GC,P	Au, Cu

Abbreviations:
BS – bulk sample
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G – geology
GC – geochemistry
GP – geophysics
M – mining
PD – percussion drilling
PF – prefeasibility
R – reconnaissance
T – trenching
U/GD – underground development

YUKON PLACER MINING OVERVIEW, 2003

William LeBarge[1]
Yukon Geological Survey

LeBarge, W., 2004. Yukon Placer Mining Overview, 2003. *In:* Yukon Exploration and Geology 2003, D.S. Emond and L.L. Lewis (eds.), Yukon Geological Survey, p. 27-30.

Placer mining continued to be an important Yukon industry in 2003. Although the number of mines at 125, decreased by 10% since 2002, direct employment held steady in 2003 at around 400. In addition, approximately 600 jobs were generated in related service and hospitality sectors. In small population centres such as Dawson and Mayo, the placer industry is a major contributor to the local economy. The majority of active placer mining operations were in the Dawson Mining District (83) followed by the Whitehorse Mining District (32) and the Mayo Mining District (10).

For 2003, over 85% of the Yukon's placer gold was produced in the Dawson Mining District, which includes the unglaciated drainages of Klondike River, Indian River, west Yukon (Fortymile and Sixtymile rivers and the Moosehorn Range) and lower Stewart River (Fig. 1). The remaining gold came from the glaciated Mayo and Whitehorse mining districts, which include the placer areas of Clear Creek, Mayo, Dawson Range, Kluane, Livingstone and Whitehorse South.

Reported placer gold production from Indian River drainages decreased compared to the previous year, from 23,745 crude ounces (738 550 g) to 16,126 crude ounces (501 570 g). Klondike River area drainages only saw a slight decrease to 16,582 crude ounces (515 760 g) from the 2002 total of 18,613 crude ounces (578 930 g); this was at least partly because Last Chance Creek production remained steady while Hunker Creek production actually increased slightly.

A fairly significant drop in production from both Sixtymile River and Miller Creek resulted in West Yukon (Sixtymile, Fortymile and Moosehorn) recording only 6264 crude ounces (194 800 g) compared to 9515 ounces (295 900 g) in 2002.

Although reported gold recovered from Black Hills Creek nearly doubled, it wasn't enough to offset 50% decreases in Henderson and Mariposa creeks, and a 75% decrease from Thistle Creek. This resulted in a total of only 3912 crude ounces (121 700 g) reported for the Lower Stewart River placer area, compared to 8151 crude ounces (253 500) reported in 2002.

A very small amount of gold was reported from the Clear Creek area, 229 crude ounces (7120 g), which was nearly the same as the 2002 total of 214 crude ounces (6660 g).

In the Dawson Range, reported placer gold production remained steady with 1664 crude ounces (51 760 g) compared to 1720 crude ounces (53 500 g) reported in 2002.

Mayo area drainages also reported similar figures with 1894 crude ounces (58 910 g) compared to 1694 crude ounces (52 690 g) in 2002. While Duncan Creek production reportedly decreased, this was offset by increases on Lightning, Owl and Swede creeks.

In the Kluane area, production in 2003 decreased by ~25% with 1619 crude ounces (50 360 g) reported. The cessation of mining on Fourth of July Creek was the major factor.

The Livingstone area remained inactive with no reported gold production.

In Whitehorse South drainages, the first gold production reported since 1993 came from Iron Creek, a tributary of Sydney Creek. The 25.4 crude ounces of gold (790 g) was derived from a small mining

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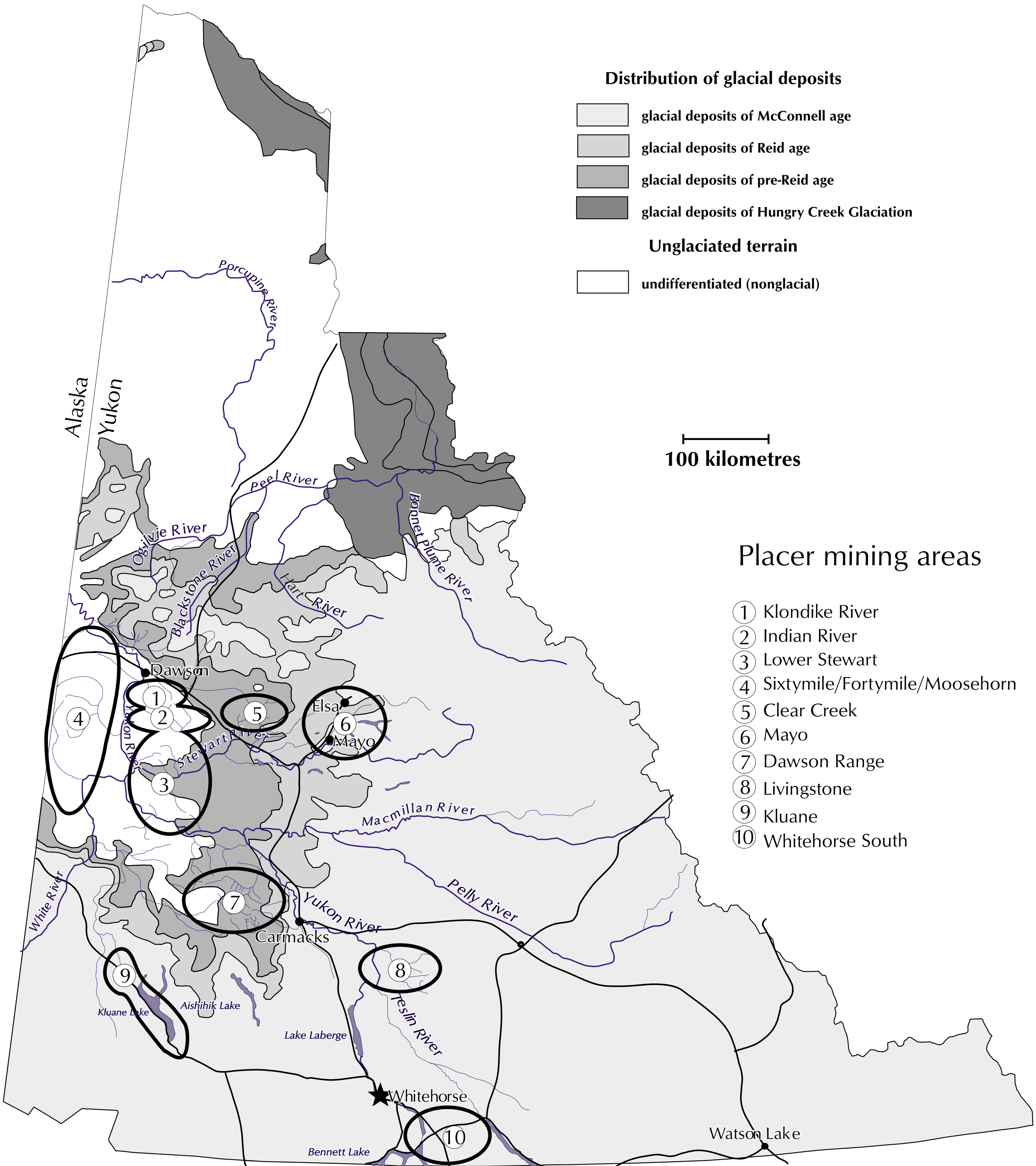

__Figure 1.__ Placer mining areas and distribution of glacial deposits in Yukon.

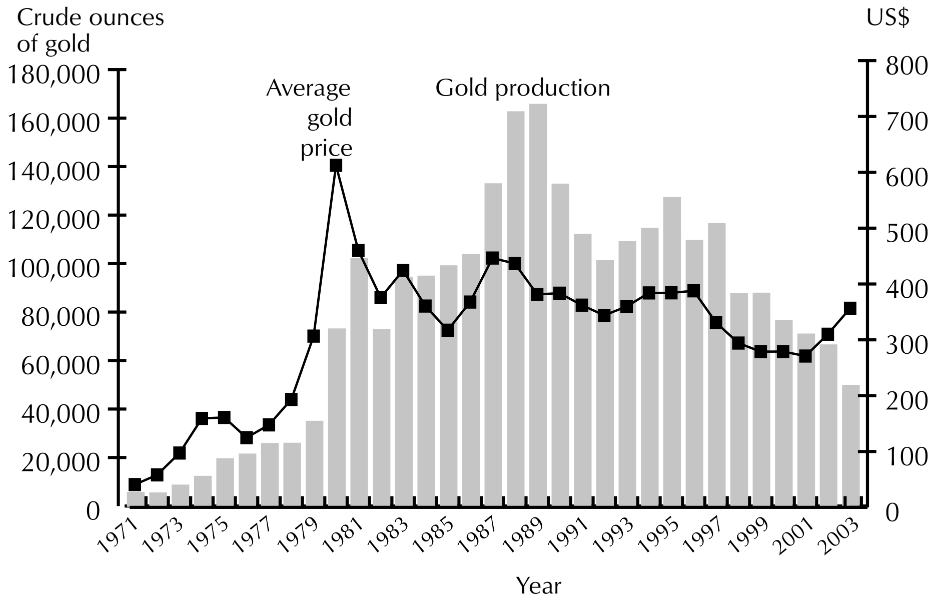

Figure 2. *Yearly gold production figures and average US gold price for the Yukon, 1971-2003.*

operation at the confluence of Iron and Sydney creeks. In addition, significant testing programs occurred on Moose Brook and Wolverine Creek.

In summary, the Yukon placer gold production in 2003 totalled 50,887 crude ounces (1 582 800 g), compared to 66,347 crude ounces (2 063 600 g) in 2002, which represents a 24% decrease (Fig. 2). Since 1999, placer gold production has dropped 43% to a level not seen since 1979. Although the world market price of gold continued to rise throughout 2002 and 2003, so did the Canadian dollar, and the effective value of gold for Yukon placer miners remained the same. The total dollar value of Yukon placer gold produced in 2003 was approximately $20.6 million, down from the $25.8 million generated in 2002.

APERÇU DE L'EXPLOITATION DES PLACERS AU YUKON EN 2003

L'exploitation de gîtes placériens est demeurée importante au Yukon en 2003. Même si le nombre de mines (125) a diminué de 10 % depuis 2002, les employés directs se sont maintenus autour de 400 en 2003. De plus, environ 600 emplois ont été créés dans les secteurs connexes des services et de l'accueil. Dans les petites agglomérations, comme Dawson et Mayo, l'exploitation des placers est un élément important de l'économie locale. La majorité des placers exploités étaient situés dans le district minier de Dawson (83), suivi du district de Whitehorse (32) et du district de Mayo (10).

En 2003, plus de 85 % de l'or placérien au Yukon provenait du district minier de Dawson où se trouvent les bassins de drainage non glaciaires de la rivière Klondike, de la rivière Indian et de l'ouest du Yukon (les rivières Fortymile et Sixtymile et le chaînon Moosehorn) et de la basse rivière Stewart. Le reste de l'or provenait des districts miniers glaciaires de Mayo et de Whitehorse où sont situés les placers de Clear Creek, Mayo, Dawson Range, Kluane, Livingstone et Whitehorse South.

En résumé, la production d'or placérien au Yukon en 2003 a totalisé 50 887 onces brutes (1 582 800 g); elle avait atteint 66 347 onces brutes (2 063 600 g) en 2002, ce qui représente un recul de 24 %. Depuis 1999, la production d'or placérien a chuté de 43 %, niveau qui n'avait pas été atteint depuis 1979. Comme le prix du marché mondial de l'or a poursuivi son ascension en 2002 et 2003, à l'instar du dollar canadien, la valeur réelle de l'or pour les placers du Yukon est demeurée la même. La valeur totale de l'or placérien au Yukon en 2003 s'est élevée à environ 20,6 millions de dollars, ce qui constitue un glissement par rapport aux 25,8 millions de dollars de 2002.

Yukon Mining Incentives Program, 2003

***Ken Galambos*[1]**
Mineral Resources Branch, Yukon Government

Galambos, K., 2004. Yukon Mining Incentives Program, 2003. *In:* Yukon Exploration and Geology 2003, D.S. Emond and L.L. Lewis (eds.), Yukon Geological Survey, p. 31-36.

The Yukon Mining Incentives Program (YMIP) received 93 applications by this year's deadline of March 1. A total of $987,000 was offered to 61 successful applicants. Nine of these were approved under the Grassroots-Prospecting module, 19 were part of the Focused Regional module, and 33 were approved under the Target Evaluation module.

With the increased price of gold on the world market, applicants were well poised with their exploration targets this season. Precious metal exploration under the program was up significantly; 56% of the applicants searched for gold and platinum group elements. Base metal exploration accounted for 30% of approved programs, while the remaining 14% of programs explored for gemstones and other commodities. Exploration programs were proposed for all four mining districts and were fairly evenly dispersed over the entire territory. This year there have been four option agreements signed for properties that have been explored under YMIP, with at least five more currently under negotiations.

Highlights for the year, for both placer and hard rock exploration programs, include the discovery of significant gold and pathfinder anomalies in both soils and rock, and the extension of known showings through prospecting and geophysics.

GRASSROOTS-PROSPECTING PROGRAMS

NUR

Peter Ross staked the Nur property, on the flanks of Mt. Haldane, north of Mayo, to cover anomalous soil geochemistry identified from previous exploration. The claims cover prospective geology very similar to that at the nearby McQuesten and Aurex properties (Yukon MINFILE 2003, 105M 029, 060, Deklerk, 2003). Soil surveys conducted this summer confirmed and expanded previous anomalies. Fourteen percent of the soils taken returned anomalous values greater than 20 ppb and up to 63 ppb Au. Fifty-eight percent returned values greater than 500 ppm and up to 9785 ppm As. The survey identified anomalous trends up to 135 m wide and in excess of 1500 m in length.

Figure 1. *Shawn Ryan indicates the apparent dip of a quartz vein containing visible gold. The vein returned values of 13.5 and 50 g/t Au.*

SOUTH DAWSON

Shawn Ryan believes his south Dawson property (Yukon MINFILE 2003, 115O 011, 012, Deklerk, 2003) covers a mineralized system that is at least 2 km x 5 km in size. Samples from a flat-lying quartz vein (Fig. 1) with minor

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***Figure 2.** Silicified and brecciated siltstone such as this, assayed up to 24 g/t Au.*

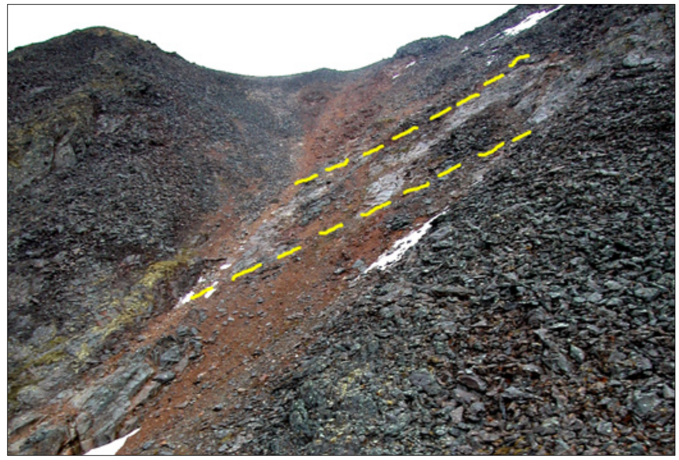

***Figure 3.** Variably mineralized beds shedding talus containing pyrite, chalcopyrite and various copper oxides.*

tetrahedrite (?) and visible gold returned assays of 50 and 13.5 g/t Au. This vein is located at the top of a ridge line and is at least 1 m thick at this location. The base of the quartz vein was not exposed. Approximately 4.5 km from this location, silicified and hydrothermally brecciated sedimentary rocks (Fig. 2) and a rusty quartz breccia returned values of 24 g/t Au and 29 g/t Au, respectively.

FOCUSED REGIONAL PROGRAMS

HART RIVER

Bernie Kreft conducted further exploration on a large iron-oxide-copper-gold (IOCG) target that he had discovered in 2002 on the Hart River property (Yukon MINFILE 2003, 116A 009, Deklerk, 2003). Previous sampling from a large mineralized talus field returned values of up to 2% Cu and 0.25% Co from brecciated intrusive and sedimentary rocks as well as quartz-siderite and ankerite veins. The talus was eroding from variably fractured and mineralized beds of chert and siltstone (Fig. 3) that were intruded by both diorite dykes and bodies of hematite breccia. Sampling of bedrock exposures returned values of up to 1.76% Cu and 2.4 g/t Au from grab samples and 0.83% Cu from a 3.2-m chip sample near the crest of the ridge (Fig. 4). Copper Ridge Explorations Inc. has recently optioned the property.

***Figure 4.** Showing on the Hart River property which assayed 0.835 % Cu over 3.2 m.*

GODDESS

Shawn Ryan staked the old Pluto property (Yukon MINFILE 2003, 116C 134, Deklerk, 2003) after researching assessment files. The property was explored from 1979-1982 by Cominco and Getty Canada Minerals

***Figure 5.** Aquamarine (blue beryl) crystals from the Goddess property.*

Ltd. for molybdenite and tungsten. Logs from diamond drill hole 80-2 made reference to 22 pegmatites, 11 of which contained beryl, intruding into the granitic host rock. In all, 10 to 14 kg of core containing the blue beryl (aquamarine) were sampled from this drill hole (Fig. 5). Drill logs of other holes on the property mentioned better intersections of beryl, but these specimens had previously been removed. Cominco geologists also noted quartz-tourmaline veins (+/- beryl) intruding into the surrounding altered ultramafic rocks.

TARGET EVALUATION PROGRAMS

MARN

Canadian United Minerals restaked the Marn property (Yukon MINFILE 2003, 116B 147, Deklerk, 2002) as the Prune claims in January, 2002. They felt that there was good potential for high-grade gold-copper mineralization such as is found on the nearby Horn claims. Geological reserves (not National Instrument 43-101 compliant) for the Marn stand at 275 000 to 300 000 tonnes, grading 8.6 g/t Au and 1% Cu. The mineralization at the main showing trench is hosted in a dark green diopside skarn with only minor sulphide minerals. Shawn Ryan conducted nearly 22 km of magnetometer and soil geochemical surveys over the property, which revealed a 150 m x 400 m magnetic anomaly with coincident soil values of up to 200 ppm copper. A new zone of skarn mineralization was found in the valley bottom (Fig. 6) with initial rock samples returning values of up to 580 ppb Au, >10 000 ppm As and 0.6% Cu.

INDIAN RIVER

Pete Risby supervised the auger drilling of two large bench deposits of White Channel Gravel on the Indian River with the intention of determining the total value of the contained heavy metals. Preliminary estimates from surface sampling is that the upstream bench contains 265 million tonnes of material valued at US$15.46/tonne. The projected metal content of the bench is over 10 million ounces (311 000 kg) gold, 73 million pounds (33 182 tonnes) of tin, 67 million pounds (30 455 tonnes) of titanium and 150,000 pounds (68.2 tonnes) of

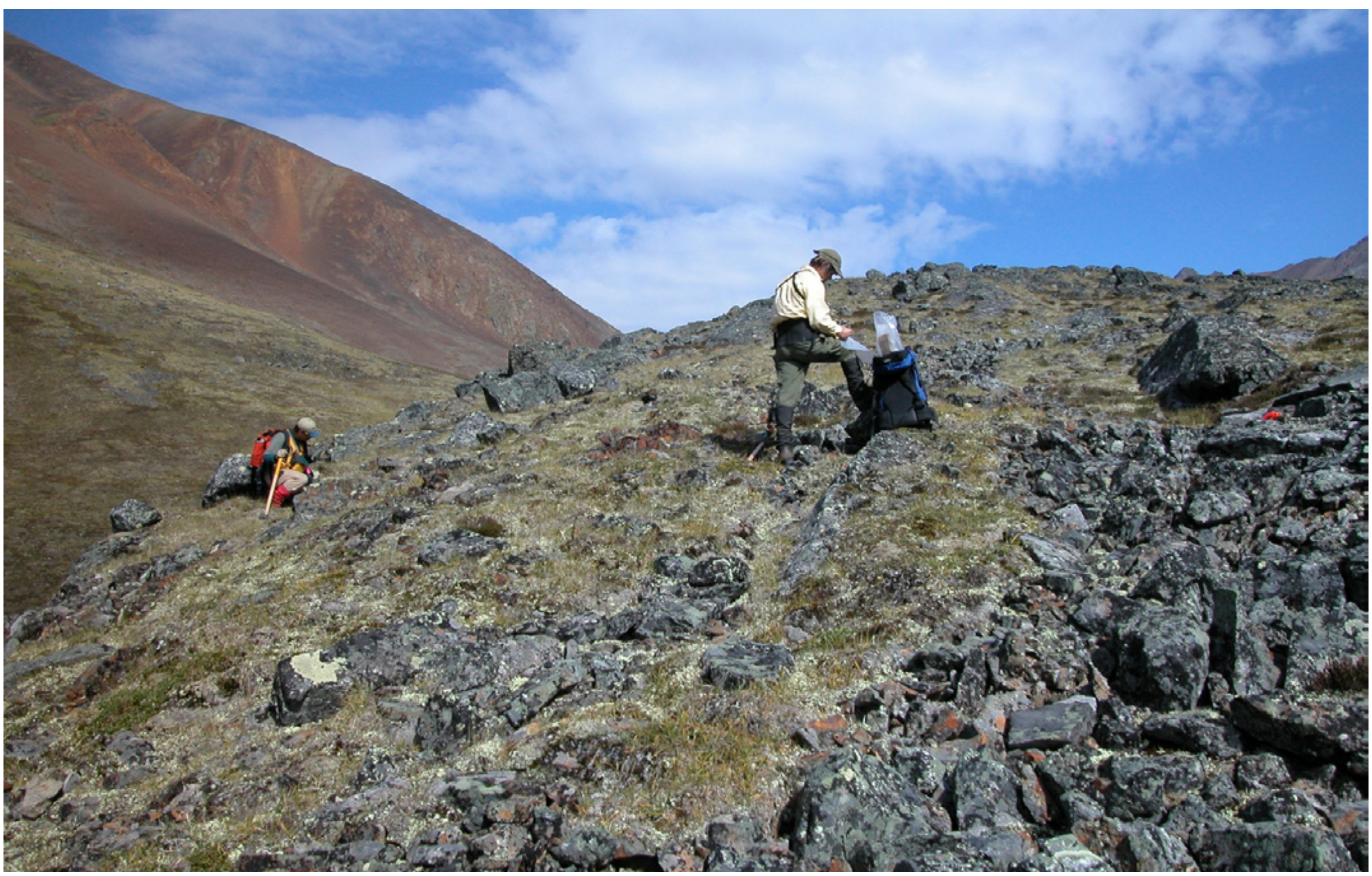

Figure 6. *A new skarn showing on the Prune claims (Marn property) was found; rock samples assayed 580 ppb Au, >10 000 ppm As and 6000 ppm Cu.*

Figure 7. Brian Thurston supervised the auger drilling and sampling program on the Indian River property.

scandium. (No recovery estimates have yet been made on the material.) Figure 7 shows Brian Thurston screening the samples. Both the oversize and the -16 mesh material were weighed to facilitate reserve calculations. Results from the late season drilling program are pending.

MAHTIN

Shawn Ryan completed geophysical and geochemical surveys over the Mahtin property (Yukon MINFILE 2003, 115P 007, Deklerk, 2003) this past summer. He outlined three magnetic anomalies associated with skarn mineralization, two IP anomalies, as well as a 900 x 200 m gold-in-soils anomaly with values up to 400 ppb Au. Rock sampling returned values of up to 4.3 g/t Au in pyrrhotite skarn (Fig. 8), and 6300 ppb Au and 948 ppm Bi in calc-silicate rocks.

SCHEELITE DOME

Copper Ridge Explorations Inc. completed 5.9 km of IP and 7.8 km of magnetometer surveys over the Tom zone located in the northwestern quadrant of the large Scheelite Dome property in the McQuesten River area (Yukon MINFILE 2003, 115P 033, Deklerk, 2003). The geophysical surveys were conducted in an effort to define drill targets for a Phase 2 drill program (Fig. 9). The program was successful in defining IP chargeability targets that correlate in part with the magnetic surveys and surface mineralization. Results from the follow-up drilling include 1.22 m of 5.06 g/t Au from Tom-1 and 6.4 m of 7.09 g/t Au (including 1.7 m of 24.42 g/t Au) and various other shorter intersections from Tom-2. Tom-4 intersected 2.55 g/t Au over 5.8 m, including 10.0 g/t over 1.37 m. Tom-5 encountered 3.35 g/t Au over 0.61 m at the collar of the hole. Tom-3 was abandoned before reaching its target depth.

ULTRA

Tom Morgan continued to explore the Ultra property (Yukon MINFILE 2003, 115B 008, Deklerk, 2003) near Haines Junction with a combination of geophysics, trenching and sampling this season. Max-min and magnetometer surveys over the Telluride showing revealed a number of good electromagnetic conductors

Figure 8. Pyrrhotite skarn mineralization from the Mahtin property typically assayed between 1 and 4.3 g/t Au.

Figure 9. Golden Patriot Mining Inc. drilled five holes into the Tom zone on the Scheelite Dome property. The drill shown is setting up on Tom-3.

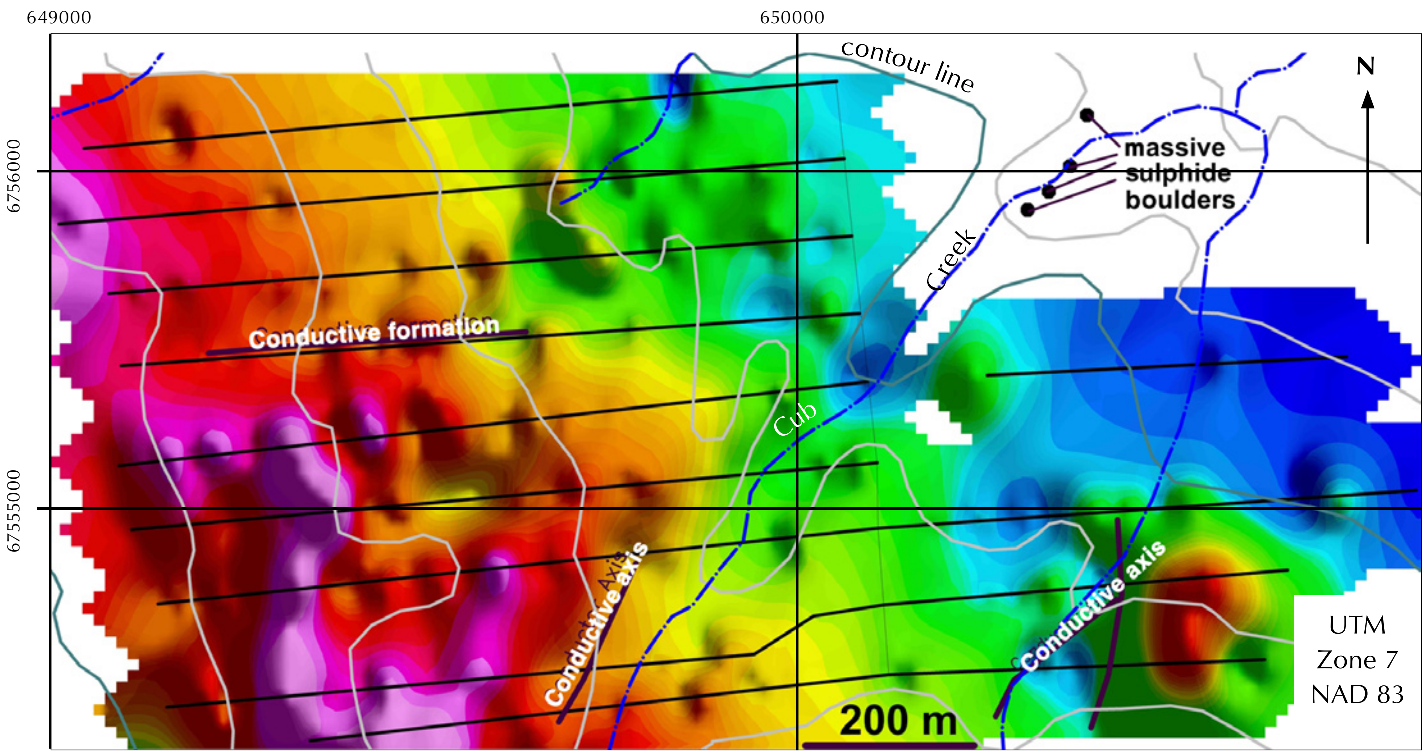

Figure 10. *Shaded relief magnetic anomalies and HLEM conductors, Ultra property. The geophysical plot shows the magnetic signature of the buried rock units with electromagnetic conductors, which may represent the source of the mineralized boulders exposed in Telluride Creek (approximate UTM coordinates).*

uphill from massive sulphide boulders that are exposed in the toe of a terminal moraine (Fig. 10). The boulders appear to be from a volcanogenic massive sulphide (VMS) source and have returned assays up to 5.1% Zn and 2.1% Cu. The Froberg showing (Fig. 11) approximately 2.5 km to the southwest, appears to be hydrothermal mineralization related to a fault. Recent sampling returned values of 5.5 g/t platinum (Pt), 13.5 g/t palladium (Pd), 4% Cu and 1.7% Ni.

SHAMROCK

Amax Molybdenum Ltd. originally staked the Shamrock property, located 82 km west of Carmacks, in 1970 and identified a 1000 m x 1200 m copper soil anomaly and a +700 gamma magnetic anomaly immediately to the north. BQ holes drilled in 1976 intersected values up to 1960 ppm Cu and up to 240 ppb Au over widths up to 100 m. In 1985 Chevron Resources Ltd. identified an 800 x 2400 m soil anomaly, with values up to 1270 ppb Au coincident with the 1970 magnetic anomalies. This year, 4763 NWT Ltd. staked the property, re-established the grid and completed soil sampling and magnetometer surveys. The program identified a 1.7-km-long gold-in-soil anomaly that is open at both ends. A number of

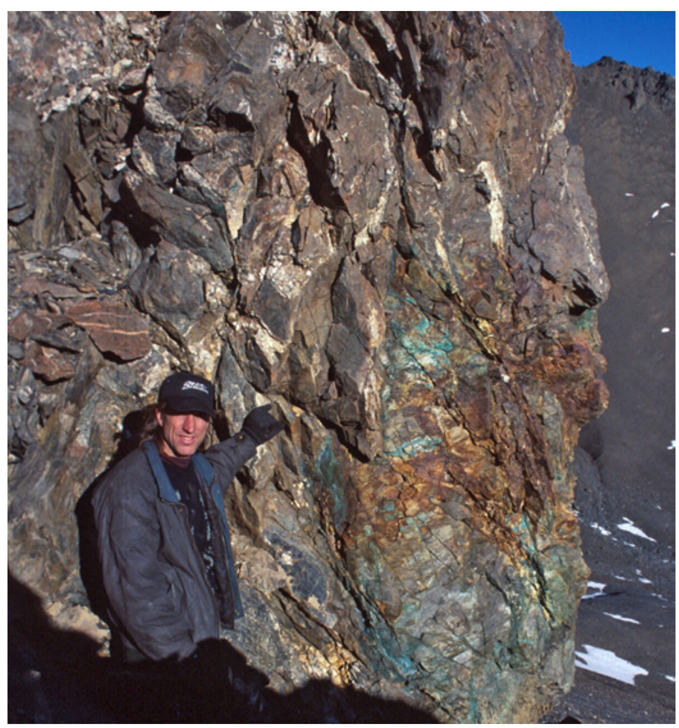

Figure 11. *Tom Morgan stands beside fracture-controlled mineralization at the Froberg showing. Trench samples from here assayed up to 5.5 g/t Pt, 13.5 g/t Pd, 4% Cu and 1.7% Ni.*

northwest and northeast anomalous trends are indicated by the soil and geophysical surveys (Fig. 12). Plans for next year are to extend the soil and magnetic grid and to trench a number of the identified anomalies.

ET

Peter Ross conducted an orientation survey on his ET claims (Yukon MINFILE 2003, 115P 042, Deklerk, 2003) this summer. He compared the results from an Enzyme Leach survey completed last year with those from a mobile metal ion (MMI) survey and a conventional inductively coupled plasma (ICP) soil survey. He found that the conventional ICP analysis gave him the best response in the area. Eleven percent of his samples returned anomalous values over 20 ppb, to a high of 169 ppb Au. The soil survey identified a number of anomalous trends up to 90 m wide and at least 230 m in length. Soil data, in addition to -200 mesh silt sample values of up to 5770 ppb Au, lead him to believe that the property is a good one.

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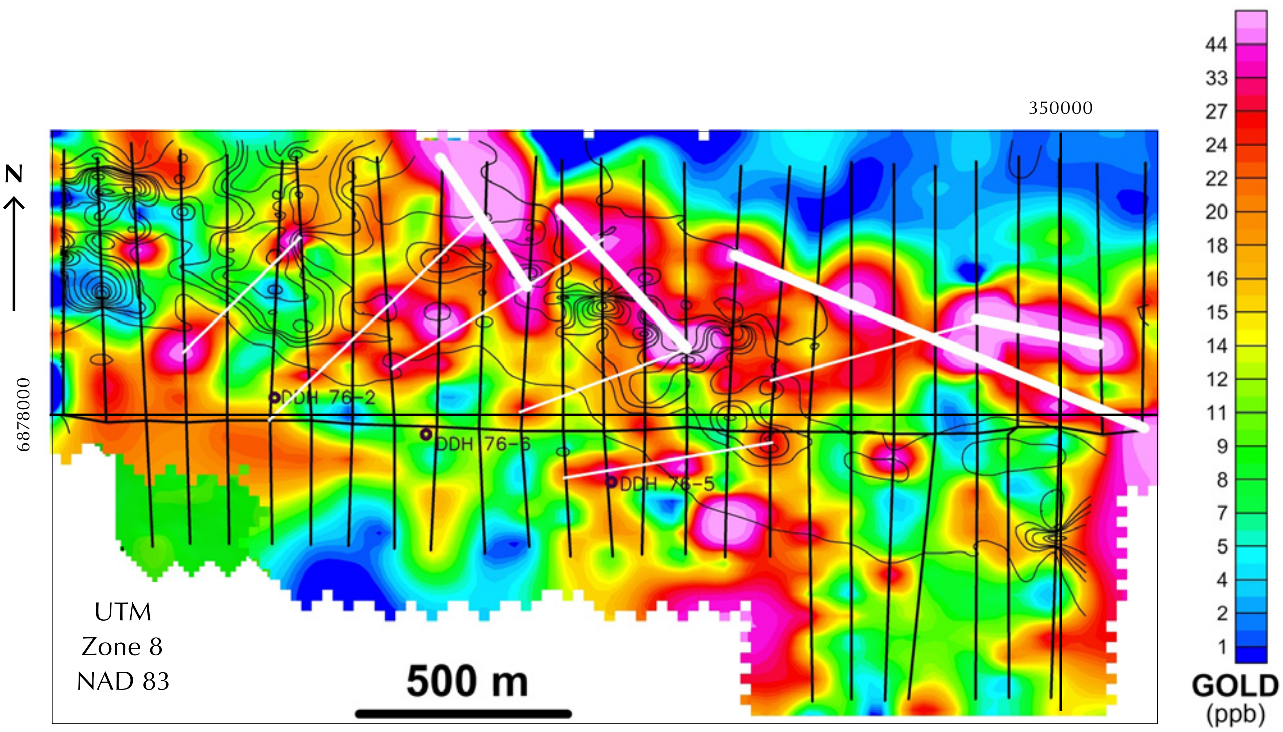

Figure 12. *Gold soil geochemistry and magnetic contours, Shamrock property. Soil sampling and magnetic surveys show strong northwest- and weaker northeast-trending anomalous zones, possibly related to faulting (from 4763 NWT Ltd., Aurora Geosciences Ltd.; approximate UTM coordinates).*

Yukon Geological Survey

Grant Abbott*[1] *and staff
Yukon Geological Survey

Abbott, J.G. and staff, 2003. Yukon Geological Survey. *In:* Yukon Exploration and Geology 2003, D.S. Emond and L.L. Lewis (eds.), Yukon Geological Survey, p. 39-55.

OVERVIEW

Eleven years ago, the Canada-Yukon Geoscience Office opened it doors and marked the beginning of a de facto Yukon Geological Survey (YGS) with the creation of the Yukon Geology Program. In April of 2003, that vision finally became a reality when responsibilities for management of Yukon's natural resources devolved from the federal government to the Government of Yukon. The Department of Energy, Mines and Resources now has responsibility for minerals, oil and gas, forestry, agriculture and lands. The new Yukon Geological Survey (Fig. 1) supercedes the Geology Program. YGS is part of the Minerals Development Branch, and is co-managed by Grant Abbott and Rod Hill,

Figure 1. *Yukon Geological Survey staff from left to right: Geoff Bradshaw, Charlie Roots, Steve Traynor, Lara Lewis, Rob Deklerk, Grant Lowey, Diane Emond, Ken Galambos, Grant Abbott, Karen Pelletier, Jo-Anne vanRanden, Ali Wagner, Bill LeBarge, Amy Stuart, Rose Williams, Lee Pigage, Craig Hart, Panya Lipovsky, Crystal Huscroft, Mike Burke, Kaori Torigai (Mining Lands), Don Murphy, Julie Hunt, Rod Hill, Jeff Bond, Maurice Colpron.*

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under the direction of Jesse Duke (Fig. 2). The Geological Survey integrates the Exploration and Geological Services Division (EGSD) of the Department of Indian Affairs and Northern Development (DIAND), with the Yukon Geoscience Office, the Mineral Assessment Group and the Yukon Mining Incentives Program (YMIP) of the Department of Energy, Mines and Resources of Government of Yukon (YTG). The Geological Survey of Canada (GSC) also maintains an office with the YGS. Activities of the Mineral Assessment Group and YMIP are described separately from this report.

Funding for the YGS remains at the same level as it was in previous years for the Geology Program. This year, in addition to core funding, we benefited from additional short-term funding from DIAND through the industry-led Northern Geoscience Initiative and through the Knowledge and Innovation Fund. The last federal budget renewed the Natural Resources Canada Targeted Geoscience Initiative for two more years. Yukon Government will see substantial funding this year, with YGS as a partner.

Over the past year we were sorry to lose Roger Hulstein and Robert Stroshein from the Mineral Assessment Group to the private sector. We are pleased to welcome mineral assessment geologist Geoff Bradshaw and project geologist Steve Israel.

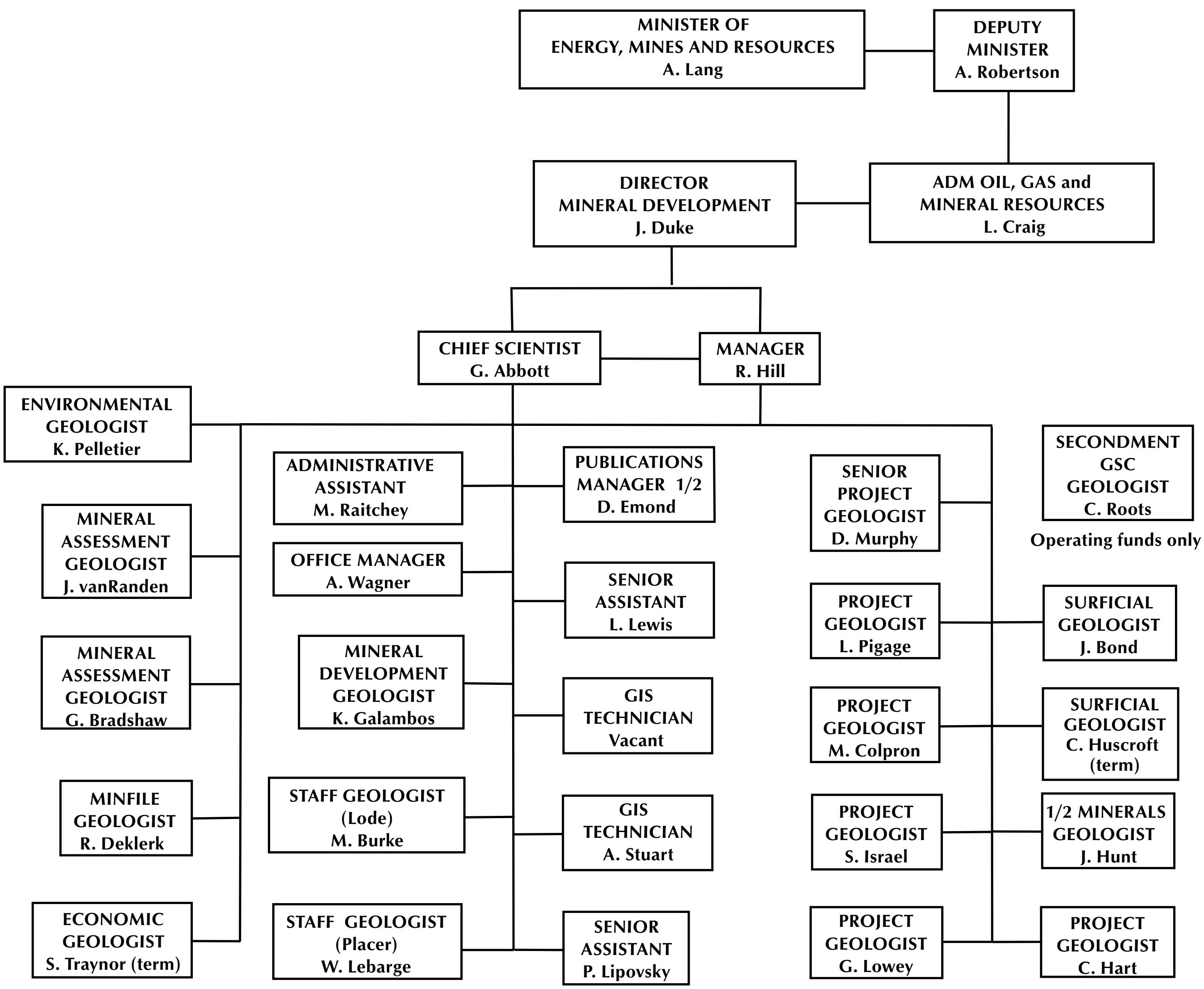

Figure 2. *Yukon Geological Survey organization chart.*

The Technical Liaison Committee to the YGS reviews our program twice a year. We are grateful to Chair Gerry Carlson and members Al Doherty, Moira Smith, Jean Pautler, Forest Pearson, Bernie Kreft, Jim Mortensen and Jim Christie for their valuable support and constructive advice.

A mandate for the YGS has been developed in consultation with senior management in Energy, Mines and Resources and the Technical Liaison Committee. The YGS now has the responsibility "to build, maintain, and communicate the geoscience and technical information base required to enable stewardship and sustainable development of the Territory's energy, mineral, and land resources." The mandate formalizes much of the work that has been underway over the last few years through the Geology Program, and opens the door for projects in new areas. Support for the mineral industry remains the primary focus, but more resources are being dedicated to mapping and studies of areas with hydrocarbon potential. Effort is also going into environmental studies that have relevance to the extractive industries and land use issues. In recent years, interest and demand for geoscience information has increased substantially from regulators, First Nations, the general public and schools. In addition, the interests of resource industries are best served by informed decision-making and informed public opinion. As a result, perhaps the largest change is not in what we do, but in the increased diversity of our clients.

FIELDWORK

The YGS is committed to providing a balanced complement of field projects that not only quickly stimulate mineral and hydrocarbon exploration, but also take the longer term view towards developing an understanding of the Yukon regional geological framework, and building the Yukon Geoscience database. Field projects carried out in 2003 are shown in Figure 3, and the present state and location of geological, geochemical and geophysical surveys are shown in Figure 4.

Bedrock mapping continues to be the cornerstone of the YGS. Several projects are in the completion and writeup stage this year. Lee Pigage has a bulletin in preparation on the geology of the Anvil District, and is writing a bulletin and papers on the La Biche mapping project as part of the Central Forelands National Mapping Project (NATMAP). Grant Lowey has a bulletin in press on the placer geology and potential of Stewart River map area, The Ancient Pacific Margin NATMAP is in its final year. Maurice Colpron and Don Murphy are each writing bulletins on the Glenlyon and Finlayson Lake areas, respectively. Maurice Colpron, together with JoAnne Nelson of the B.C. Geological Survey Branch, is organizing and editing the synthesis volume for the Ancient Pacific Margin NATMAP project, to be published by the Geological Association of Canada. The volume will summarize the results of more than four years of work in Stewart River, Glenlyon, Finlayson Lake and Wolf Lake map areas in Yukon, parts of northern and southern British Columbia and eastern Alaska by authors from the YGS, Geological Survey of Canada, British Columbia Geological Survey, United States Geological Survey, and several universities. This work has made a seminal leap in our understanding of the geology and mineral potential of the Yukon-Tanana Terrane, up until now the least understood part of the North American Cordillera.

Field work in 2003 included ongoing bedrock mapping in the Finlayson Lake map area where Don Murphy continues to define and expand areas of potential for volcanic-hosted massive sulphide (VMS) deposits and emeralds. Maurice Colpron and Charlie Roots participated in the GSC's Stewart River mapping project where the additional manpower allowed for timely completion of fieldwork. Lee Pigage undertook a short exploratory trip into eastern Coal River map area to determine possible correlations of Late Proterozoic and Early Paleozoic volcanic and siliciclastic rocks near Toobally Lakes with possibly equivalent strata in the adjacent La Biche map area. Our most important new initiative is the Whitehorse Trough project. The Whitehorse Trough project will be a multidisciplinary partnership with the Geological Survey of Canada and universities, much like the current NATMAP. The purpose is to more accurately determine the hydrocarbon potential of the northern portion of the Trough by more clearly defining its stratigraphic and structural framework. This year, Grant Lowey began a stratigraphic and sedimentological study of the Lebarge Group. Later this year, the GSC, with funding from the Targeted Geoscience Initiative will conduct a seismic survey across the Trough along the Campbell and Klondike highways. Stratigraphic, sedimentological and structural studies, and bedrock mapping will continue over the next two years.

Craig Hart is completing a PhD Program at the University of Western Australia. Most of the requirements for the degree will entail writing papers on his previous field studies of the Tintina Gold Belt and other Yukon gold occurrences. This year, Craig and Lara Lewis carried out a wide-ranging reconnaissance study of tungsten and beryl occurrences.

Julie Hunt has returned to school to undertake a PhD program at James Cook University in Australia. YGS is funding her fieldwork. Julie partnered with Derek Thorkelson of Simon Fraser University to complete fieldwork on the Wernecke Breccias, and is taking advantage of the Australian connection by comparing the Yukon breccias with similar Australian rocks which host giant copper-gold ore deposits.

Bill LeBarge and Mark Nowasad completed their studies of the relationship between sedimentology, grain size distribution and water quality of effluent from placer deposits. Their results will be evaluated for possible long-term applications and further research. Data gathered from this study was useful in the 2003 review of the Yukon Placer Authorization.

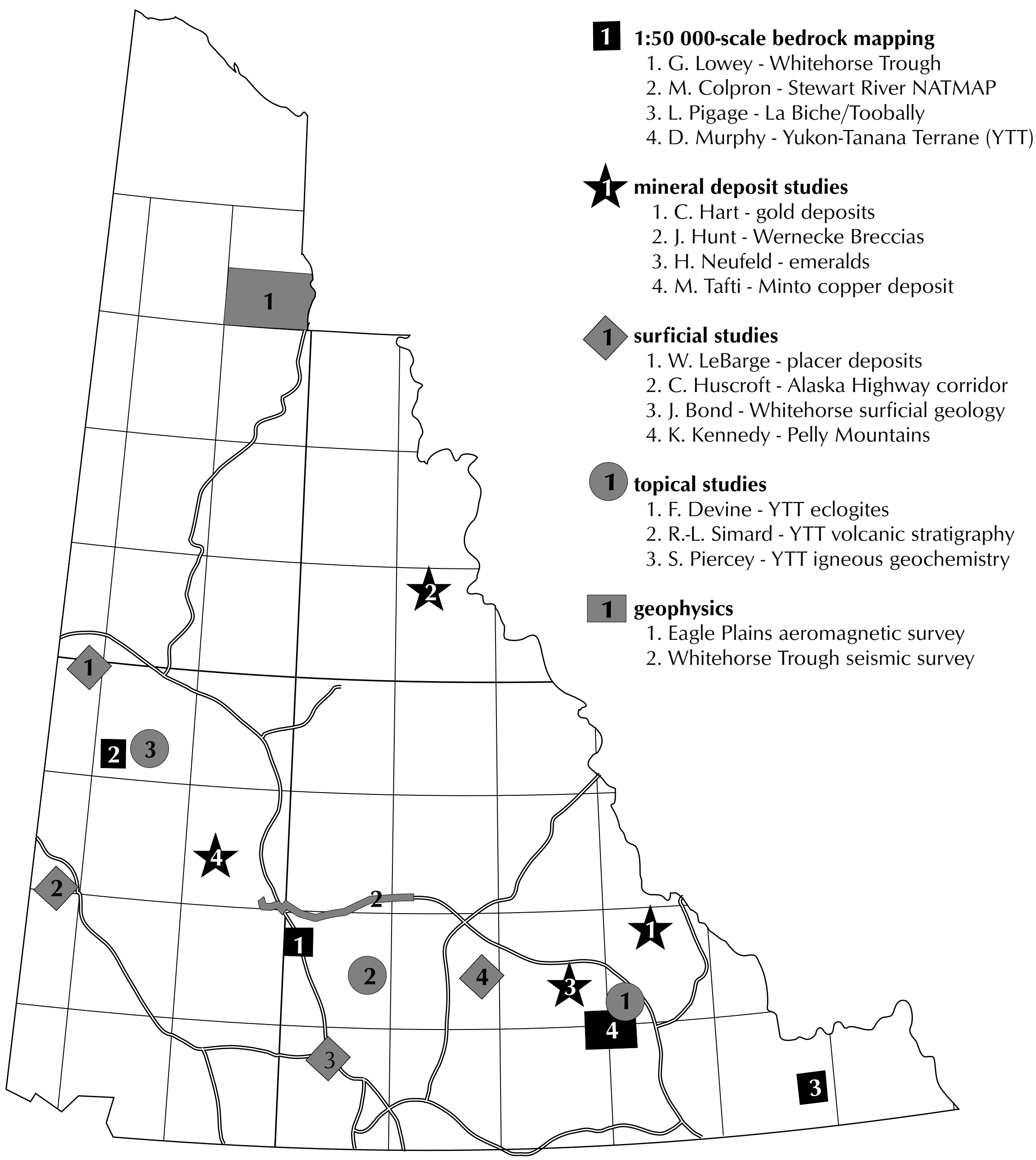

Figure 3. *Field projects carried out or sponsored by the Yukon Geological Survey in 2003.*

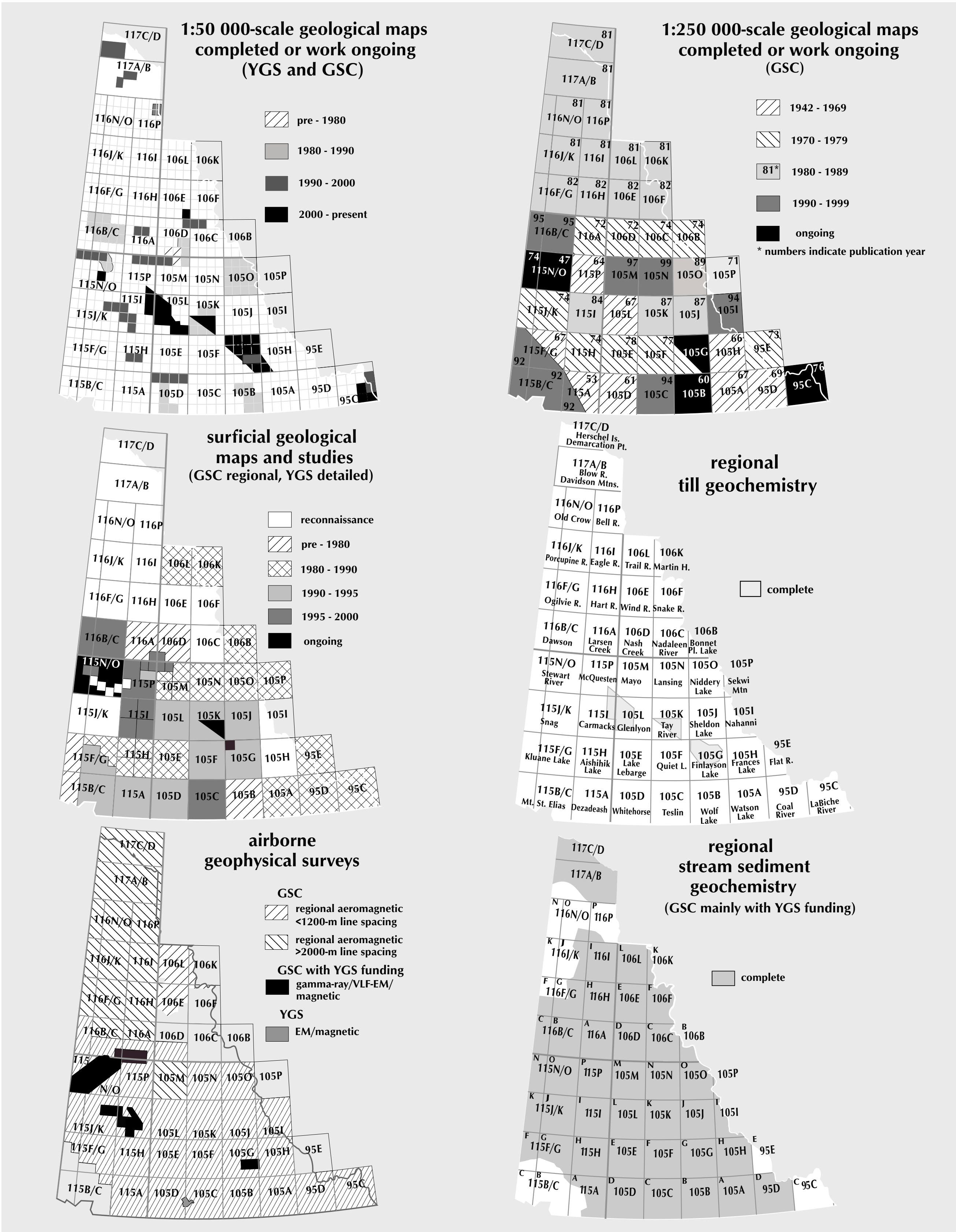

Figure 4. *Summary of available geological maps, and regional geochemical and geophysical surveys in the Yukon, in 2003.*

Jeff Bond continued surficial mapping of the greater Whitehorse area to be published as two 1:50 000-scale maps. The project will provide baseline information to support land-use decisions, groundwater studies and public education.

Jeff and Kristen Kennedy studied the surficial geology and ice-flow patterns in the Seagull Creek area, and determined that glacial flow was to the north, up-valley, in the opposite direction to what had previously been believed. These results have a significant bearing on the interpretation of soil geochemical anomalies and potential of known gold occurrences in the area.

Jeff also provided advice and support to placer miners, First Nations and to the Department of Fisheries and Oceans on matters related to surficial geology.

EXTERNAL SUPPORT

The Yukon Geological Survey (YGS) is providing financial and logistical support, or is a partner with graduate students and university researchers in the following projects.

Fionnuala Devine began field work in the Finlayson Lake area for a Master's thesis under Dr. S. Carr at Carleton University, Ottawa, Ontario. Her study of the geological setting and geochemical, petrological and geochronological character of high pressure metamorphic rocks of the Yukon-Tanana Terrane will provide critical information on the metamorphic and tectonic history of these rocks.

Reza Tafti is completing a study of the Minto copper deposit for his MSc at the University of British Columbia, Vancouver, British Columbia, under the supervision of Dr. Jim Mortensen. Through the project we will attempt to gain a better understanding of the nature, age and origin of the main host rocks to the Minto deposit and the copper-gold mineralized rock contained within them. This information will be used as a basis for developing an exploration model for similar mineralization elsewhere in the Minto-Williams Creek belt.

Heather Neufeld is completing a study of emerald and beryl occurrences in the Yukon and Northwest Territories for her MSc degree at the University of British Columbia under the supervision of Drs. Jim Mortensen and Lee Groat. The main focus of the study will be the Regal Ridge emerald deposit in the Finlayson Lake district. The purpose of the project is to understand the origin of the emerald occurrences and to develop exploration guidelines for the northern Canadian Cordillera.

Renée-Luce Simard is completing a study of the volcanic stratigraphy, composition and tectonic evolution of Late Paleozoic successions in central Yukon for her PhD thesis at Dalhousie University, Halifax, Nova Scotia, under the direction of Dr. J. Dostal. The project compares and contrasts the depositional style, composition and tectonic setting of several volcanic successions within the belt of pericratonic terranes in the Northern Cordillera. These include the Klinkit Group in Wolf Lake map area, the Little Salmon formation in Glenlyon map area, and the Boswell and Semenof formations in central Laberge map area.

Dr. Steve Piercey at Laurentian University, Sudbury, Ontario, as part of the Ancient Pacific Margin NATMAP Project, is completing a study of the field, geochemical and isotopic attributes of volcanic and intrusive rocks in the Stewart River map area. The study will, in part, determine the similarities and differences of these rocks to volcanogenic massive sulphide (VMS)–bearing rocks in the Finlayson Lake district.

In addition to providing geochronological support to the GSC's Stewart River project, Mike Villeneuve (GSC – Ottawa) has been using argon geochronology to 1) determine the cooling and uplift history of the Klondike region to aid in understanding mineralizing and tectonic processes in that region; 2) define the timing of recent volcanism in the Yukon, particularly the Fort Selkirk region; and 3) provide timing constraints on intrusion-related gold mineralization in the Tintina Gold Belt.

ENVIRONMENTAL STUDIES

Karen Pelletier continued to administer the Mining and Environmental Research Group (MERG), YTG. The 2003-funded studies include: *The Evolution of Metal Tolerant Vegetation in Native Yukon Vegetation Invading Abandoned Mine Sites: A Strategy for Long-Term Regulation* by Thomas Hutchinson, Trent University; *Bioengineering Experimentation - Noname Creek and Gold Run Creek, Feasibility Study and Field Trials* by Laberge Environmental Services; *Permafrost and Freezing: Implications for Northern Mine Sites* by EBA Engineering Consultants Ltd.; *Examination of Natural Attenuation of Metals in Soils in Northern Environments* by Access Consulting Group; and *Evaluation of Distributions of Bacteria, Sediments, Aqueous Chemistry and Heavy Metals in Yukon Wetlands* by EBA Engineering Consultants Ltd.

Karen continues to review Mining Land Use and Water License applications, and monitor reclaimed sites to document the effectiveness of mitigation practices. Karen also represents YGS on several committees which sponsor environmental research that involves geology.

Funding from the DIAND Knowledge and Innovation Fund has supported a project by Crystal Huscroft to characterize the settings of landslide hazards along the Alaska Highway Corridor. Many of the landslides in the region are related to degradation of permafrost and the influence of frozen ground on soil drainage. This study will help to assess the potential impact of global warming on terrain stability and the risk to future development such as the Alaska Highway pipeline.

LIAISON AND SUPPORT TO INDUSTRY, FIRST NATIONS AND THE PUBLIC

Mike Burke and Bill LeBarge, our main links to the exploration industry, continued to monitor Yukon hard-rock and placer mining and mineral exploration activity, visit active properties, review reports for assessment credit, and maintain the assessment report library.

The YGS continues to focus more attention on increasing awareness among the public, schools and First Nations of geology and its importance to the mining industry, land use planning and environmental management. Karen Pelletier, Charlie Roots and other YGS staff continue to make presentations in the schools and conduct field trips in the communities. Karen also organized field trips with First Nations groups to visit exploration properties to examine modern reclamation practices. We are in the process of developing an interpretive guide to the Whitehorse Copper Belt through a contract with Danièle Héon.

INFORMATION MANAGEMENT AND DISTRIBUTION

With the increasing volume of information generated by YGS and others, and rapidly evolving digital technology, the Survey has placed more effort and resources into making geological information more accessible. A large part of our effort has gone into developing and maintaining key databases, and making all of our information internet-accessible. Ongoing activities include support for the H.S. Bostock Core Library and the Energy, Mines and Resources (EMR) library (Elijah Smith Building).

DATABASES

With new reporting requirements to securities regulators, widely recognized mineral deposit models are becoming increasingly important. In cooperation with the British Columbia Geological Survey, the YGS has contracted Anna Fonseca to adapt the British Columbia Geological Survey Mineral Deposit Models for the Yukon. These models are now incorporated into Yukon MINFILE and will be published in early 2004.

Yukon MINFILE, the Yukon's mineral occurrence database, is maintained by Robert Deklerk. An update was released in November, 2003. The database now contains 2603 records, of which 500 have been revised, and is complete to the end of 2001. All mineral occurrences are now assigned to a deposit model. Reserve tables have been completely revised and updated to match, as closely as possible, the Canadian Institute of Mining Standards for Reporting Mineral Resources and Reserves.

The Yukon Placer Database, compiled under the direction of Bill LeBarge, was released in the fall of 2002. The database is in Microsoft Access 2000 format and is a comprehensive record of the geology and history of Yukon placer mining. The database contains descriptions of 440 streams and rivers, and 1356 associated placer occurrences. It also includes location maps in Portable Document Format (PDF). An update is scheduled for the spring of 2004.

The Yukon GEOPROCESS File, under the direction of Diane Emond, is an inventory of information on geological process and terrain hazards, including 1:250 000-scale maps showing permafrost, landslides, recent volcanic rocks, structural geology, and seismic events, and also includes references and summaries of bedrock and surficial geology. The GEOPROCESS File is intended as a planning aid for development activities and is available for most areas south of 66° latitude. The maps are now standardized in colour, and available on a single compact disk. Maps with text are in AutoCAD 2000 and PDF formats.

The Yukon Digital Geology compilation was updated this year by Steve Gordey and Andrew Makepeace of the Geological Survey of Canada with funding from YGS. It includes syntheses of bedrock geology and glacial limits, compilations of geochronology, paleontology, and mineral occurrences, and a compendium of aeromagnetic images, as well as an oil and gas well database. All are now available on CD-ROM. Bedrock geology and glacial limit paper maps are also available at 1:1 000 000 scale.

The Yukon Regional Geochemical Database 2003, compiled by Danièle Héon, contains all of the available digital data for regional stream sediment surveys that have been gathered in the Yukon under the Geological Survey of Canada's National Geochemical Reconnaissance Program. It is available on CD-ROM in Microsoft Excel 2000 format and in ESRI ArcView Shapefile format.

The YukonAge 2002 Database, compiled by Katrin Breitsprecher and Jim Mortensen at the University of British Columbia with funding from YGS, can now be viewed on the YGS Map Gallery in a version modified by Mike Villeneuve and Linda Richard with the Geological Survey of Canada. The database contains over 1500 age determinations, derived from over 1100 rock samples from the Yukon Territory, in both Microsoft Access 2000 format and as a flat file in Microsoft Excel 2000 format so that the data may be viewed without Microsoft Access. The database will be updated in the spring of 2004.

The Yukon Geoscience Publications Database, 2003, compiled by Lara Lewis and Diane Emond, is current to 2003 and contains more than 5000 references to papers on Yukon geology and mineral deposits, including YGS publications.

Funding from DIAND for Northern Geoscience announced in May, 2003 will be used in part to complete scanning of assessment reports and conversion to PDF format. The complete database of over 5000 files is expected to be available on-line by the spring of 2005.

H. S. BOSTOCK CORE LIBRARY

Mike Burke and Ken Galambos maintain the H.S. Bostock Core Library. The facility contains about 128 000 m of diamond drill core from about 200 Yukon mineral occurrences. Confidentiality of material is determined on the same basis as mineral assessment reports. Confidential core can be viewed with a letter of release from the owner. Rock saws and other rock preparation equipment are available to the public.

EMR LIBRARY

The EMR library in the Elijah Smith Building is an invaluable resource that is available to the public, but often overlooked. It is Yukon's largest scientific library and includes collections that, prior to devolution, belonged to Indian and Northern Affairs Canada and the Department of Energy, Mines and Resources, Yukon Government. The library also houses Yukon assessment reports and contains most geological journals and a good selection of references on general geology, Yukon geology and economic geology.

INFORMATION DISTRIBUTION

The YGS distributes information in three formats. We sell and distribute paper maps and reports through our Geoscience Information and Sales Office. In addition, many of our recent publications and databases are available in digital format at considerably lower prices than for paper copies. Most of our publications are available as PDF files on our website (www.geology.gov.yk.ca), free of charge. A directory of assessment reports is also available online. We are pleased to make spatial data available through our interactive map server; the Map Gallery can be accessed through the YGS website. We are continuing to improve the Map Gallery and have added coverages of regional stream geochemistry, mineral claims and geochronology to the existing coverages of regional geology, MINFILE locations, topography, roads and communities, and First Nations land selections. Vector data can now be clipped and downloaded. Planned enhancements include addition of geophysics and paleontology, and addition of more attribute data to existing coverages. Users are encouraged to provide feedback and suggest improvements.

Hard copies of YGS publications are available at the following address:

Geoscience Information and Sales
c/o Whitehorse Mining Recorder
102-300 Main Street (Elijah Smith Building)
P.O. Box 2703 (K102)
Whitehorse Yukon Y1A 2C6
Ph. (867) 667-5200
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To access publications and to learn more about the Yukon Geological Survey, visit our website at http://www.geology.gov.yk.ca or contact us directly:

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La Commission géologique du Yukon

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APERÇU

Il y a onze ans, le Bureau de la géoscience Canada-Yukon ouvrait ses portes, ce qui marquait dans les faits les débuts d'une Commission géologique du Yukon (CGY) par la création du Programme géologique du Yukon. En avril 2003, cette vision se concrétisait enfin lorsque les responsabilités en gestion des ressources naturelles du Yukon étaient transférées du gouvernement fédéral au gouvernement du Yukon. C'est maintenant le ministère de l'Énergie, des Mines et des Ressources qui est responsable des minéraux, du pétrole et du gaz, de la foresterie, de l'agriculture et des terres. La nouvelle Commission géologique du Yukon remplace le Programme géologique. La CGY fait partie de la Direction de la mise en valeur des ressources minérales et est gérée conjointement par Grant Abbott et Rod Hill sous la direction de Jesse Duke. La Commission géologique regroupe la Division des services d'exploration et de géologie (DSEG) du ministère des Affaires indiennes et du Nord canadien (MAIN), le Bureau de la géoscience du Yukon, le Groupe d'évaluation du potentiel minéral et le Programme d'encouragement pour l'exploration minérale du Yukon (PEEMY) du ministère de l'Énergie, des Mines et des Ressources du gouvernement du Yukon. La Commission géologique du Canada (CGC) conserve en outre un bureau à la CGY. Les activités du Groupe des évaluations minières et du PEEMY sont décrites dans un rapport distinct.

Le financement de la CGY reste ce qu'il était les années précédentes dans le cadre du Programme géologique. Cette année, en plus du financement de base, nous recevons un financement additionnel à court terme du MAIN par l'entremise de l'Initiative géoscientifique dans le Nord menée par l'industrie ainsi que du Fonds pour le savoir et l'innovation. Dans le cadre du dernier budget fédéral, l'Initiative géoscientifique ciblée de Ressources naturelles Canada a été renouvelée pour deux autres années. Le gouvernement du Yukon recevra un financement substantiel cette année et la CGY est un partenaire.

Pendant l'année écoulée, nous déplorons la perte de Roger Hulstein et de Robert Stroshein du Groupe d'évaluation du potentiel minéral qui ont accepté des emplois dans le secteur privé. Il nous fait plaisir d'accueillir Geoff Bradshaw à titre de géologue d'évaluation du potentiel minéral et Steve Israel comme géologue de projet.

Le Comité de liaison technique à la CGY examine nos programmes deux fois par année. Nous remercions le président, Gerry Carlson et les membres du comité Al Doherty, Moira Smith, Jean Pautler, Forest Pearson, Bernie Kreft, Jim Mortensen et Jim Christie de leur précieux appui et des conseils constructifs qu'il nous fournissent.

Un mandat pour la CGY a été élaboré en consultation avec la haute direction d'Énergie, Mines et Ressources et le Comité de liaison technique. La CGY a maintenant la responsabilité «d'accumuler, de gérer et de communiquer la base d'information géoscientifique et technique nécessaire pour la gérance et le développement durable des ressources en énergie, en minéraux et en terres du territoire». Le mandat formalise une bonne part des travaux déjà entrepris ces quelques dernières années dans le cadre du Programme géologique et ouvre la voie à de nouveaux projets dans de

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nouveaux domaines. Le soutien à l'industrie minière reste l'objectif premier, mais davantage de ressources sont consacrées à la cartographie et aux études des régions présentant des possibilités pour les hydrocarbures. Des efforts sont également consacrés aux études environnementales pertinentes pour les industries de l'extraction et pour l'utilisation des terres. Ces dernières années, la demande des organismes de réglementation, des Premières nations et du grand public pour l'information géoscientifique a considérablement augmenté. De plus, les intérêts des industries des ressources sont au mieux servis par une prise de décisions éclairée et un public bien informé. Le changement le plus important se manifestera en conséquence non pas au niveau de la nature de nos activités, mais plutôt au niveau de la diversité de notre clientèle.

TRAVAUX SUR LE TERRAIN

La CGY s'est engagée à exécuter un ensemble complémentaire équilibré de projets sur le terrain visant non seulement à stimuler rapidement l'exploration à la recherche de minéraux et d'hydrocarbures, mais, à plus long terme, à comprendre le cadre géologique régional du Yukon et à constituer la base de données géoscientifiques du Yukon.

La cartographie du socle rocheux reste la pierre angulaire de la CGY. Cette année plusieurs projets ont été complétés ou ont atteint le stade de la rédaction du rapport. Lee Pigage a rédigé un bulletin sur la géologie du district d'Anvil actuellement sous presse et des communications concernant le projet de cartographie La Biche mené dans le cadre du Projet de cartographie nationale de l'avant-pays central (CARTNAT). Grant Lowey a rédigé un bulletin, sous presse, sur la géologie et le potentiel des placers de la région de la carte Stewart River. Le CARTNAT de l'ancienne marge du Pacifique en est à sa dernière année. Maurice Colpron et Don Murphy rédigent actuellement des bulletins concernant respectivement les régions de Glenlyon et de Finlayson Lake. Maurice Colpron, en collaboration avec JoAnne Nelson de la Commission géologique de C.-B., travaille à l'organisation et à la direction d'un volume de synthèse portant sur les résultats de plus de quatre années de recherches dans les régions de Stewart River, Glenlyon, Finlayson Lake et Wolf Lake au Yukon, sur les régions septentrionale et méridionale de la C.-B. et sur l'est de l'Alaska par des chercheurs de la CGY, de la Commission géologique du Canada, de la Commission géologique des États-Unis et de plusieurs universités. Ce volume sera publié par l'association géologique du Canada. Ces travaux ont permis d'accroître considérablement notre compréhension de la géologie et du potentiel minier du terrane de Yukon-Tanana jusqu'à présent l'une des région les moins bien comprises de la Cordillère nord-américaine.

Parmi les travaux sur le terrain en cours en 2003, mentionnons la cartographie du socle rocheux dans la région de la carte Finlayson Lake où Don Murphy continue à définir et à étendre les régions propices aux gisements de sulfures massifs volcanogènes (SMV) et d'émeraudes. Maurice Colpron et Charlie Roots ont participé au projet de cartographie de la CGC à la rivière Stewart où la main-d'œuvre additionnelle a permis de compléter les travaux sur le terrain en temps opportun. Lee Pigage a effectué un bref voyage d'exploration dans la partie de la région de la carte Coal River pour déterminer des corrélations possibles entre les roches volcaniques et siliciclastiques du Protérozoïque tardif et du Paléozoïque précoce près des lacs Toobally et des strates peut-être équivalentes de la région de l'adjacente carte La Biche. Notre plus importante nouvelle initiative est le projet du bassin de Whitehorse. Il s'agit d'un partenariat multidisciplinaire avec la Commission géologique du Canada et des universités ressemblant beaucoup à l'actuel CARTNAT. L'objectif en est de déterminer avec exactitude le potentiel pour les hydrocarbures de la partie septentrionale du bassin en définissant plus nettement ses cadres stratigraphique et structural. Cette année, Grant Lowey a entrepris une étude stratigraphique et sédimentologique du Groupe de Lebarge. Plus tard pendant l'année, la CGC effectuera, à même un financement fourni dans le cadre de l'Initiative géoscientifique ciblée, un levé sismique transversal du bassin le long des routes de Campbell et du Klondike. Les études stratigraphiques, sédimentologiques et structurales ainsi que la cartographie du socle rocheux se poursuivront pendant les deux prochaines années.

Craig Hart complète un programme de doctorat à l'Université d'Australie occidentale. Les exigences pour l'obtention du diplôme comprennent surtout la rédaction d'articles sur ses antérieures études sur le terrain dans la zone aurifère de Tintina et dans d'autres manifestations d'or au Yukon. Cette année, Craig et Lara Lewis ont effectué sur une grande étendue une reconnaissance des manifestations de tungstène et de béryl.

Julie Hunt est retournée aux études pour entreprendre un programme de doctorat à l'Université James Cook en

Australie et la CGY finance ses travaux sur le terrain. Julie a fait équipe avec Derek Thorkelson pour compléter des travaux sur le terrain dans les brèches de Wernecke et tire avantage de ses contacts en Australie pour comparer les brèches du Yukon avec des roches similaires en Australie dans lesquelles on trouve des gîtes géants de cuivre et d'or.

Bill LeBarge et Mark Nowasad ont complété leurs études des relations entre la sédimentologie, la distribution granulométrique et la qualité de l'eau provenant de gîtes placériens. Leurs résultats seront évalués à des fins d'application éventuelle à long terme et pour des recherches plus poussées. Les données recueillies dans le cadre de cette étude ont été utiles pour la revue du processus d'autorisation des placers de 2003 au Yukon.

Jeff Bond a poursuivi ses travaux de cartographie des dépôts meubles dans le grand Whitehorse qui doivent être publiés sous forme de deux cartes à l'échelle de 1/50 000. Le projet fournira l'information de base à l'appui de décisions en aménagement des terres , pour les études de l'eau souterraine et pour l'éducation du public.

Jeff et Kristen Kennedy ont étudié la géologie des dépôts meubles et les configurations de l'écoulement glaciaire dans la région du ruisseau Seagull; ils ont pu déterminer que la glace s'écoule vers le nord en remontant la vallée contrairement à ce que l'on avait d'abord pensé. Ces résultats ont une importante portée pour l'interprétation des anomalies géochimiques des sols et le potentiel pour les manifestations aurifères dans la région.

Jeff a également fourni des conseils aux entreprises d'exploitation de placers, aux Premières nations et au ministère des Pêches et Océans en matière de géologie des dépôts meubles.

Finallement, le Commission géologique du Yukon continue son assistance financière et logistique de nombreuses études thématiques conduites par des étudiants de deuxième et de troisième cycle, et par des chercheurs universitaires.

PROGRAMME D'ENCOURAGEMENT POUR L'EXPLORATION MINÉRALE DU YUKON

Le Programme d'encouragement pour l'exploration minérale du Yukon (PEEMY) a reçu 93 demandes avant la date limite du 1er mars. Une somme totale de 987 000 $ a été versée à 61 demandeurs répondant aux exigences. Des programmes présentés, 9 ont été approuvés dans le cadre du module Prospection primaire, 19 dans le cadre du module Objectif régional et, enfin, 39 dans le cadre du module Évaluation des cibles.

La hausse du prix de l'or et de certains métaux de base sur le marché mondial a incité les demandeurs à explorer leurs cibles cette saison. L'exploration visant les métaux précieux menée dans le cadre du programme a grimpé, 56 % des demandes portant sur l'or et les éléments du groupe du platine. Les métaux de base ont représenté 30 % des programmes approuvés; le reste, 14 %, a été consacré à l'exploration pour découvrir des pierres précieuses et d'autres substances utiles. Les programmes d'exploration proposés ont touché les quatre districts miniers du Yukon, leur répartition ayant été relativement uniforme sur le territoire. Cette année, quatre conventions d'option ont été signées pour des propriétés explorées dans le cadre du PEEMY et au moins cinq autres sont en cours de négociation.

Les faits saillants de cette année pour les programmes d'exploration visant à découvrir des gîtes placériens et des gîtes en roche dure sont la découverte d'anomalies significatives d'or et d'éléments associés tant dans les sols que dans la roche et le prolongement d'indices connus par des travaux de prospection et de géophysique.

PRIX ROBERT E. LECKIE

Les noms des récipiendaires des prix Robert E. Leckie décernés pour la cinquième année consécutive pour des travaux exceptionnels de restauration de gîtes de quartz et de placers ont été annoncés le 16 novembre 2003 au Forum géoscientifique du Yukon. Ce sont Atac Resources Ltd. pour la restauration exceptionnelle d'un site d'exploration en roche dure au gisement de Mechanic Creek près de Carmacks, et Frank et Karen Hawker pour la restauration exceptionnelle d'un placer au gîte de Sixtymile River près de Dawson.

DIFFUSION DE L'INFORMATION

La Commission géologique du Yukon (CGY) produit maintenant une gamme complète de publications numériques. Toutes nouvelles cartes et rapports géologiques sont disponibles sur demande en format numérique, et toutes publications récentes sont aussi disponibles (sous format PDF) sans frais sur notre site internet (http://www.geology.gov.yk.ca). De plus, une gammes de rapports d'évaluation de propriété minières est maintenant disponible par l'entremise de notre site internet. Nous sommes aussi fier de notre service de carte interactive ('Map Gallery'). Ce service est disponible par l'entremise de notre site internet et permet la visualisation de la géologie régionale, des sites MINFILE, des levés régionaux de géochimie des sédiments de ruisseaux, de la topographie, des routes et des communautés du Yukon, et des sélections des terres des nations authochtones. Les données vectorielles peuvent maintenant être sélectionnées et téléchargées. Certaines des améliorations à venir incluent l'addition de données géophysiques, géochronologiques et paléontologiques. De plus, la couverture des concessions minières sera bientôt disponible.

Les publications de la Commission géologique du Yukon sont diffusées par le Bureau d'information et des ventes en géoscience. Elles sont disponible à l'addresse suivante :

Bureau d'information et des ventes en géosciences
a/s Conservateur des registres miniers
le ministère de l'Énergie, des Mines et des Ressources
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C.P. 2703 (K102)
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Courriel : geosales@gov.yk.ca

Pour en savoir plus long sur le Commission géologique du Yukon, visitez notre page d'accueil à www.geology.gov.yk.ca ou communiquez directement avec :

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Yukon regional mineral potential by deposit models

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Yukon Geological Survey

Bradshaw, G.D. and vanRanden, J.A., 2004. Yukon regional mineral potential by deposit models. *In:* Yukon Exploration and Geology 2003, D.S. Emond and L.L. Lewis (eds.), Yukon Geological Survey, p. 61-68.

ABSTRACT

The results from four separate regional mineral potential assessments initiated by the Yukon Government from 1999 to 2001 are presented as mineral potential maps for specific deposit models. A quantitative method was used for the prediction of undiscovered deposits based on 44 mineral deposit models applicable to the Yukon. A panel of industry experts predicted the probability of discovering new deposits of each type within individual pre-defined tracts of land. Their predictions were based on all available geoscientific and mineral exploration data, combined with their own knowledge and experience. A statistical simulator produced scores for each tract for each individual deposit model, and these were given relative rankings. The accuracy of mineral potential maps is limited by the quality and quantity of geoscientific and mineral exploration history data, and by the level of geological knowledge at the time of the assessments. The mineral potential of a region should be re-evaluated when there is a significant advance in the knowledge of the geology of the region or when new data becomes available.

RÉSUMÉ

Les résultats de quatre évaluations distinctes du potentiel minéral régional entrepris par le gouvernement du Yukon de 1999 à 2001 sont présentés sous forme de cartes du potentiel minéral pour des modèles gîtologiques spécifiques. Pour prédire les gîtes non découverts, on a utilisé une méthode quantitative basée sur 44 modèles applicables au Yukon. Un groupe d'experts de l'industrie ont prédit la probabilité de découverte de nouveaux gisements pour chaque type dans des bandes de terrain prédifinies. Leurs prédictions étaient basées sur les données géoscientifiques et les données d'exploration minérale actuelles, combinées à leurs propres connaissances et expérience. Un simulateur statistique a produit des pointages pour chaque bande et pour chaque modèle, ce qui a permis de les classer. L'exactitude des cartes sur le potentiel minéral est limitée par la qualité et la quantité des données recueillies au cours de travaux géoscientifiques et d'exploration minérale et par le niveau des connaissances géologiques au moment des évaluations. Il faudrait réévaluer le potentiel minéral d'une région lorsqu'on aura accompli des progrès importants dans la connaissance de la géologie de la région ou lorsque de nouvelles données seront accessibles.

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INTRODUCTION

This contribution summarizes the results from four separate regional mineral potential assessments initiated by the Yukon Government from 1999 to 2001. The assessments were designed to assist in land use planning exercises, but also may be of interest to the mineral exploration industry. Data are presented as 18 maps; each one illustrates the mineral potential of a different deposit model. In addition to the mineral potential maps, this paper provides detailed information on the purpose, methodology and limitations of the mineral assessment process. This information is now available as a CD open file (Bradshaw and vanRanden, 2003).

REGIONAL MINERAL POTENTIAL ASSESSMENTS

Regional mineral potential studies have been completed over the majority of Yukon (with the exception of the northernmost Yukon and southwest of the Alaska Highway). Regional mineral potential was assessed in four phases (Fig. 1). These regional mineral resource assessments were conducted using a quantitative method for prediction of undiscovered deposits that was developed by the United States Geological Survey (USGS). This method is based on 39 mineral deposit types (i.e., mineral deposit models of Cox and Singer, 1986) and their probability of being hosted in a particular geological environment. The British Columbia Geological Survey (BCGS) modified the deposit models defined by the USGS and added others to best fit the geological and metallogenic setting of the southern Canadian Cordillera (Lefebure and Ray, 1995; Lefebure and Höy, 1996). For the Yukon assessments, the deposit models utilized by the BCGS were further modified to incorporate Yukon deposits (Fonseca and Abbott, in press). This method is best suited for regions such as Yukon where vast tracts of land commonly lack complete geological characterization and may contain a variety of mineralization styles. Although this method of mineral assessment is not without limitations, it yields reproducible and unbiased results.

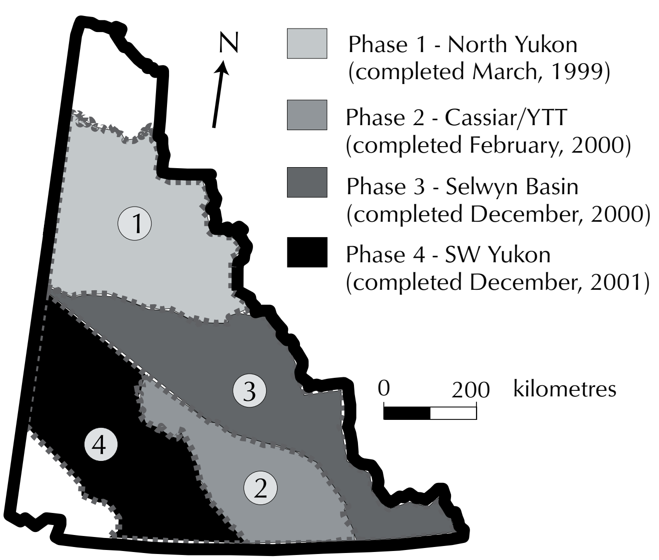


Figure 1. Locations and completion dates of Yukon regional mineral assessment phases.

MINERAL POTENTIAL

The mineral potential of a region describes the probability for the existence of undiscovered metallic mineral deposits. This mineral potential is based on the current state of geoscientific knowledge, and its accuracy is dependent upon the availability and quality of geoscientific data (also supplemented by the mineral exploration history records). Regional mineral resource assessments utilize the following geoscientific and mineral exploration data: (1) bedrock geology maps at 1:250 000 and 1:50 000 scale (digital compilation by Gordey and Makepeace, 1999); (2) regional airborne geophysical surveys (Lowe et al., 1999); (3) regional stream sediment, lake sediment (RGS), and till surveys (Héon, 2003); and (4) exploration history (Deklerk, 2002). These regional assessments were based on existing, publicly available data. Mineral potential of a region is a 'snapshot in time' and should be re-evaluated when there is a significant advance in the knowledge of the geology and the mineral deposit types in the region, or when new base data (e.g., RGS data) becomes available.

ASSESSMENT METHODOLOGY

Each mineral resource assessment consists of seven phases: (1) compilation, (2) definition of tracts, (3) preparation of deposit models, (4) assessment workshop, (5) data entry, (6) statistical simulation, and (7) ranking.

COMPILATION

Yukon Digital Geology (Gordey and Makepeace, 1999) was used as the geological base map at 1:250 000 scale. The overall accuracy of this compilation on a regional scale is considered to be very good, although the geology in some areas is based on studies done as long as

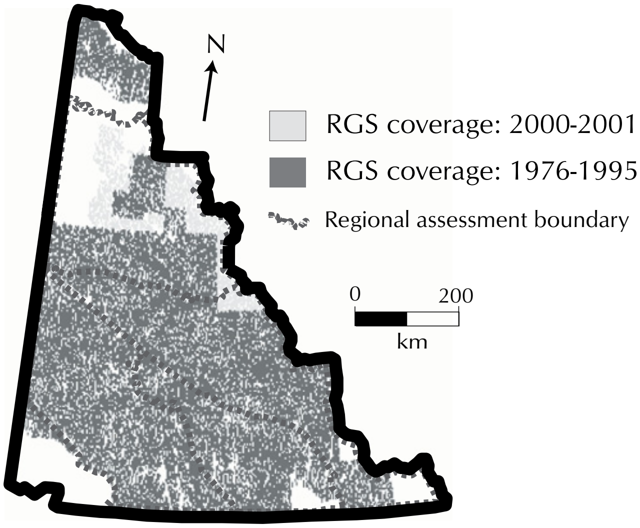


Figure 2. *Yukon regional geochemical survey (RGS) coverage.*

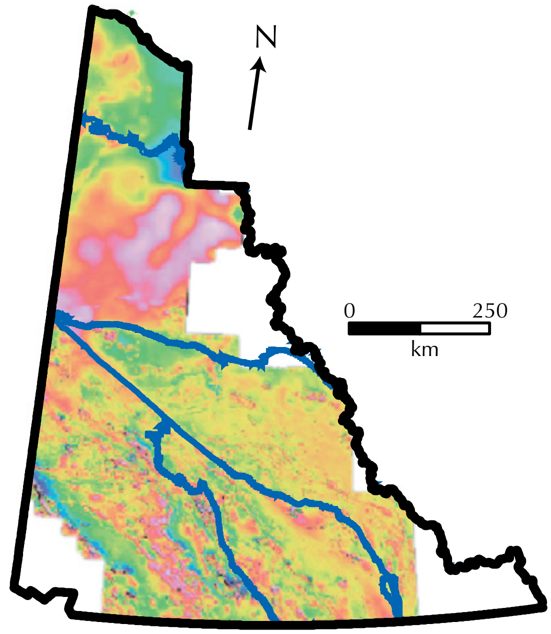


Figure 3. *Yukon airborne magnetic geophysical coverage.*

60 years ago. The Yukon Digital Geology compilation includes many recent 1:50 000-scale maps produced by the Yukon Geological Survey (YGS), and 1:250 000-scale maps produced by the Geological Survey of Canada (GSC).

Regional stream sediment geochemical surveys (RGS) have been completed over a large part of the Yukon Territory and have been digitally compiled (Héon, 2003). Median values were calculated for 21 diagnostic elements, and multiples of the medians were reported on 1:250 000-scale geochemical maps for each element. At the time of the mineral assessments, geochemical coverage was absent or incomplete in the following 1:250 000-scale map sheets: NTS 95C and 95E in southeast Yukon; NTS 106B, 106C, 106E, 106F, and 106L in northeast Yukon; and NTS 116F, 116G, 116H, 116I, 116J, 116K, 116N, 116O and 116P in north Yukon. RGS coverage has improved considerably since the completion of the regional mineral assessments, especially in the north Yukon (Fig. 2).

Aeromagnetic coverage is available for most of the Yukon (Fig. 3; Lowe et al., 1999). There is little or no geophysical coverage for NTS 106C, 106D, 106E and 106F in northeast Yukon. Most flight lines in the southern Yukon are at 0.8-km spacing. Flight lines in the north Yukon (north of ~65° latitude) are at 2-km spacing. Digital data was captured by digitizing contoured analog data, because most surveys are 1950-1960 vintage. Coloured maps illustrating the variations in the aeromagnetic total residual field were provided for each of the assessments (Lowe et al., 1999).

Mineral occurrences from the Yukon MINFILE database (anomalies, showings and deposits; Deklerk, 2002) were plotted on geological and geochemical maps to highlight areas of known mineralization and past exploration activity. Summaries and original descriptions of the mineral occurrences in each assessment area, which include deposit type, status, commodities, work history, and geological description, were provided to the estimators as supplements to the geology and geochemistry maps.

TRACTS

The Yukon Territory was divided into four large regions (each corresponding to a distinct mineral assessment phase) based on the large scale geological environment (e.g., Selwyn Basin). The area of each assessment phase was separated into a large number of tracts of approximately equal area (~1000 km^2). Tracts were defined on the basis of the regional geology. Tract boundaries are most commonly geological contacts (more specifically faults, lithologic contacts, or limits of Quaternary cover). A few tracts were assigned arbitrary boundaries, such as drainage patterns or roads, in order to maintain similar areas.

DIGITAL DEPOSIT MODELS

Tonnage and grade curves for 44 metallic mineral deposit types were utilized for the regional assessments. These deposit models are described by Fonseca and Abbott (in press).

ASSESSMENT WORKSHOPS

Assessment workshops hosted by the Yukon Geology Program took place in Whitehorse following the data compilation for each of the four phases. Five industry geologists (hereafter referred to as 'the estimators'), with considerable field experience and knowledge of the geology and mineral deposit models applicable to each region, participated in the assessment workshops. The following procedure was used for each of the four assessments: (1) for each tract, the estimators decided on the mineral deposit models that could potentially occur; (2) for each mineral deposit model, and for each individual tract, the estimators evaluated the percent probability (from 100 to 0) of discovering new deposits of that type in that tract; (3) for each tract, the estimators recorded their confidence (from 100 to 0 percent) in the current knowledge of the geology; and, (4) for each mineral deposit model, and for each tract, each estimator evaluated the relative knowledge and experience of each of the other four estimators and distributed 100 points between them. No estimates were made for non-metallic minerals such as diamonds, asbestos, emeralds and rhodonite. Likewise, potential for placer gold deposits and gravel deposits was not evaluated.

STATISTICAL SIMULATION AND RANKING

Data provided by the estimators were entered into a spreadsheet. Measurements of tract confidence and confidence level for undiscovered deposits were digitized in AutoCAD, and then copied to the spreadsheet. The data were then converted to a single evaluation for each tract/deposit model combination. The Monte Carlo Mark 3b simulator used the data to produce metal tonnages at the 90%, 50%, 10%, 5% and 1% confidence level intervals for each tract. The tonnages represent a combination of all possible mineral deposit models that could potentially occur within a given tract. These tonnages were then converted to dollar values using 10-year average prices for each of the commodities that are dictated by the relevant mineral deposit models. A 'confidence index' were derived from each of these dollar values by dividing the dollar value that corresponds to each confidence interval by the tract area. A 'confidence score' was calculated for each of the confidence level intervals by sorting and ranking the confidence index for each tract (i.e., the lowest confidence index has a score of 1, and the highest has a score equal to the total number of tracts). A final confidence score, referred to as 'sum score', was then calculated for each tract using the individual confidence scores weighted according to the 90%, 50%, 10%, 5% and 1% confidence level intervals. The sum score value was then ranked from highest to lowest, and defined the rank intervals used on the mineral potential maps.

For this compilation, the data provided by the estimators from all four regional assessments were used to calculate, in the same manner as described above, the potential for each tract to host a particular deposit type (i.e., a new 'sum score' was calculated for every tract that was assessed for a given deposit model). This value was used to rank the relative potential for each deposit type throughout the Yukon.

MINERAL POTENTIAL MAPS BY DEPOSIT MODELS

The mineral potential of the Yukon is ranked on 18 maps (Figs. 4a-r) using 18 individual deposit models. Of the 44 deposit models utilized in the 4 regional assessments, these 18 deposit types were deemed the most beneficial for publication as mineral potential maps. Relative rankings are from higher to lower and are illustrated using three categories for purposes of simplicity and ease of display. The maps show the relative potential, from higher to lower, for each tract to contain a specific deposit type. Every tract that was assessed for a given deposit model is ranked, and therefore tracts defined during different assessment phases are now ranked relative to one another. Tracts that were not assessed for a given deposit model are not ranked, and are displayed as white tracts on the respective mineral deposit model map. It should be emphasized, however, that no tract has zero potential and it still may be possible for a mineral deposit of a specific type to exist within a tract not assessed for that deposit model.

Figure 4. Yukon mineral potential maps by deposit models: *(a)* gold-quartz vein deposits; *(b)* Carlin-type deposits; *(c)* copper porphyry deposits; *(d)* copper skarn deposits; *(e)* epithermal gold vein deposits; *(f)* iron formation deposits. Park areas were not assessed.

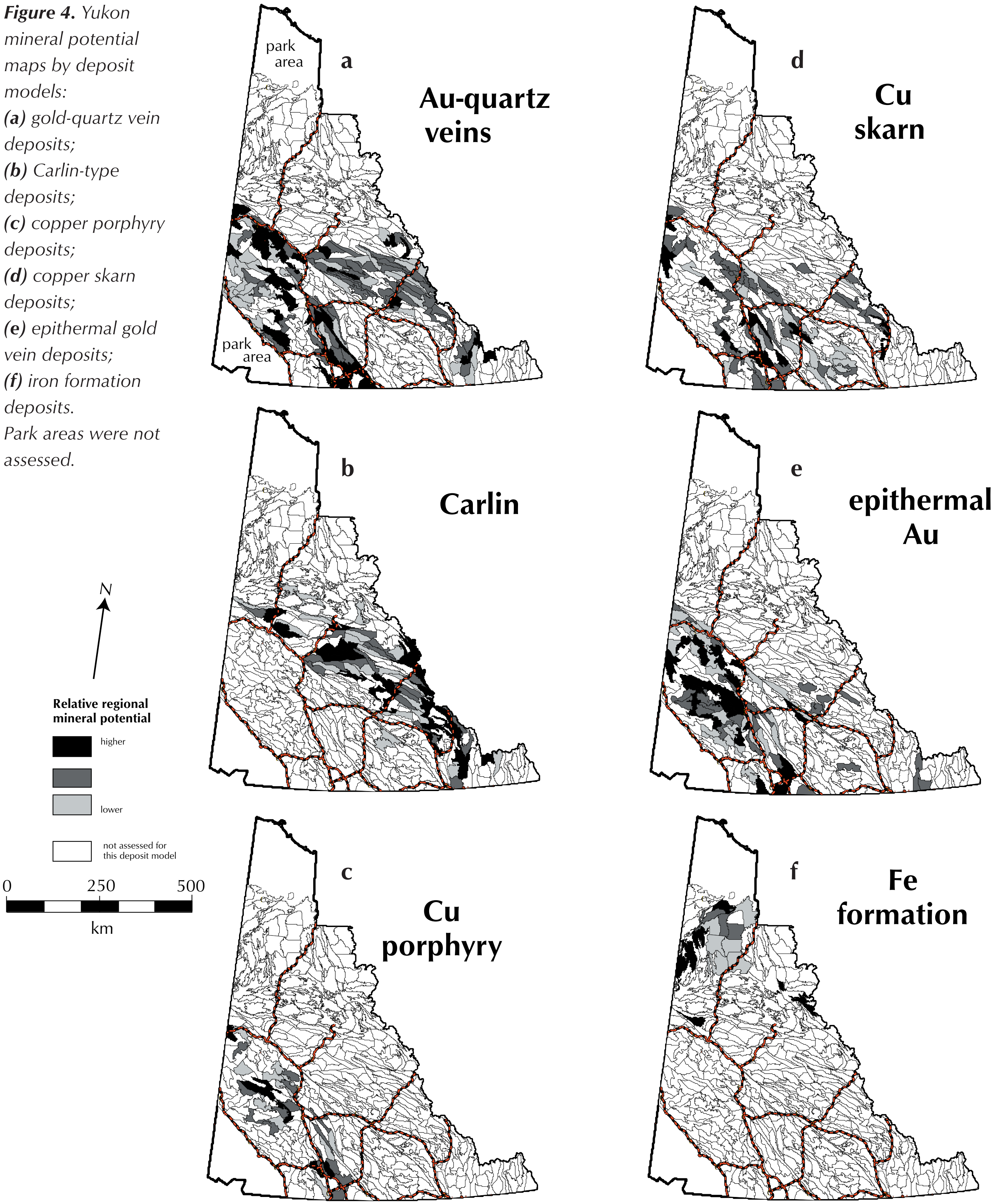
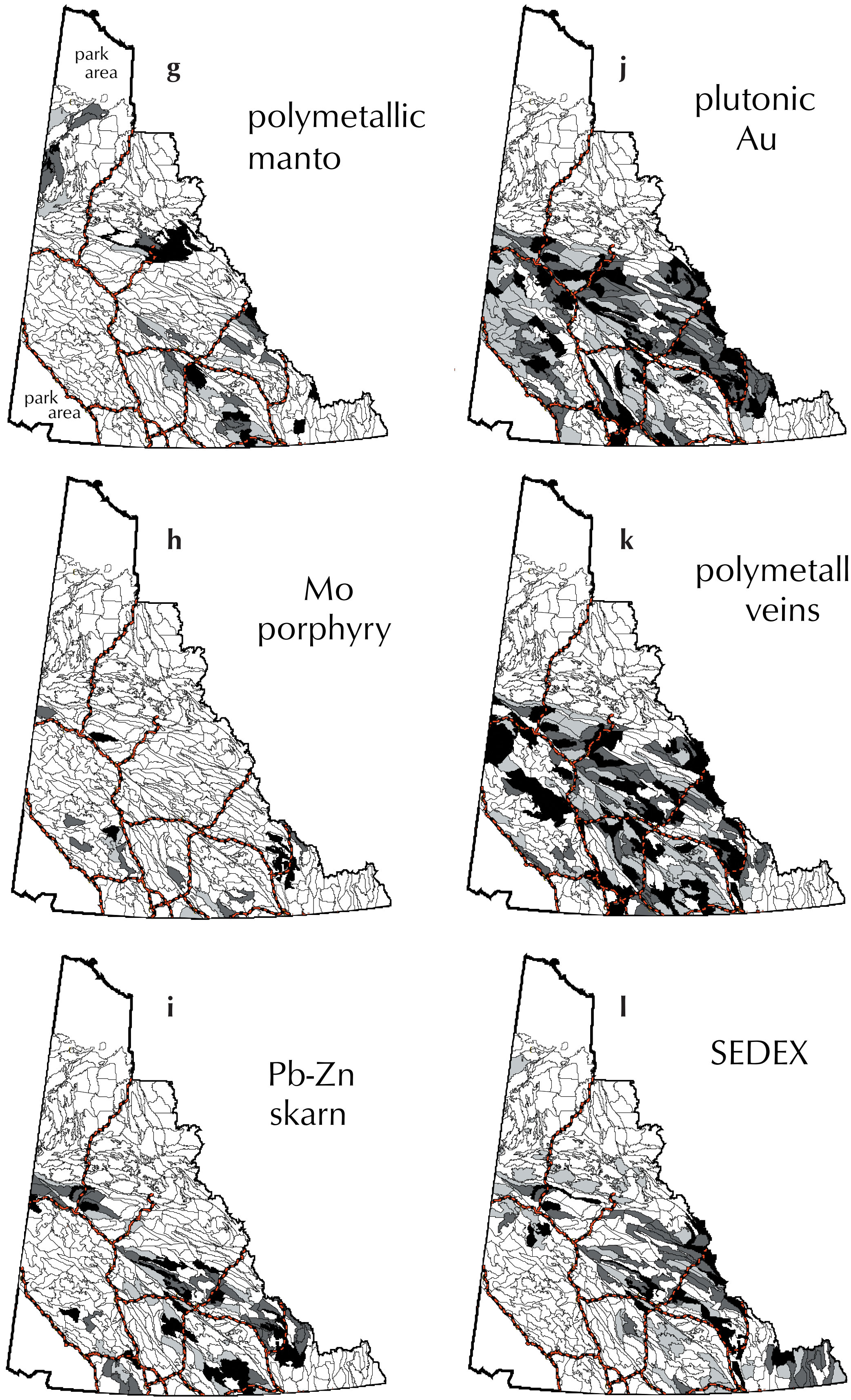


__Figure 4.__ (continued) Yukon mineral potential maps by deposit models:
***(g)** polymetallic manto deposits;*
***(h)** molybdenum porphyry deposits;*
***(i)** lead-zinc skarn deposits;*
***(j)** plutonic-related gold deposits;*
***(k)** polymetallic vein deposits;*
***(l)** sedimentary-exhalative (SEDEX) deposits.*
Park areas were not assessed.



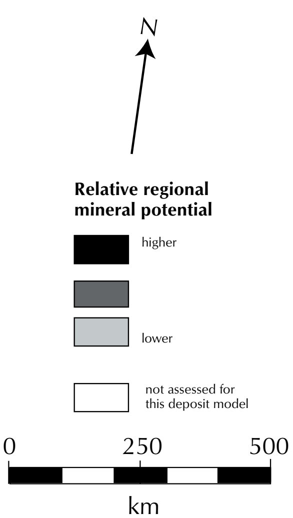
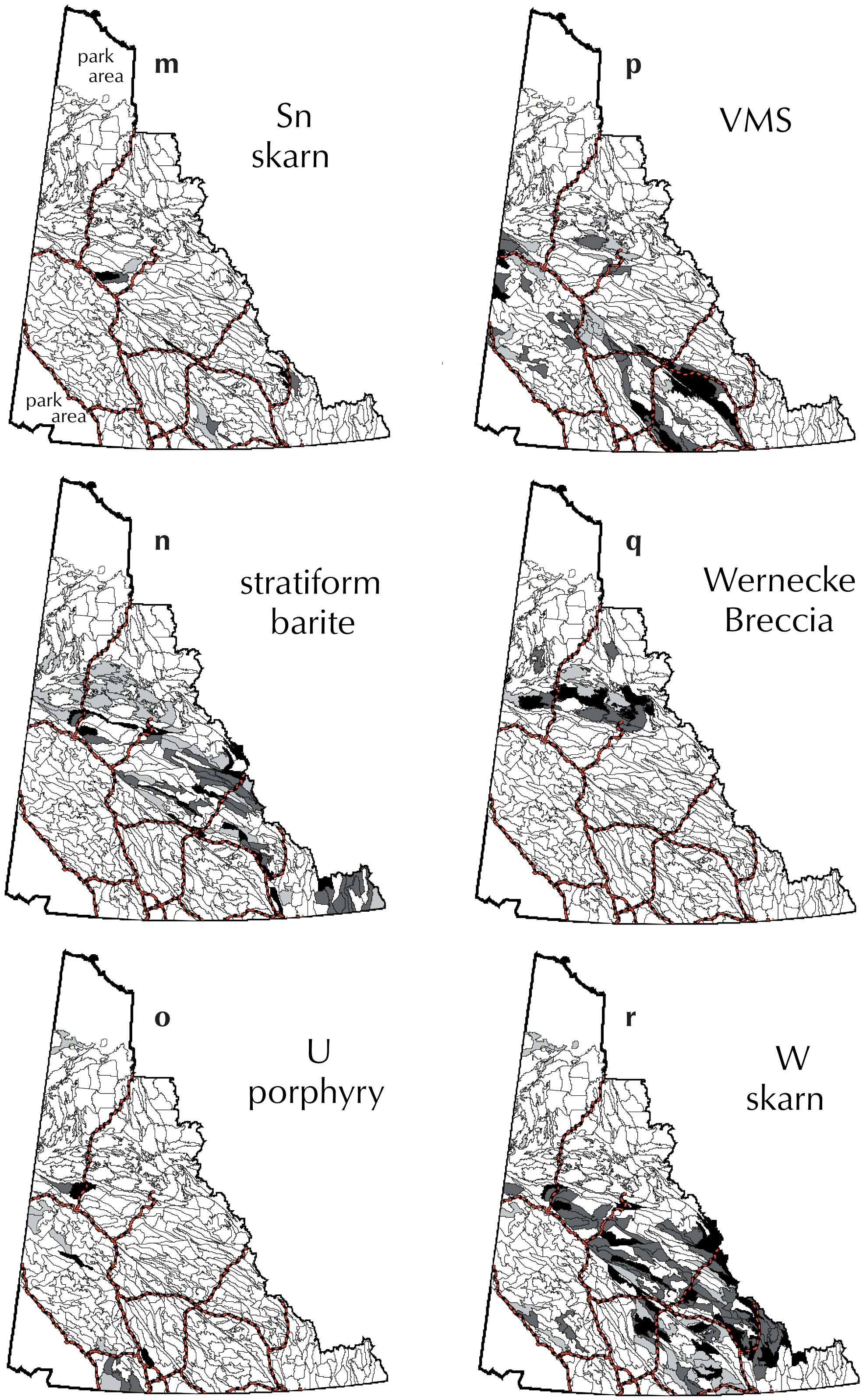
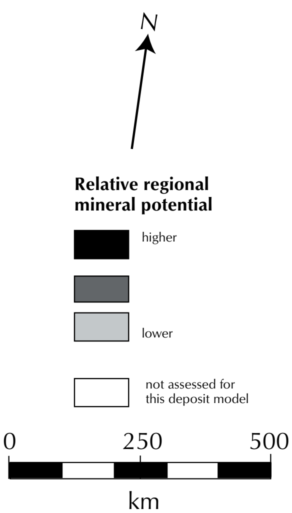


Figure 4. *(continued) Yukon mineral potential maps by deposit models:* ***(m)*** *tin skarn deposits;* ***(n)*** *stratiform barite deposits;* ***(o)*** *uranium porphyry deposits;* ***(p)*** *volcanogenic massive sulphide (VMS) deposits;* ***(q)*** *Wernecke breccia deposits; and* ***(r)*** *tungsten skarn deposits. Park areas were not assessed.*





LIMITATIONS OF REGIONAL MINERAL ASSESSMENTS

The primary limitation of mineral potential studies is that they are based on geological knowledge and data that was available at the time of the assessments. Rankings are subject to change as more data becomes available and geological knowledge improves. Although the estimators recorded their confidence in the current knowledge of the geology for each tract, it was not possible to integrate this information into the simulator. Furthermore, there may be potential in Yukon for deposit models that have not yet been recognized. Most commonly, tracts with limited baseline data were ranked as lower potential. For example, many tracts in the North Yukon were either not assessed or were found to have lower potential for most mineral deposit types. This is, at least partly, because of the relatively low level of geological knowledge and lack of baseline data (e.g., RGS) at the time of the North Yukon assessment.

Mineral potential assessments are also limited by the quality of the data on which they were based. For example, RGS data collected in 1976 does provide important information, but has not benefited from recent advances in the science of geochemistry and may prove to be unreliable for certain elements due to improvements in our understanding in how to collect and analyse samples. The number, locations, and types of mineral occurrences (from the Yukon MINFILE database, Deklerk, 2002), although controlled primarily by geology, also depend on the amount of exploration work done, which in turn depends on ease of access, price of commodities, and other non-scientific issues. Also, information pertaining to geology and mineral deposit models from the MINFILE database may require updating, particularly where derived from properties not recently worked.

Despite the limitations, quantitative regional mineral assessments yield reproducible and unbiased results. The deficiencies are a direct consequence of the fact that the mineral potential of a region is a 'snapshot in time' and should be re-evaluated when there is a significant advance in the knowledge of the geology and the mineral deposit types in the region, or when new base data (e.g., RGS data) becomes available.

ACKNOWLEDGEMENTS

This compilation is the result of the extensive efforts of former Yukon Government mineral assessment geologists: in particular A. Fonseca, with large contributions from D. Héon, R. Hulstein and R. Stroshein. Geologists M. Baknes, E. Balon, G. Bidwell, M. Burke, R. Carne, A. Doherty, G. Jilson, M. Jones, P. Holbek, B. Mawer, R. Stroshein, P. MacRobbie, J. Pautler and M. Stammers are thanked for sharing their considerable knowledge of Yukon geology, mineral exploration history, and deposit model profiles during the assessment workshops.

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Robert E. Leckie Awards for Outstanding Reclamation Practices

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Mining Lands, Energy Mines and Resources

St. Amand, J., 2004. Robert E. Leckie Awards for Outstanding Reclamation Practices. *In:* Yukon Exploration and Geology 2003, D.S. Emond and L.L. Lewis (eds.), Yukon Geological Survey, p. 69-70.

The fifth annual Robert E. Leckie Awards for outstanding reclamation practices were presented in Whitehorse, November, 2003. The awards, both for quartz and placer exploration or mining, were first established in November, 1999. The two awards are given for reclamation and site restoration efforts that go well beyond what is required by law, either by reclaiming land for which there is no obligation to reclaim, adding features to the land that have enhanced the area and local community, or returning mined land to a condition that is not only sound but aesthetically pleasing. The award is named after the late Robert (Bob) Leckie, a mining inspector with Indian and Northern Affairs Canada, who passed away in November, 1999 (see Yukon Exploration and Geology 1999).

QUARTZ MINING RECLAMATION

The 2003 Robert E. Leckie Award for Outstanding Reclamation Practices in Quartz Exploration and Mining was presented to Atac Resources Ltd. Atac is a junior exploration company, based in Vancouver, BC. Their commitment to reclamation is "to accomplish as good a job as it is humanly possible to do."

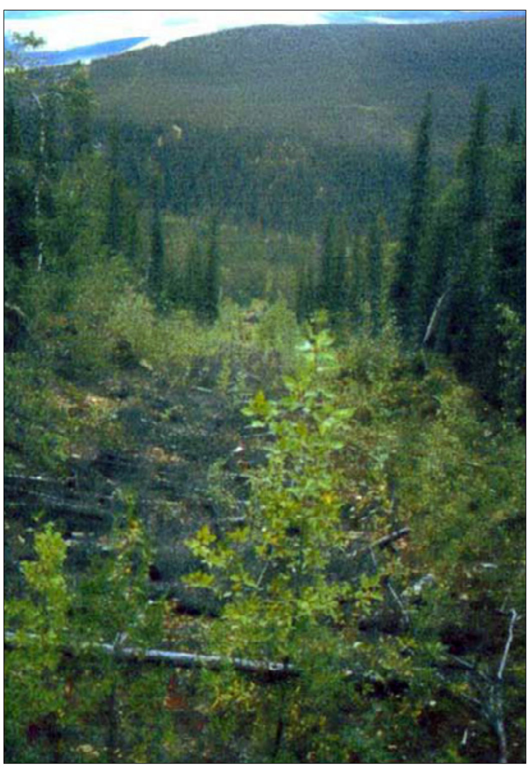

Figure 1. *Reclaimed trench at Mechanic Creek.*

In 2001, they carried out exploration on the Golden Revenue property at Mechanic Creek. The area was heavily disturbed with many old trenches scarring the landscape. Where the company partially entered these dated trenches, they restored the entire trench. In addition, organic debris was collected throughout the area, and transported to be used for site reclamation. Atac returned what was an unsightly area and a potential fire hazard back to its natural state. The company has been actively removing waste such as scrap metal and plastics from the area, consulting with local placer miners for possible recycling prior to removal.

The reclamation activities undertaken by Atac Resources Ltd. were a huge effort and they are without doubt worthy recipients of this award.

Honourable mention was also given to Viceroy Minerals Corporation for leadership and innovation in their reclamation efforts at Brewery Creek gold mine near Dawson City. Viceroy has carried out progressive reclamation at the site since operations

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Figure 2. *Kokanee pit at Viceroy's Brewery Creek gold mine.*

Figure 3. *Reclaimed Sixtymile River stream channel and banks.*

began in 1996; they won two previous awards for outstanding clean-up practices. Reclamation work has included the following: staging of mine open-pit development for waste rock disposal, reducing surface disturbances; heap detoxification and neutralization with innovative technology — nutrient addition with a contingency biological treatment cell; stockpiling and reuse of organic soils as a growth media for reclamation; and testing of revegetation, seeding with native and non-native species. Most of the waste rock dumps and pits have already been reclaimed and liability of the site has been greatly reduced.

PLACER MINING RECLAMATION

The 2003 Robert E. Leckie Award for Outstanding Reclamation Practices in Placer Mining Reclamation was presented to Fox Placer Exploration. Frank and Karen Hawker have been mining the Sixtymile River area near Dawson since 1993. This ground had been previously dredged and mined by bulldozer. Frank and Karen believe that reclamation is part of the mining process and, as a result, have consistently achieved land restoration beyond what was required.

Mining this previously dredged area has brought organic materials, which were buried under coarser material during the dredging process, back to the surface to be redistributed over recontoured tailings piles. Presence of this organic material will now promote natural revegetation. While contouring, the area was scarified to encourage entrapment of water and airborne seeds. The area where the Hawkers have mined supports rapid natural revegetation and has been converted from a virtually barren landscape of dredge tailings and old abandoned cuts to aesthetic rolling hills.

Honourable mention was also given to Mr. Geoffrey Jacobs of Downunder Joint Mining Ventures. He added to the well-being of the community at large for his outstanding reclamation efforts at both Lousetown and Hunker Creek. At Lousetown, the entire pit face was contoured for stability and safety. Relocated material was used and all wastes removed. The bench at Hunker Creek had been mined by a number of previous operators. Mr. Jacobs cleaned up the site, and removed fuel containers and oil pails, as well as miscellaneous waste materials. The bench was contoured, including the pit wall; then this was covered with an organic soil/root mix to promote revegetation.

Figure 4. *Natural revegetation at Hunker Creek.*

Late Wisconsinan McConnell glaciation of the Whitehorse map area (105D), Yukon

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ABSTRACT

Ice accumulations in the Coast Mountains of southwestern Yukon and the Cassiar Mountains of south-central Yukon during the late Wisconsinan were responsible for glaciation of the Whitehorse area. Cirques in the Coast Mountains likely supported the first glaciers that advanced out of the mountain valleys ahead of the more distal Cassiar accumulation. Glacial maximum is characterized by topographically unconstrained ice flow trending northwesterly over most of the map area. Ice thickness over the city of Whitehorse exceeded 1350 m during full glacial conditions. Deglaciation is characterized by frontal retreat punctuated by periods of dynamic equilibrium and readvances. Differential retreat of the Cassiar and Coast Mountain ice lobes enabled the Cassiar lobe to penetrate, and at times readvance, up-gradient into Coast Mountain valleys. This pattern of deglaciation created ice dams and a series of proglacial lakes that submerged valleys under as much as 300 m of meltwater.

RÉSUMÉ

Les accumulations de glace dans la chaîne Côtière du sud-ouest du Yukon et les monts Cassiar dans le centre-sud du Yukon au Wisconsinien tardif sont à l’origine de la glaciation de la région de Whitehorse. Les cirques de la chaîne Côtière ont probablement contenu les premiers glaciers qui se sont avancés au-delà des vallées de montagne devant l’accumulation plus distale de Cassiar. Le maximum glaciaire est caractérisé par un écoulement glaciaire sans contraintes topographiques orienté vers le nord-ouest sur presque toute la région cartographique. L’épaisseur de glace au dessus de la ville de Whitehorse dépassait 1350 m lorsque les conditions étaient complètement glaciaires. La déglaciation est caractérisée par un recul frontal ponctué par des périodes d’équilibre dynamique et des réavancées. Le recul différentiel des lobes glaciaires de Cassiar et de la chaîne Côtière a permis au lobe de Cassiar de pénétrer, et parfois de réavancer vers l’aval des vallées de la chaîne Côtière. Ce mode de déglaciation a créé des barrages de glace ainsi qu’une série de lacs proglaciaires qui ont submergé les vallées d’eau de fonte pouvant atteindre 300 m de profondeur.

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INTRODUCTION

During the Late Wisconsinan McConnell Glaciation (~20,000 years ago), the Whitehorse map area (105D) was glaciated by ice lobes originating in the Coast Mountains and the Cassiar Mountains of southern Yukon (Fig. 1). This paper describes the regional interaction and relative influence of these ice lobes, beginning with the onset of glaciation and finishing with final deglaciation. While the chronology of these events is poorly constrained, a reconstruction of glacial stages according to ice-flow indicators, ice-stagnation episodes and glacial-lake history is possible.

PREVIOUS WORK

Much of the early geological work in the Whitehorse map area focused on the mineral deposits at Windy Arm, Wheaton River and Whitehorse (Dawson, 1889; McConnell, 1906, 1909; Cairnes, 1908, 1912, 1916; Bostock, 1941; Wheeler, 1961; Hart and Radloff, 1990). The first surficial geology descriptions were completed by Denny (1952) in a reconnaissance survey of Late Quaternary geology along the Alaska highway. Wheeler (1961) described the style of glaciation in the Whitehorse map area and produced the first geomorphological map.

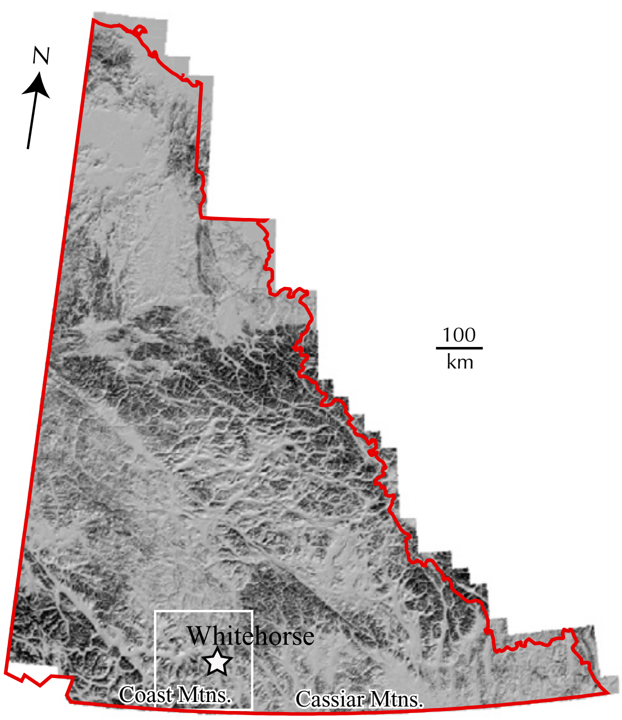


Figure 1. *Map of Yukon showing the location of the Coast Mountains, Cassiar Mountains and study area (outlined box).*

Surficial geology and soils mapping by Morison and McKenna (1980) at 1:100 000 scale provided the first Quaternary geology maps of the region. Morison and Klassen (1990) completed the surficial geology of the Whitehorse map (105D) at 1:250 000 scale. Soils mapping by Mougeot and Smith (1992, 1994) at 1:20 000 scale in the Takhini River valley and the Carcross valley provide detailed descriptions of soil parent materials. Thesis investigations into the sedimentology and paleogeography of Glacial Lake Champagne, in the vicinity of Whitehorse, were completed by Barnes (1997), and the glacial geomorphology of Whitehorse was studied by Ayers (2000). Finally, Mougeot et al. (1998) mapped the terrain and surficial geology of the city of Whitehorse (1:30 000 scale).

PHYSIOGRAPHY

The Whitehorse map area encompasses the physiographic transition between the southern portion of the Yukon Plateau and the northeastern extent of the Coast Mountains (Fig. 2). The eastern half of the region, including the area north of the Takhini River, lies within the Yukon Plateau, a region of accordant uplands ranging between 800 and 2000 m in elevation (Bostock, 1948). The western half, south of the Takhini River, lies within the Coast Mountains. Wheeler (1961) referred to this portion of the Coast Mountains as a transitional zone between the two regional physiographic subdivisions. The characteristic cirque- and horn-strewn topography associated with the Coast Mountains is found only in the southern portion of the map area west of Bennett Lake. The remainder of the 'transitional zone' is an upland plateau dissected by relatively narrow and deep river valleys. In this paper, the Coast Mountains occurring in the Whitehorse map area will be referred to as the 'Coast Mountains transitional zone'.

DRAINAGE

The Whitehorse map area lies within the Yukon River drainage basin. The larger drainages include the Primrose, Wheaton, Watson and Ibex rivers in the Coast Mountains transitional zone, and the Yukon and M'Clintock rivers in the Yukon Plateau. The Yukon River flows northerly through a system of interconnected valley-bound lakes in the southeast corner of the map area. North of the city of Whitehorse, the Yukon River flows into Lake Laberge, a 50-km-long lake that extends north into the Lake Laberge map sheet (105E).

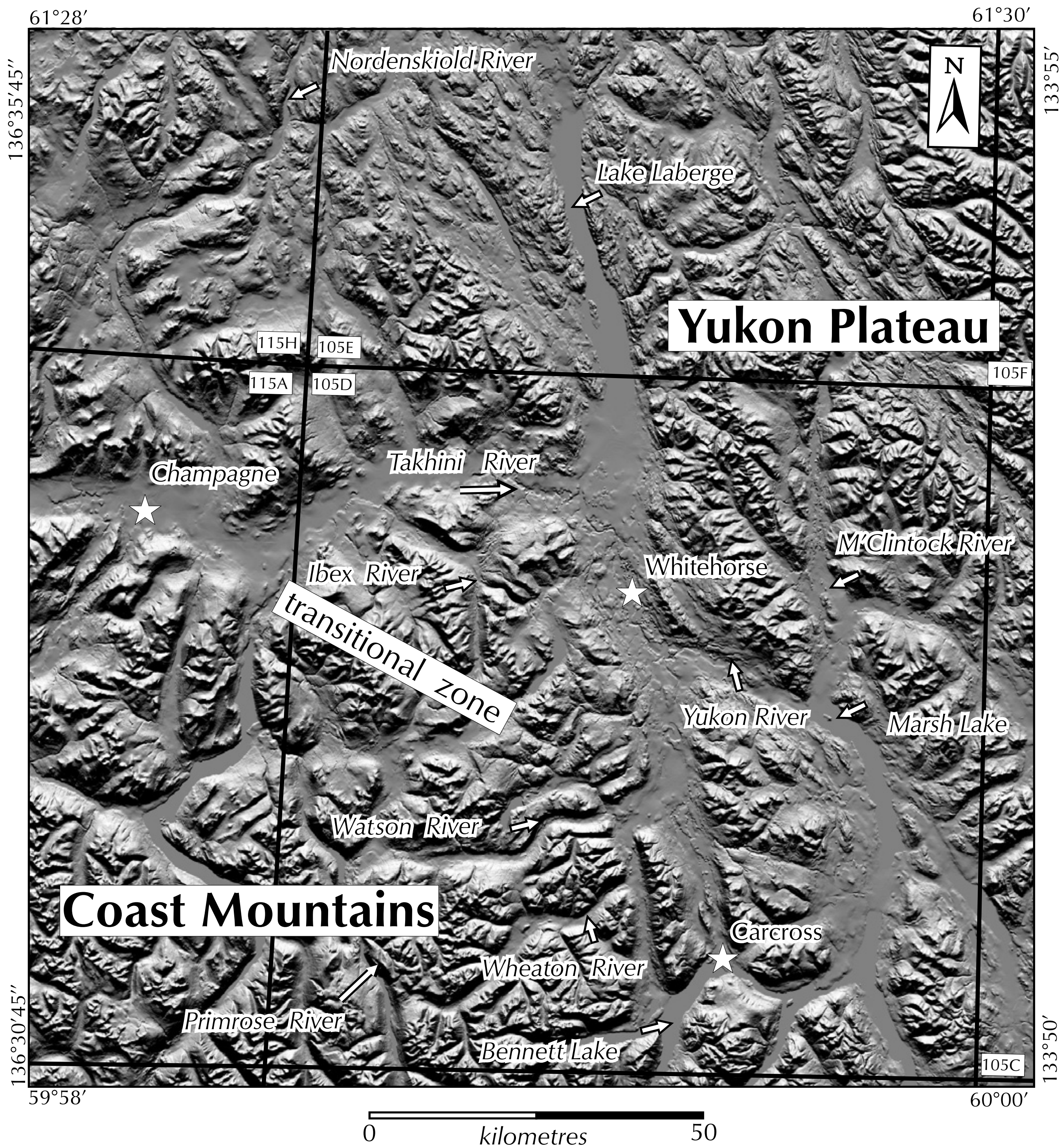
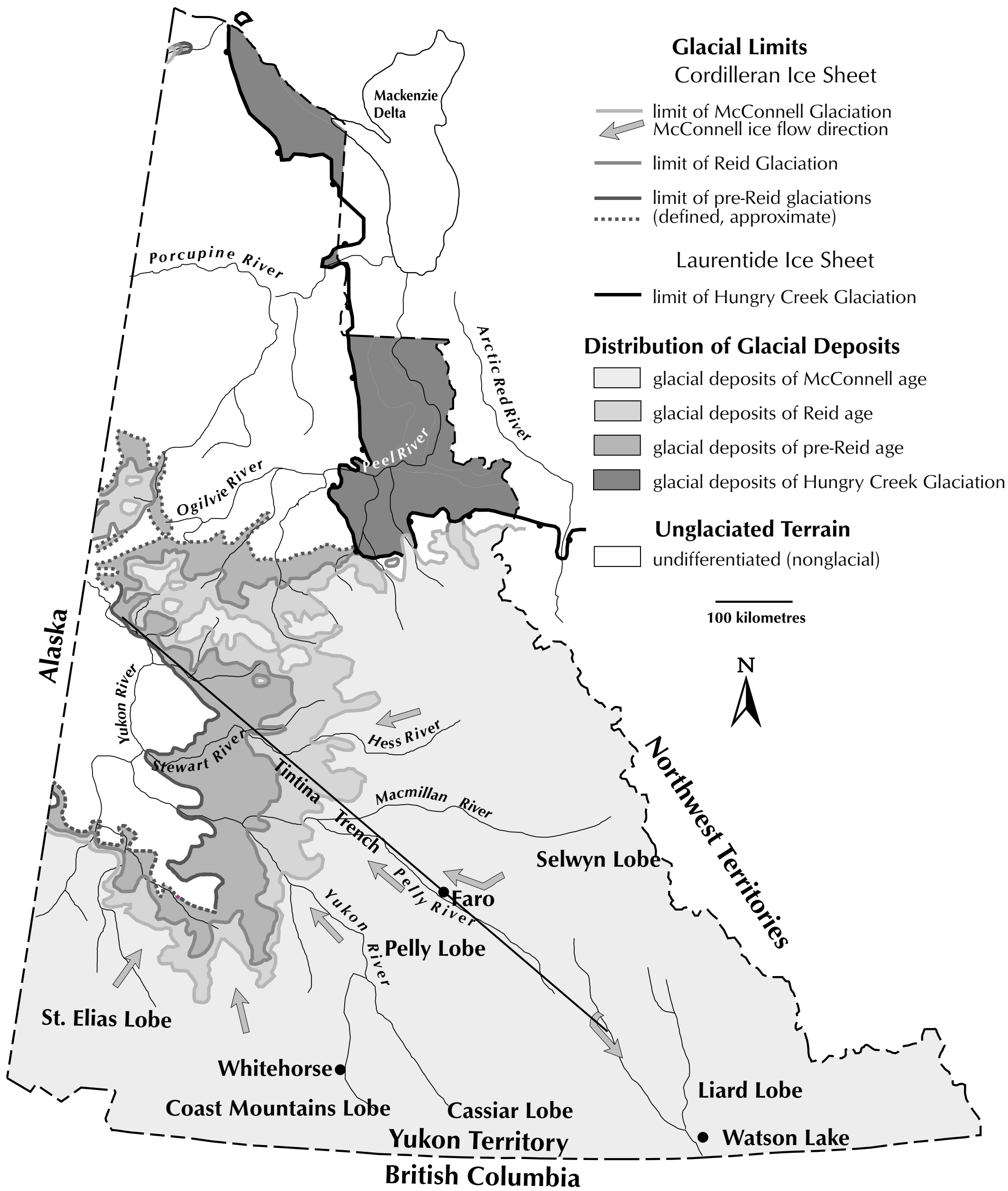


Figure 2. *Detailed location map of the study area showing major physiographic divisions.*

YUKON GLACIAL HISTORY

The long Quaternary glacial and interglacial history of Yukon is preserved in the stratigraphic record found at the margins of glaciation and in unglaciated terrain. The preservation of this record is due to aridity in central Yukon, which inhibited the extent of glaciers in this region (Armentrout, 1983; Jackson et al., 1991). As a result of limited glacial erosion, long stratigraphic records and multiple glacial margins are preserved in central Yukon, which has enabled researchers to piece together the Quaternary history (Fig. 3). The first Cordilleran glaciation in Yukon occurred between 2.6-2.9 Ma years ago (Froese et al., 2000; Duk-Rodkin and Barendregt, 1997; Duk-Rodkin et al., 2001). This first glaciation is thought to have been the most extensive; subsequent Pleistocene glacial advances were less extensive. As many as six glaciations during the Pleistocene are recorded in the stratigraphy of Tintina Trench near Dawson City (Duk-Rodkin and Barendregt, 1997; Duk-Rodkin et al., 2001). In the Whitehorse area, pre-McConnell deposits have not been observed, which suggests that sediments associated with previous advances were eroded or buried during the last glaciation (Wheeler, 1961).

__Figure 3.__ Glacial limits map of Yukon (after Duk-Rodkin, 1999).



The onset of climatic cooling associated with the late Wisconsinan McConnell Glaciation had begun by 29.6 ka BP according to organic deposits containing arctic floral assemblages under McConnell drift in the Stewart River valley near Mayo (TO-292, University of Toronto Laboratory; Matthews et al., 1990). By that time, alpine glaciers likely started to form in the higher accumulation zones of Yukon. However, the timing of the great ice sheets emanating from southern and eastern Yukon is poorly constrained. Ice-free conditions at 26 ka BP in the Tintina Trench near Ross River suggest that glaciers had not advanced out of the Pelly Mountains accumulation zone (TO-393; Jackson and Harington, 1991). In addition, ice-free conditions persisted near Watson Lake until 23.9 ka BP (GSC-2811; Klassen, 1987). Glacial maximum, ice retreat, and the re-establishment of vegetation in the Whitehorse area was complete by 10.7 ka BP according to terrestrial and aquatic macrofossils from lacustrine sediments in Marcella Lake (Kettlehole Pond) in southern Yukon (Anderson et al., 2002). From the radiocarbon chronology, the Late Wisconsinan McConnell Glaciation of Yukon occurred from approximately 23.9 ka to 10.7 ka BP.

MCCONNELL GLACIATION

STAGE 1: ONSET OF GLACIATION

Evidence of the McConnell glacial advance in the Whitehorse map area is absent and was likely removed or buried during later periods of the glaciation. Therefore, the reconstruction of the onset of glaciation is speculative and based on modern glacier analogues such as the St. Elias ice cap. It is assumed that ice first accumulated in cirques of the Coast Mountains, while at lower elevations tundra environments expanded with a descending tree-line elevation (Fig. 4 and 5). Alpine glaciers eventually

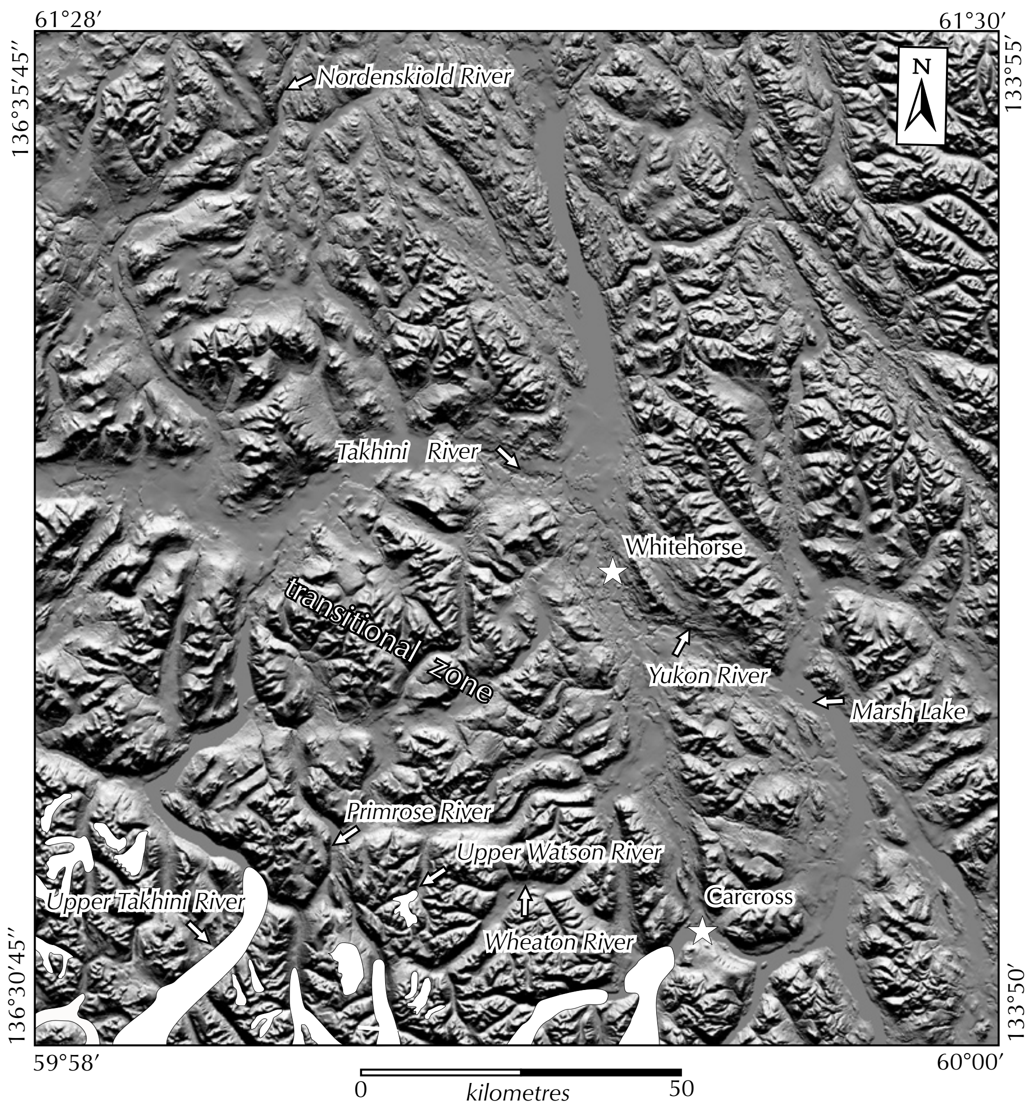


Figure 4. *Stage 1 – McConnell glacial advance. A schematic depiction of ice accumulations in the Coast Mountains (white glacial lobes in southern map area).*

Figure 5. *A modern glacier on the upper reaches of the Wheaton River. Cirques at high elevation in the Coast Mountains were occupied by similar glaciers at the onset of the McConnell Glaciation.*

coalesced to form valley glaciers in the Wheaton River, Bennett Lake and upper Watson River valleys. With continued glaciation, a Coast Mountain ice cap developed with radiating valley glaciers occupying major valleys such as the upper Takhini, Primrose, Wheaton and Watson rivers. These were the precursors of the Coast Mountains Lobe.

Ice accumulation had also begun in the Cassiar Mountains of south-central Yukon and Atlin District of northern British Columbia. The leading edge of this ice cap advanced northwestward into the Whitehorse map area via the Marsh Lake valley and continued north down the Yukon River valley. This portion of the Cordilleran Ice Sheet is referred to as the Cassiar Lobe (Wheeler, 1961).

The chronology of the onset of glaciation is uncertain. Evidence from central Yukon, near the McConnell glacial limit, indicates that tundra expansion may have preceded actual glaciation by anywhere from 5000 to 8000 years (Matthews et al., 1990; Jackson and Harington, 1991). In the Whitehorse area, it is estimated that the initial advance had begun by 29 ka BP, however significant ice accumulations may not have developed until after 26 ka BP.

STAGE 2: GLACIAL MAXIMUM

At the climax of the McConnell Glaciation, a continuous carapace of ice covered southern and eastern Yukon (Fig. 3 and 6). Ice thickness over the city of Whitehorse (700 m above sea level (a.s.l.)) exceeded 1350 m during glacial maximum according to the elevation of an erratic on the summit of Mount Granger (Fig. 7; 2087 m a.s.l.). Nunataks would have been scarce in this area and probably only present at the headwaters of the Wheaton River where summits reach 2460 m (Fig. 5). The northwest trajectory of the Cassiar Lobe was maintained through glacial maximum according to striae trending at 325° on Grey (Canyon) Mountain. The influence of the Cassiar Lobe also extended onto the Coast Mountains transitional zone west of Whitehorse, where striae and flutings having a northwest trajectory were observed near Alligator Lake, Mount Granger and Skukum Creek. The Coast Mountains Lobe, according to scanty evidence gathered by Wheeler (1961), moved in a northerly direction. The boundary between the Coast Mountains

__Figure 6.__ Stage 2 – McConnell glacial maximum. The dashed line represents the approximate boundary between the Coast Mountains and Cassiar lobes. Long arrows indicate direction of ice flow.

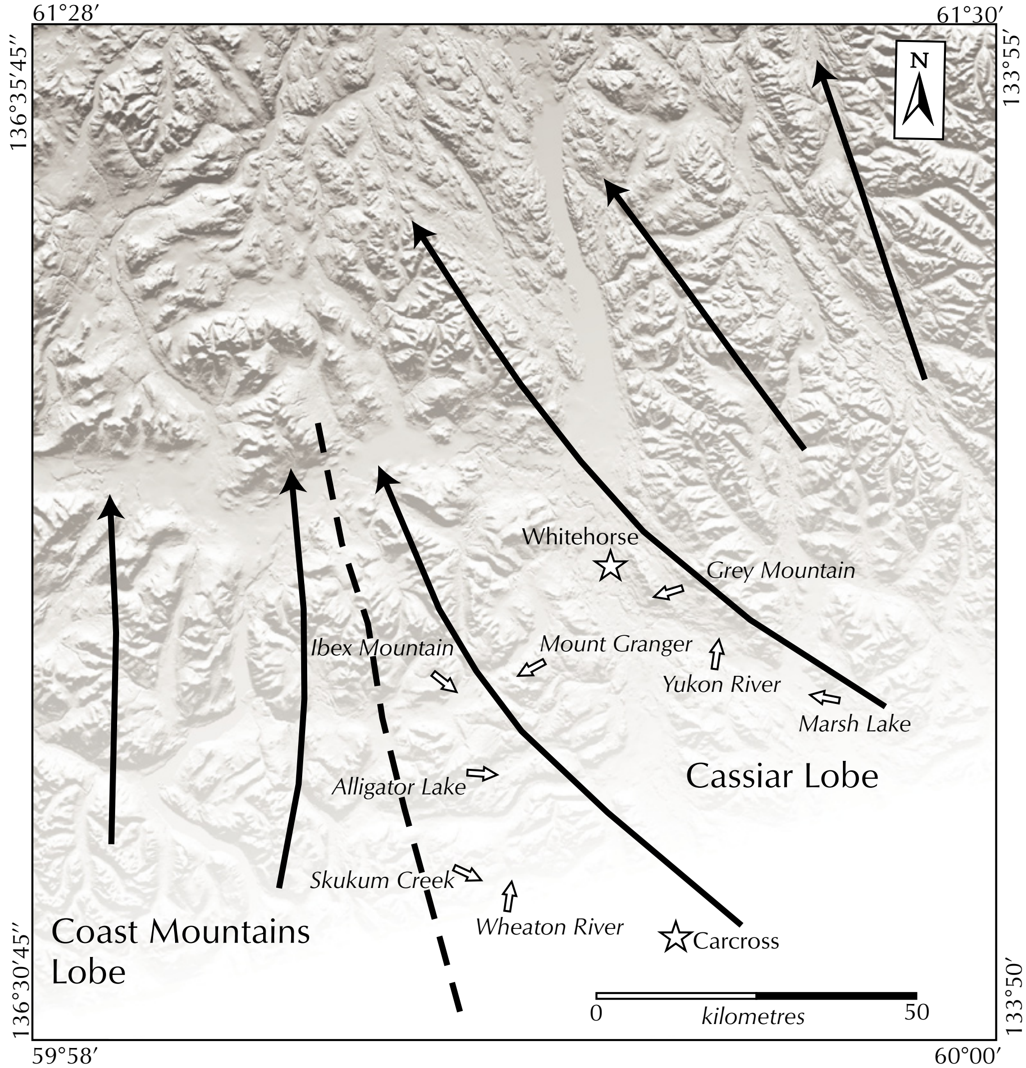


__Figure 7.__ A granitic erratic on the summit of Mount Granger (2087 m) west of the city of Whitehorse.

and the Cassiar lobes is not well defined but was most likely located over the transitional zone west of Alligator Lake and Ibex Mountain (Fig. 6).

STAGE 3: DEGLACIATION

McConnell deglaciation in the Whitehorse map area is divided into seven stages and presented in a series of schematic diagrams. These stages were identified based on changes in ice flow, glacial readvances, periods of dynamic equilibrium, or glacial lake development.

Stage 3a: Early deglaciation

Deglaciation brought a wholesale reduction of the ice thickness in the Whitehorse map area. As a result, more nunataks would have been exposed above the ice surface. Movement of a thinner ice sheet would also have become more susceptible to topographic control. For example, multiple striae observed in the Takhini River valley indicate that ice flow became increasingly controlled by topography. Ice flow readjustments also occurred at the margin between the Coast Mountains and Cassiar lobes. High-elevation northeast-descending meltwater channels, west and north of Alligator Lake, suggest the western margin of the Cassiar Lobe retreated before the Coast Mountains Lobe, allowing the Coast Mountains Lobe to occupy parts of the transitional zone (Fig. 6).

Stage 3b: Cassiar re-advance

A large magnitude re-advance of the Cassiar Lobe occurred in the Whitehorse map area after early deglaciation (Fig. 8). Up-valley descending moraines and meltwater channels in the Wheaton and Watson river valleys suggest that the Cassiar Lobe re-advanced into the transitional zone after the Coast Mountains Lobe had retreated to the west. The climatic force responsible for

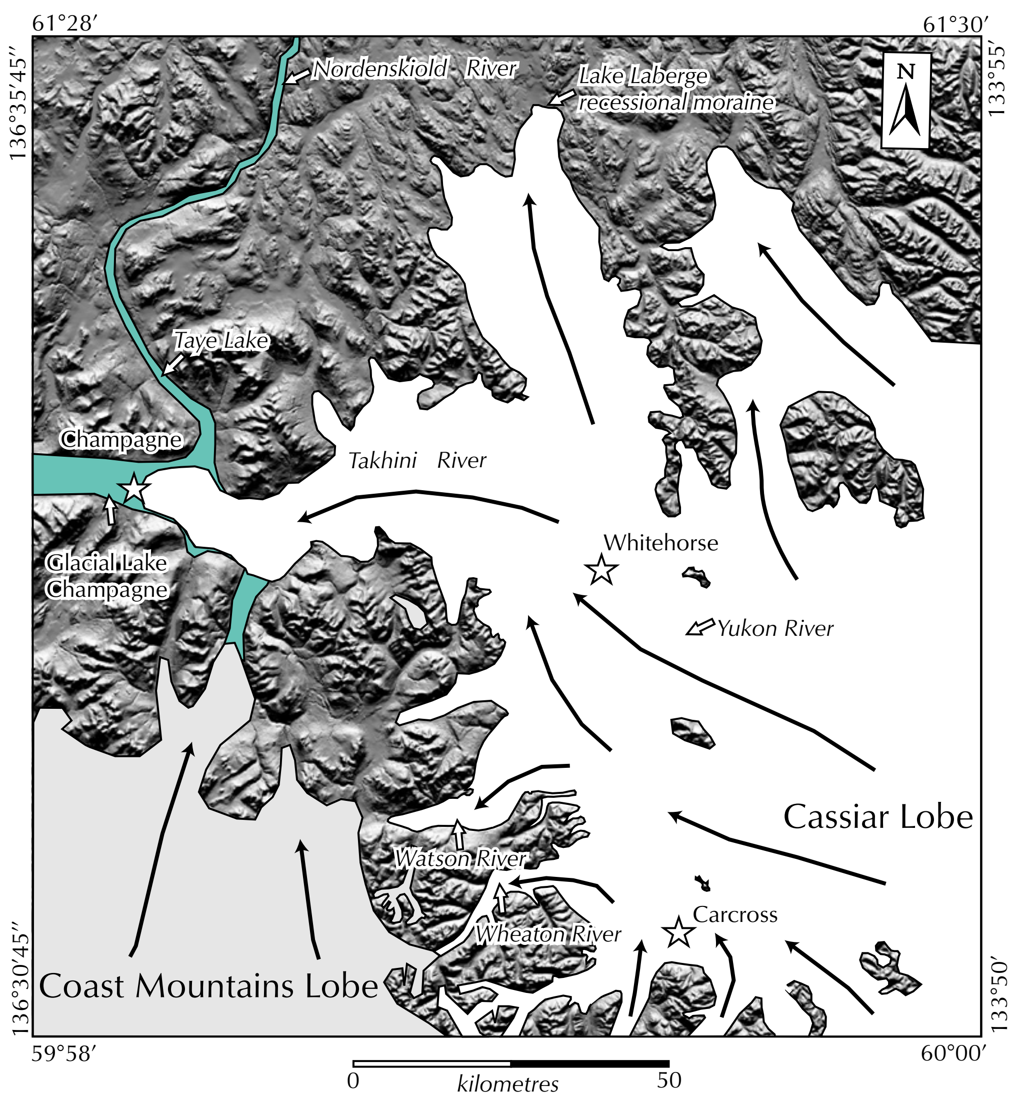


Figure 8. *Stage 3b – Cassiar re-advance. A schematic diagram showing the approximate limit of the Cassiar re-advance during deglaciation. Up-valley ice flow in the Takhini River valley dammed the westward drainage and created Glacial Lake Champagne.*

the re-advance appears to have had less influence on ice accumulations in the Coast Mountains. Reasons for this apparent precipitation deficit are unclear.

The limit of the re-advance in the Takhini River and the Yukon River valleys is poorly defined. This limit is drawn along the boundary of ice stagnation moraines which are thought to be concordant in both of these valleys.

At the village of Champagne, in the Takhini River valley, a well developed up-valley-oriented moraine may mark the limit of the Cassiar re-advance. Glacial Lake Champagne is thought to have been created by the retreat of the Cassiar Lobe from the Takhini River valley in the east and blockage of the Dezadeash River drainage by St. Elias ice to the west. Drainage for this lake occurred through the Taye Lake – Nordenskiold River divide. This outlet maintained a maximum water level of 746 m a.s.l. for drainage of Glacial Lake Champagne.

At the north end of Lake Laberge in the Yukon River valley, a large recessional moraine complex is preserved (Fig. 8). The magnitude of this stagnation complex suggests a significant pause occurred in the glacier's recession and is thought to correlate with the limit of the Cassiar Lobe re-advance. As the ice receded from this moraine, Glacial Lake Laberge developed behind the moraine of stagnating ice and sediment. Elevations of a fluvial terrace within the moraine and the upper-most strandline indicate that the highest outlet was at 699 m (a.s.l.) which is 65 m above the modern outlet. Flights of strandlines below the 699 m elevation suggest that erosion of the outlet was relatively constant during deglaciation.

Stage 3c: Ibex

The Ibex recessional stage is recognized from well developed morainal deposits extending from Fish Lake to the Ibex River valley (Fig. 9). The ice margin at this stage

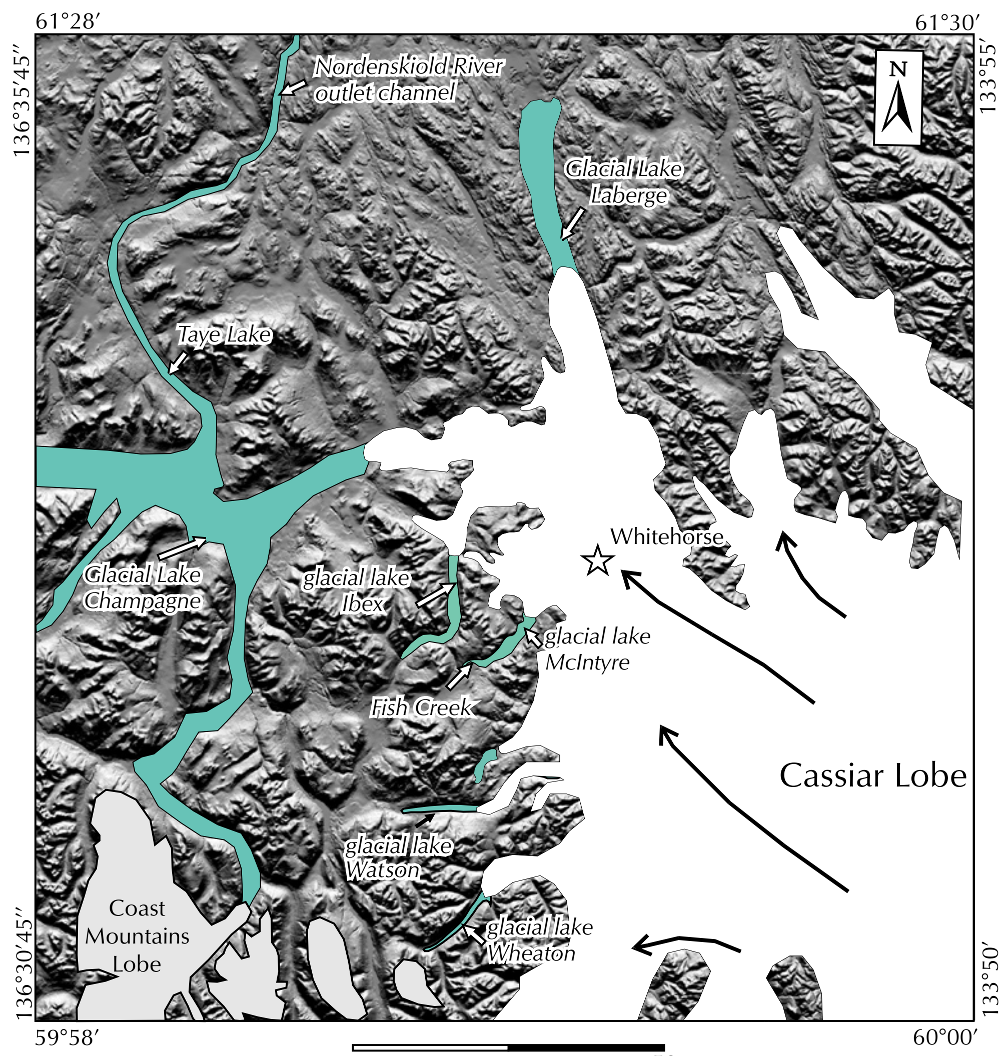


Figure 9. *Stage 3c – Ibex stage. This stage is defined by a recessional glacial limit that blocked the mouths of the Ibex River valley and Fish Lake. Ice tongues in the Yukon and Takhini river valleys retreated from the Cassiar re-advance limit, enlarging the glacial lakes in these valleys.*

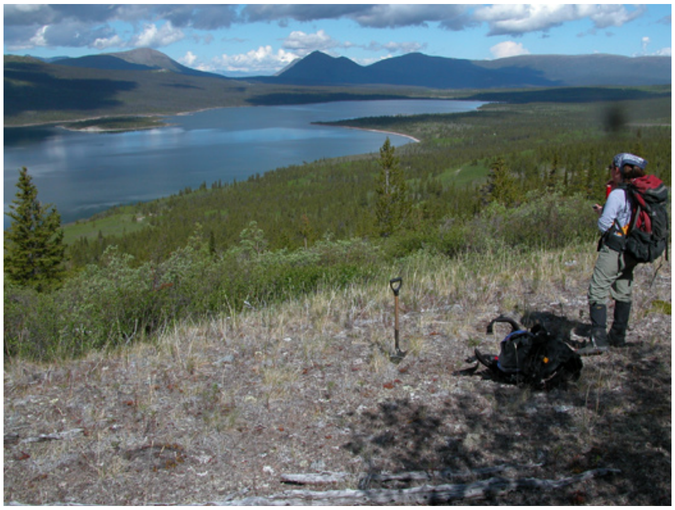


Figure 10. *View looking northwest across Fish Lake. The photograph is taken from the upper-most strandline of glacial lake McIntyre in Fish Lake valley (1250 m a.s.l.). This shoreline lies 120 m above the present shoreline of Fish Lake.*

Figure 11. *Scoured granite canyons in Ibex River valley formed from the draining of glacial lake Ibex.*

dammed both the Ibex River and Fish Lake valleys resulting in the development of two glacial lakes. The pro-glacial lake in Fish Lake valley, informally termed glacial lake McIntyre, reached an elevation of 1250 m a.s.l., that is, 120 m above modern Fish Lake (Fig. 10). The outlet for this glacial lake was located at the headwaters of Fish Creek and drained into the Ibex River valley. Upper strandline elevations in the Ibex River valley indicate that the water level reached an elevation of 1080 m a.s.l. The level of glacial lake Ibex was controlled by an outlet along the ice margin and possibly through sub-glacial channels, as evidenced by scoured granite bedrock in this area (Fig. 11).

During the Ibex stage, Glacial Lake Champagne would have increased in size as the Cassiar Lobe retreated to the east. Likewise, in the Yukon River valley, Glacial Lake Laberge would have increased in size as the ice receded to the south. Smaller pro-glacial lakes developed in the Wheaton and Watson river valleys.

Stage 3d: Chadburn

The Chadburn stage marks a significant pause in the retreat of the Cassiar Lobe from the Whitehorse area (Fig. 12). Large volumes of stagnation moraine in the vicinity of Whitehorse (Chadburn Lake area), Lewes Lake and Annie Lake all correlate to this period of dynamic equilibrium (Fig. 13). Further south, in the Wheaton River valley, glacial lake Wheaton would have persisted behind the ice front at Annie Lake (Fig. 12). Similarly, glacial lake Watson was impounded by the ice fronts at Lewes Lake and in the Yukon River valley at Cowley Creek. Each of these glacial lakes drained via outlets at their respective headwaters. The multiple ice fronts impounding glacial lake Watson acted as important sediment sources resulting in thick accumulation of glaciolacustrine deposits in that valley. To the north of the city of Whitehorse, glacial lakes Champagne and Laberge had joined following retreat of the Cassiar Lobe from the Takhini River valley. Drainage for the combined waters was through the Glacial Lake Laberge outlet, resulting in abandonment of the Nordenskiold outlet.

Figure 12. *Stage 3d – Chadburn stage. The Chadburn stage is a well defined recessional limit in the Whitehorse area.*

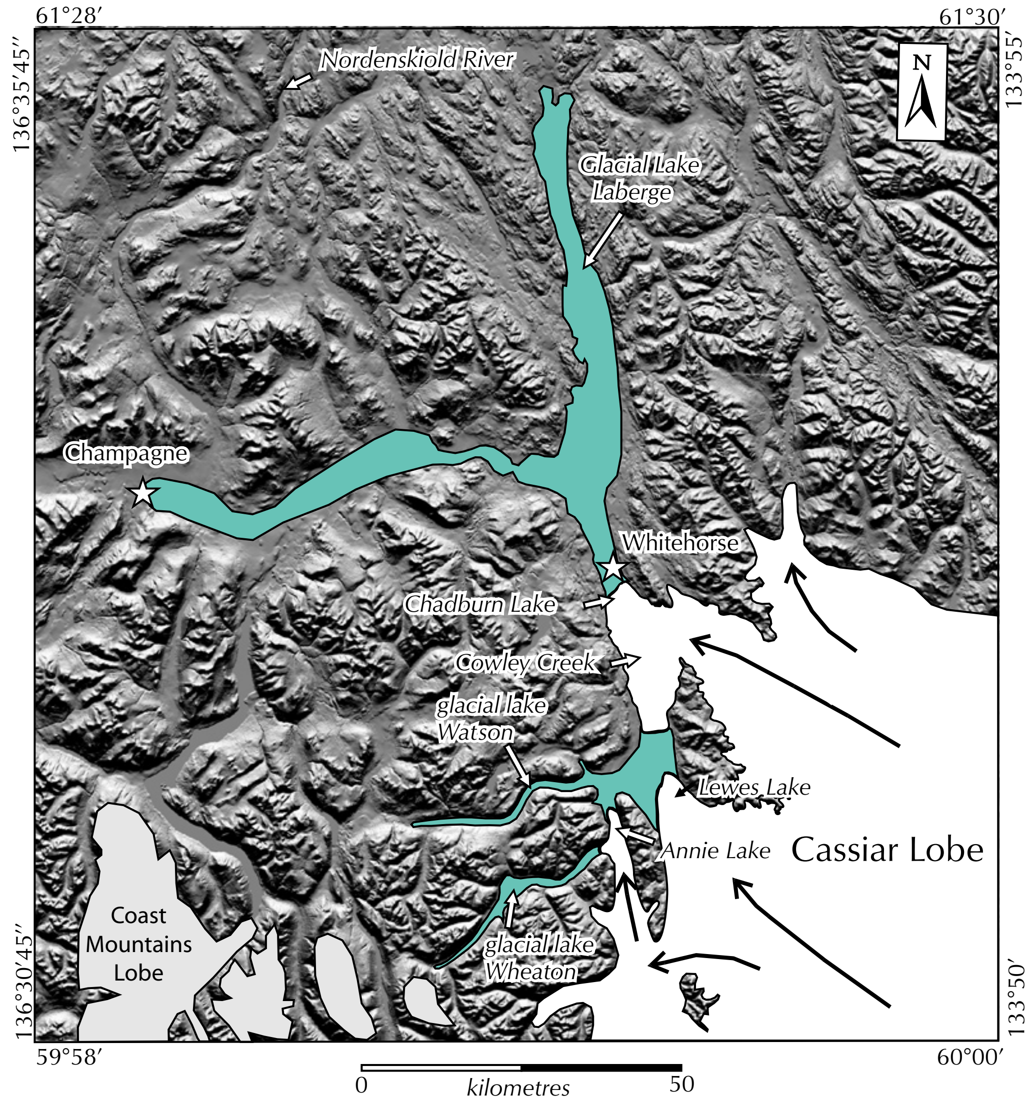
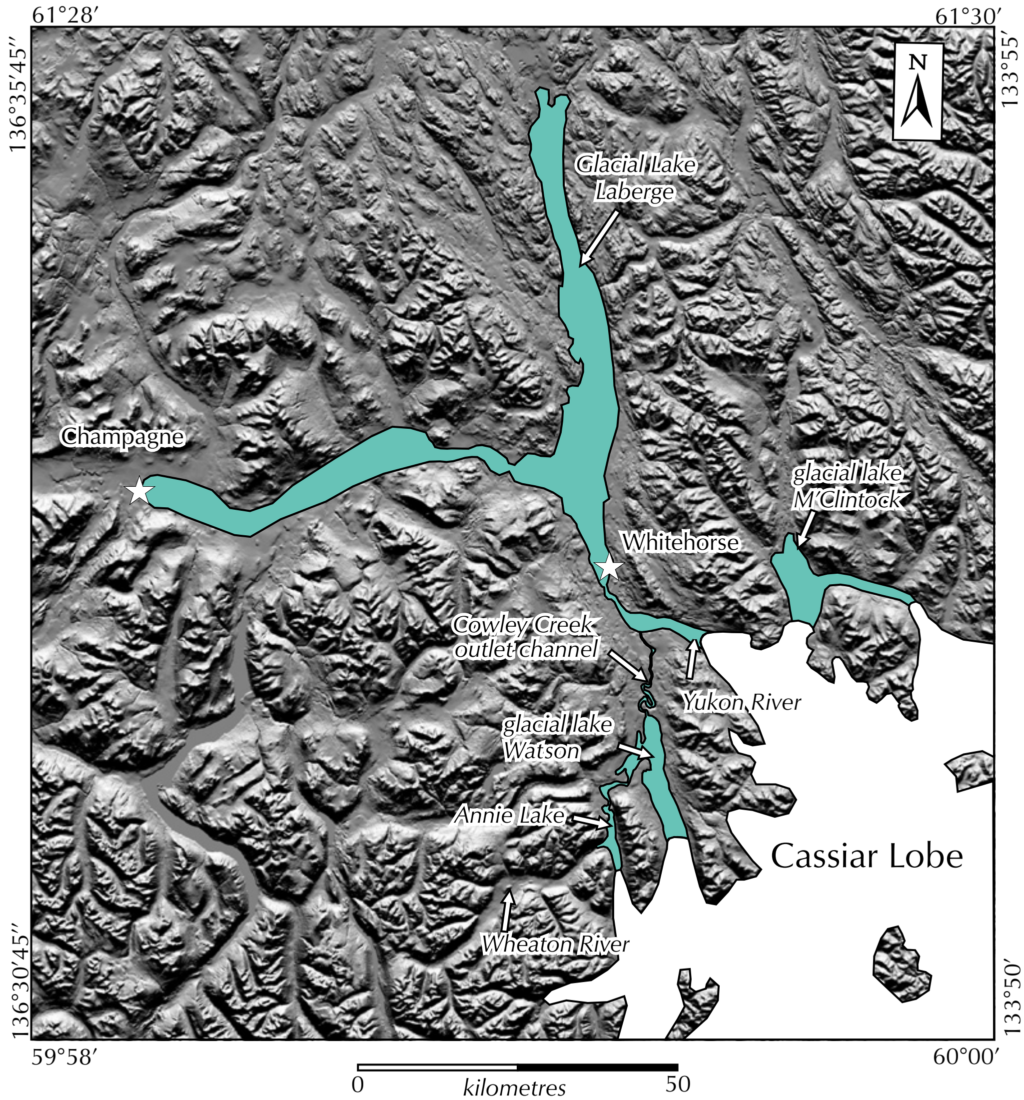


Figure 13. *A view to the north of Chadburn Lake near the city of Whitehorse. The rolling stagnation moraine topography is a remnant of the Chadburn recessional stage.*

Figure 14. *Stage 3e – Cowley stage. This stage is defined by the activation of the Cowley Creek outlet channel for glacial lake Watson.*



Stage 3e: Cowley

The Cowley stage marked a rearrangement of drainage for glacial lake Watson (Fig. 14). The eastward retreat of ice near Whitehorse permitted glacial lake Watson to drain northward into the Yukon River valley via the Cowley Creek outlet channel. The channel cuts through a sediment dam deposited during the Chadburn stage. Also at this time, the Wheaton River ice lobe would have retreated south from Annie Lake, permitting water from the upper Wheaton River to drain into glacial lake Watson (Fig. 15). A glacial lake would have also developed in the M'Clintock River valley as ice receded south in that drainage.

Figure 15. *A paleo-outwash channel at the north end of Annie Lake. This channel carried northward-flowing waters from the Wheaton River valley and a nearby melting ice tongue into glacial lake Watson.*

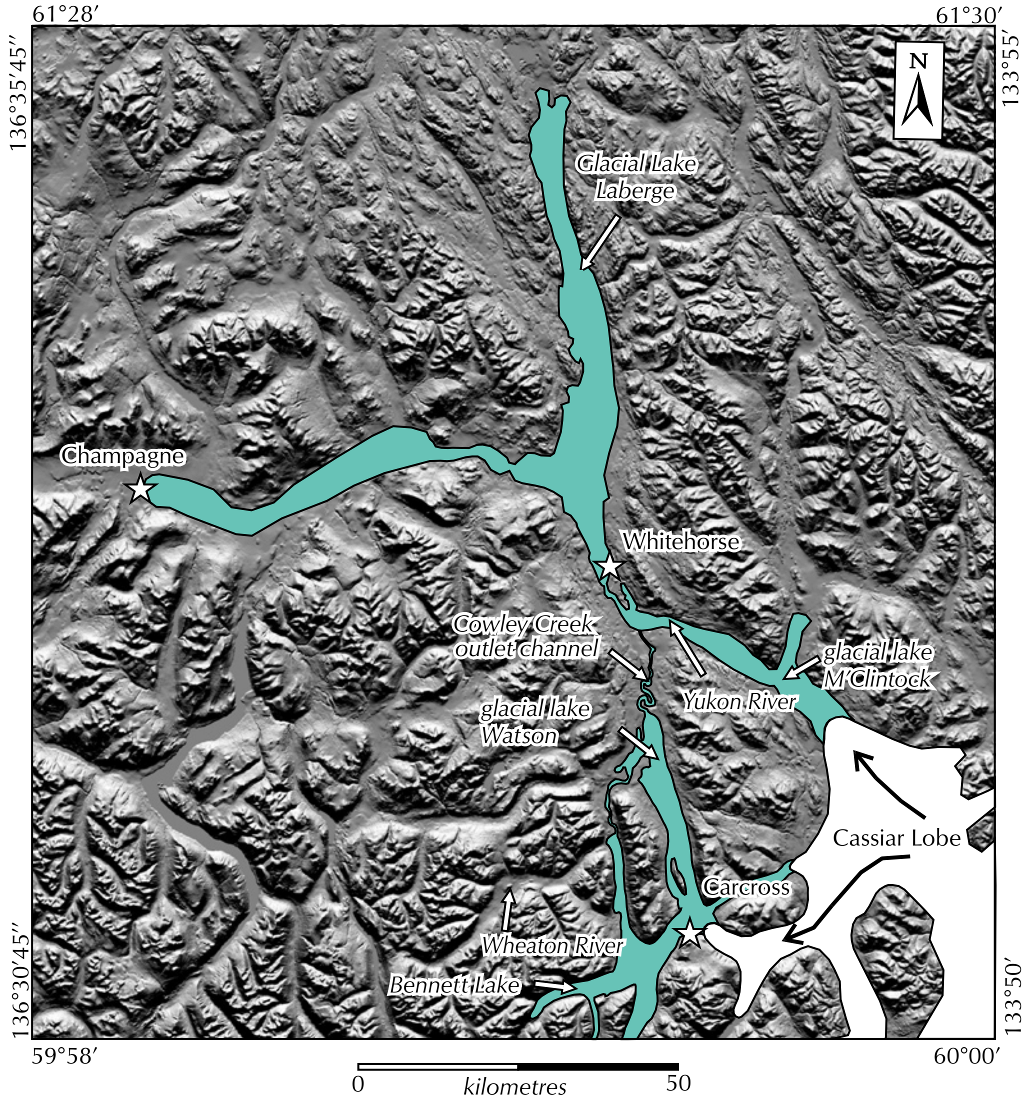


Figure 16. *Stage 3f – Bennett stage. This recessional stage is defined by an ice limit near the village of Carcross at the east end of Bennett Lake. Glacial lake ponding in Bennett Lake would have been part of glacial lake Watson.*

Stage 3f: Bennett

Continued retreat of the Cassiar Lobe from the Watson, Wheaton and Yukon river valleys allowed glacial lakes to expand in the Whitehorse map area (Fig. 16). The Bennett stage contained the most extensive glacial lake coverage during deglaciation. To the south of Whitehorse, the Cowley Creek outlet maintained drainage from an expanded glacial lake Watson as ice retreated south and east. Strandlines along Bennett Lake at 778 m a.s.l. correlate with the Cowley Creek outlet elevation which means the Carcross area was once submerged under 120 m of lake water (Fig. 17). In the Yukon River valley, glacial lake ponding extended into the Marsh Lake area and M'Clintock River watershed. This is informally referred to as glacial lake M'Clintock. Drainage of glacial lake M'Clintock was through a short section of river or narrow lake connecting it with Glacial Lake Laberge. The water level of this large system of glacial lakes was maintained through the outlet of Glacial Lake Laberge.

Figure 17. *Strandlines above Bennett Lake (see arrows). These former shorelines are wave-modified landforms that consist mostly of winnowed till deposits.*

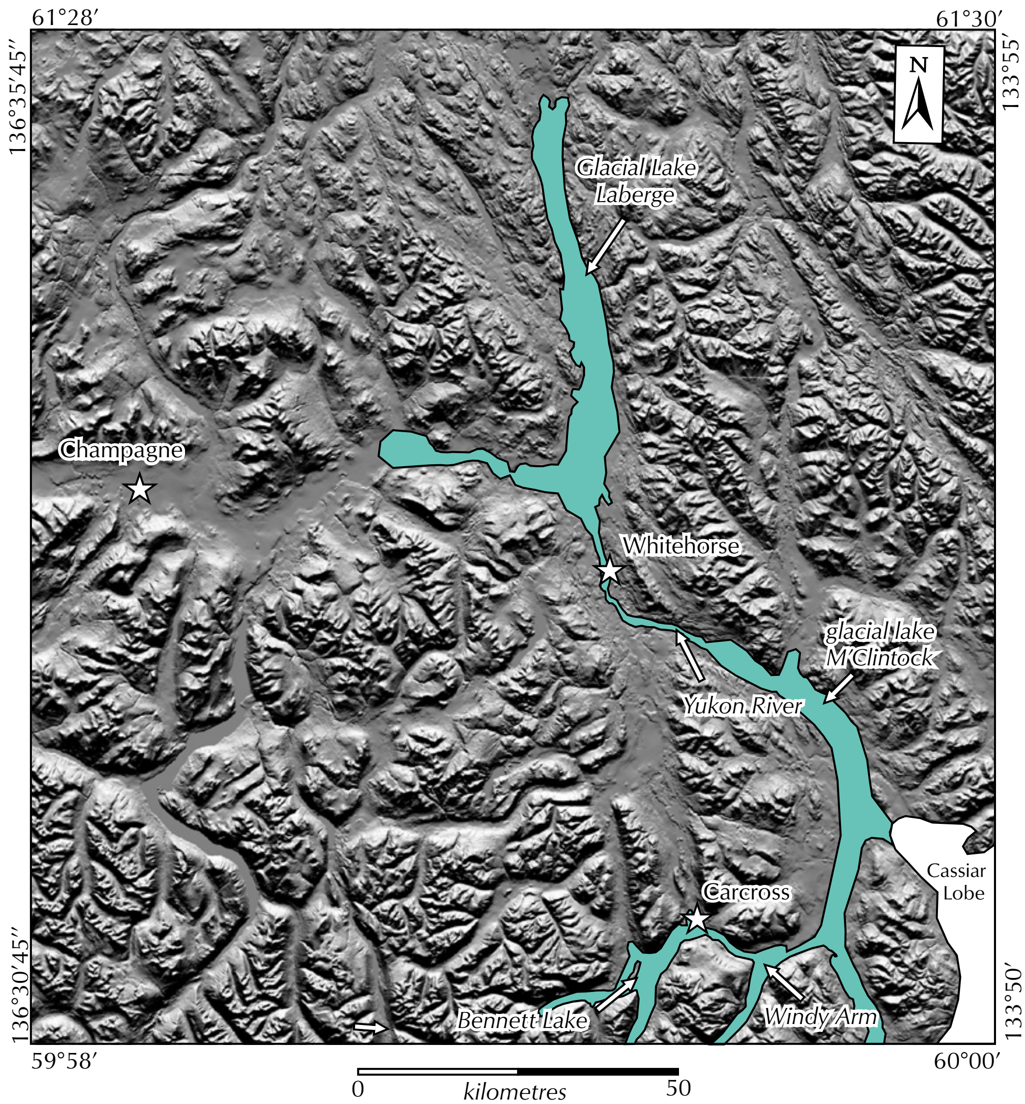


Figure 18. *Stage 3g – M'Clintock stage. The last stage of McConnell ice in the Whitehorse map area.*

Stage 3g: M'Clintock

The final stage of deglaciation in the Whitehorse area is marked by a withdrawal of ice from the Bennett Lake/ Windy arm area causing the abandonment of the Cowley Creek outlet channel (Fig. 18). Water from glacial lake Watson was incorporated into glacial lake M'Clintock. This vastly increased the size of glacial lake M'Clintock. Thin deposits of glaciolacustrine sediment bordering Marsh Lake suggest that glacial lake M'Clintock was relatively short lived. This may have been attributed to rapid incision into the sediment constriction controlling the glacial lake drainage.

STAGE 4: EARLY HOLOCENE

On-going fluvial incision of the sediment dam on Lake Laberge, into the Holocene, continued to affect the geography of the Yukon River valley near Whitehorse. The decreasing level of Lake Laberge caused the Yukon River to downcut into the glaciolacustrine and morainal deposits to the south. The retreating waters of Lake Laberge also caused the southern shoreline and the Yukon River delta to migrate northward, thus depositing deltaic sands over the lacustrine fill. Once subaerially exposed, the deltaic sand was reworked by aeolian processes to form the Whitehorse dune field (immediately north of the city). Optical dating of the aeolian sediments is currently in progress to improve the chronology of the deglaciation history of the Whitehorse region.

SUMMARY

During the McConnell Glaciation, the Whitehorse map area was situated at the boundary of two ice lobes of the Cordilleran Ice Sheet: the Cassiar and Coast Mountains lobes. Initial ice accumulations in the map area probably began in the higher regions of the Coast Mountains. It was not until localized ice caps had formed that the more distal Cassiar Lobe advanced into the map area from the southeast. The convergence of the two lobes at glacial maximum occurred over the Coast Mountains transitional zone west of the city of Whitehorse. Movement of the Cassiar Lobe over this portion of the map area was to the northwest and was unobstructed by underlying topography. Movement of the Coast Mountains Lobe was northward. The pattern of deglaciation is highlighted by periods of differential retreat and fluctuating ice fronts. A large re-advance of the Cassiar Lobe occurred into the already deglaciated Coast Mountains transitional zone. This had a significant influence on sediment deposition within the map area. In particular, systems of pro-glacial lakes developed marginally to the Cassiar Lobe as it retreated. Deposition within these lakes is evident in many of the major valleys in the map area. The early Holocene is highlighted by drainage of the glacial lakes, incision into the glaciolacustrine fill and aeolian activity.

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Geological setting of retrogressed eclogite and jade in the southern Campbell Range: Preliminary structure and stratigraphy, Frances Lake area (NTS 105H), southeastern Yukon

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ABSTRACT

The southern Campbell Range is underlain by greenschist facies volcaniclastic, epiclastic and sedimentary units of the Tuchitua River and Money Creek formations. Stratigraphy is deformed by at least three syn- to post-Early Permian folding events. Northwest-striking, high-angle faults imbricate the folded metasedimentary package with sheets of serpentinite. These rocks are juxtaposed against basinal rocks of the Fortin Creek group, to the east, along the Jules Creek fault.

Coarse-grained quartz-muscovite schist with lenses of retrogressed eclogite occurs within serpentinite and also in immediate fault contact with greenschist facies Tuchitua River and Money Creek metasedimentary rocks in the western field area. At the King Arctic mine, nephrite jade is the result of metasomatic replacement of Money Creek chert-pebble conglomerate and serpentinite by microcrystalline tremolite-actinolite along late high-angle faults.

RÉSUMÉ

Sous le sud du chaînon Campbell reposent des unités sédimentaires, épiclastiques et volcanoclastiques à faciès des schistes verts des formations de Tuchitua River et de Money Creek. La stratigraphie est déformée par au moins trois plissements du Permien précoce (synchrones à postérieurs). Les failles à direction nord-ouest fortement inclinées imbriquent les roches métasédimentaires plissés avec des lentilles de serpentinite. Ces roches sont juxtaposées à des roches de bassin du groupe de Fortin Creek le long de la faille de Jules Creek.

Le schiste à quartz-muscovite à grain grossier renfermant des lentilles d'éclogite rétromorphisée se trouve au sein d'un mélange de serpentinite et en contact de faille avec les roches métasédimentaires à faciès des schistes verts dans la portion ouest de la zone. À la mine King Arctic, le jade néphritique est le résultat du remplacement métasomatique du conglomérat à cailloux de chert de Money Creek et de la serpentinite par une trémolite-actinolite microcristalline le long de failles tardives à angle fort.

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INTRODUCTION

The occurrences of eclogite in Yukon-Tanana Terrane (YTT) are important clues to the terrane's Late Paleozoic tectonic development (Erdmer et al., 1998; Erdmer, 1992; Erdmer, 1987; Erdmer and Helmstaedt, 1983). Permian-age eclogites in central Yukon (Fig. 1) can reasonably be interpreted to mark the suture between YTT and North America. However, little is known about eclogites with Mississippian ages in the southern Campbell Range and Stewart Lake areas, Frances Lake map area (NTS 105H). No detailed geological framework has been presented for these occurrences and the reason for their presence near the eastern margin of Yukon-Tanana Terrane remains uncertain. Recently completed compilations of geology and stratigraphy in several regions of Yukon-Tanana Terrane, including the nearby Finlayson Lake area, provide a broad regional geological and tectonic context for the Frances Lake project. The project was initiated with the objective of constraining the geological relationships around the Mississippian-age (Erdmer et al., 1998) southern Campbell Range eclogite locality.

The study area covers the hills of the southern Campbell Range which rise to the west of the Robert Campbell Highway directly north of Tuchitua Junction (Fig. 1). This

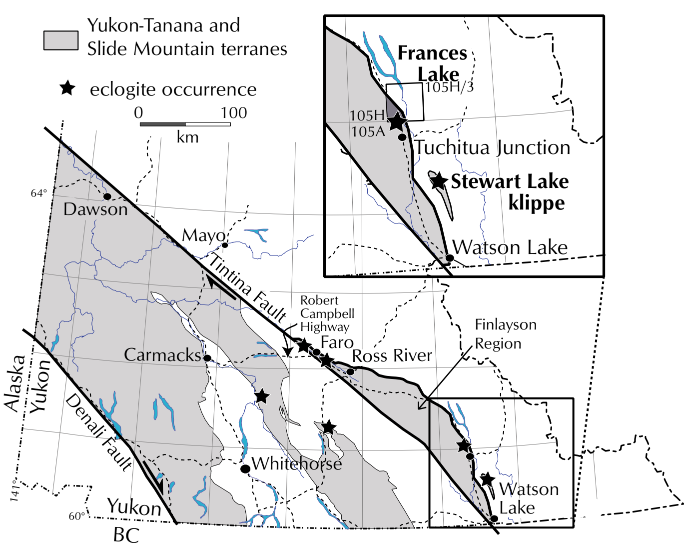

Figure 1. *Southern Campbell Range location map. The southern Campbell Range field area is marked by the shaded southwestern corner of the box outlining 1:50 000-scale NTS map sheet 105H/3. The field area overlies one eclogite occurrence; all others are marked by black stars. The southern Campbell Range and Stewart Lake localities are the only known eclogite occurrences with Mississippian ages in Yukon.*

paper summarizes stratigraphy and structure of the southern Campbell Range and places the eclogite and jade occurrences into a geological framework. It is based on 1:10 000- and 1:20 000-scale geological mapping completed during 2003 in the southwestern corner of the Klatsa River map area (NTS 105H/3).

PREVIOUS WORK

The southern Campbell Range was included in 1:253 440-scale mapping of the Frances Lake map area (105H) by Blusson (1966 a,b, 1967). Mortensen (1983), and Mortensen and Jilson (1985) also included the area in their regional reconnaissance of Yukon-Tanana Terrane (YTT) north of the Tintina Fault. The discovery of volcanogenic massive sulphide (VMS) deposits in the Finlayson region in the mid-1990s increased awareness of the mineral potential of YTT and prompted the initiation of a 1:50 000-scale mapping program of the Finlayson Lake region by the Yukon Geological Survey under the direction of D.C. Murphy. The Klatsa River map area (105H/3) was included in the areas covered during this program (Murphy, 2001). Regional geological compilations which are pertinent to the present study include the federal Targeted Geoscience Initiative (TGI) focused on the Finlayson Lake area in 2001 (Murphy et al., 2002) and studies of correlative rocks elsewhere in Yukon-Tanana Terrane under the NATMAP program (e.g., Colpron et al., 2003).

The coarse-grained metamorphic rocks in the southern Campbell Range were studied by Erdmer et al. (1998) and Creaser et al. (1999) who presented geochronological and geochemical data, respectively, of eclogites in central Yukon. However, the work presented in this paper is the first detailed geological compilation of the southern Campbell Range.

REGIONAL GEOLOGY

Current tectonic models for the development of YTT (e.g., Murphy et al., 2003) describe a western North American marginal crustal fragment which experienced arc growth in the Devonian to Early Permian. This began with eastward-directed subduction of proto-Pacific oceanic crust, and continued again in the middle to Late Permian as the Slide Mountain ocean basin separating the arc from North America closed through westward-directed subduction. In the Early Permian, prior to initiation of closure of the Slide Mountain ocean, the arc was shortened by regional-scale northeast-vergent

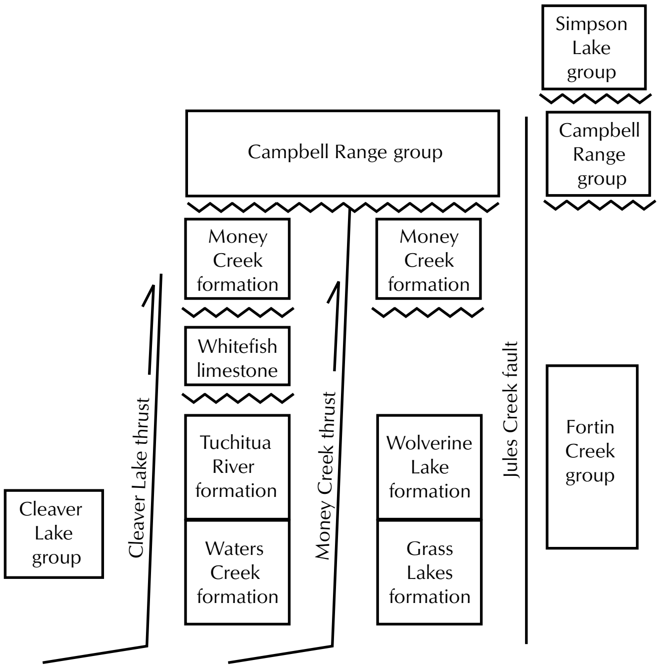

Figure 2. *Schematic stratigraphic diagram showing the fault relationships between different Devono-Mississippian to Early Permian successions in the Finlayson Lake region. Based on Murphy (2004, this volume).*

thrusting. Geology in the Finlayson Lake region shows Early Permian-age displacement along the Money Creek and Cleaver Lake thrusts (Murphy et al., 2003) which resulted in the stacking of Devono-Mississippian successions that formed in different arc environments (Murphy, this volume).

Southwestern Frances Lake map area is underlain primarily by rocks in the hanging wall of the Money Creek thrust fault. The volcanic-dominated Tuchitua River formation rests unconformably on the arc volcanic rocks and metasedimentary rocks of the Waters Creek formation (Fig. 2). Two episodes of plutonism coeval with the Waters Creek and Tuchitua River formations are represented by rocks of the Simpson Range plutonic suite (Mortensen and Jilson, 1985; Murphy, this volume). Together, these rocks represent the transitional arc environment between coeval arc (Cleaver Lake group) and backarc rocks (Wolverine Lake group), now stacked together. Clastic rocks of the Money Creek formation sit unconformably above rocks in different thrust sheets and were likely deposited synchronously with the Early Permian thrust-faulting event.

In the Finlayson Lake region, Early Permian thrusting was succeeded by deposition of the Campbell Range formation and emplacement of associated mafic and ultramafic intrusions. As these rocks occur on both sides of the Jules Creek fault near the eastern margin of YTT, Murphy et al. (2003) have suggested that the Jules Creek fault is a lithospheric-scale transform fault with associated plutonism, active during the Middle to Late Permian closure of the Slide Mountain ocean. The Late Permian and/or Triassic Simpson Lake group (Simpson Lake assemblage of Mortensen et al., 1997, 1999) conglomerate is the forearc, possibly progressive to foreland, sedimentary deposit resulting from Slide Mountain ocean closure. The conglomerate unconformably overlies the Fortin Creek group along the eastern margin of YTT.

A Triassic overlap sequence on YTT and North American rocks constrains the timing of terrane-continent amalgamation. Later crustal shortening in Jurassic to Cretaceous time imbricated YTT, and resulted in motion along the eastern YTT/Slide Mountain-bounding Inconnu thrust fault. This was followed by an extensional faulting event in the Cretaceous.

GEOLOGY OF THE SOUTHERN CAMPBELL RANGE

Three geological domains have been recognized in the southern Campbell Range (Fig. 3a). The break in slope along the east side of the range marks the boundary between the two eastern domains and coincides with the southeast-striking, shallowly west-dipping Jules Creek fault, a reactivated fault with most recent east-vergent thrust motion. To the east are basinal rocks of the Fortin Creek group of Slide Mountain Terrane (Murphy et al., 2002) unconformably overlain by the Late Permian and/or Triassic Simpson Lake group (Mortensen et al., 1997, 1999). To the west are Mississippian arc-derived clastic rocks of the Tuchitua River formation and unconformably overlying basinal deposits of the Early Permian Money Creek formation. The third domain occurs along the western edge of the area where poorly exposed metavolcanic and metaintrusive rocks of the Waters Creek formation and Simpson Range plutonic suite occur in presumed fault contact with adjacent Tuchitua and Money Creek rocks.

At least three early folding and two faulting events deform the Tuchitua River and Money Creek formation rocks. Southeast-striking faults imbricate the metasedimentary rocks with sheets of serpentinite, and dominate the structural pattern of the area (Fig. 3a,b). Serpentinite is host to blocks of locally-derived metasedimentary rocks,

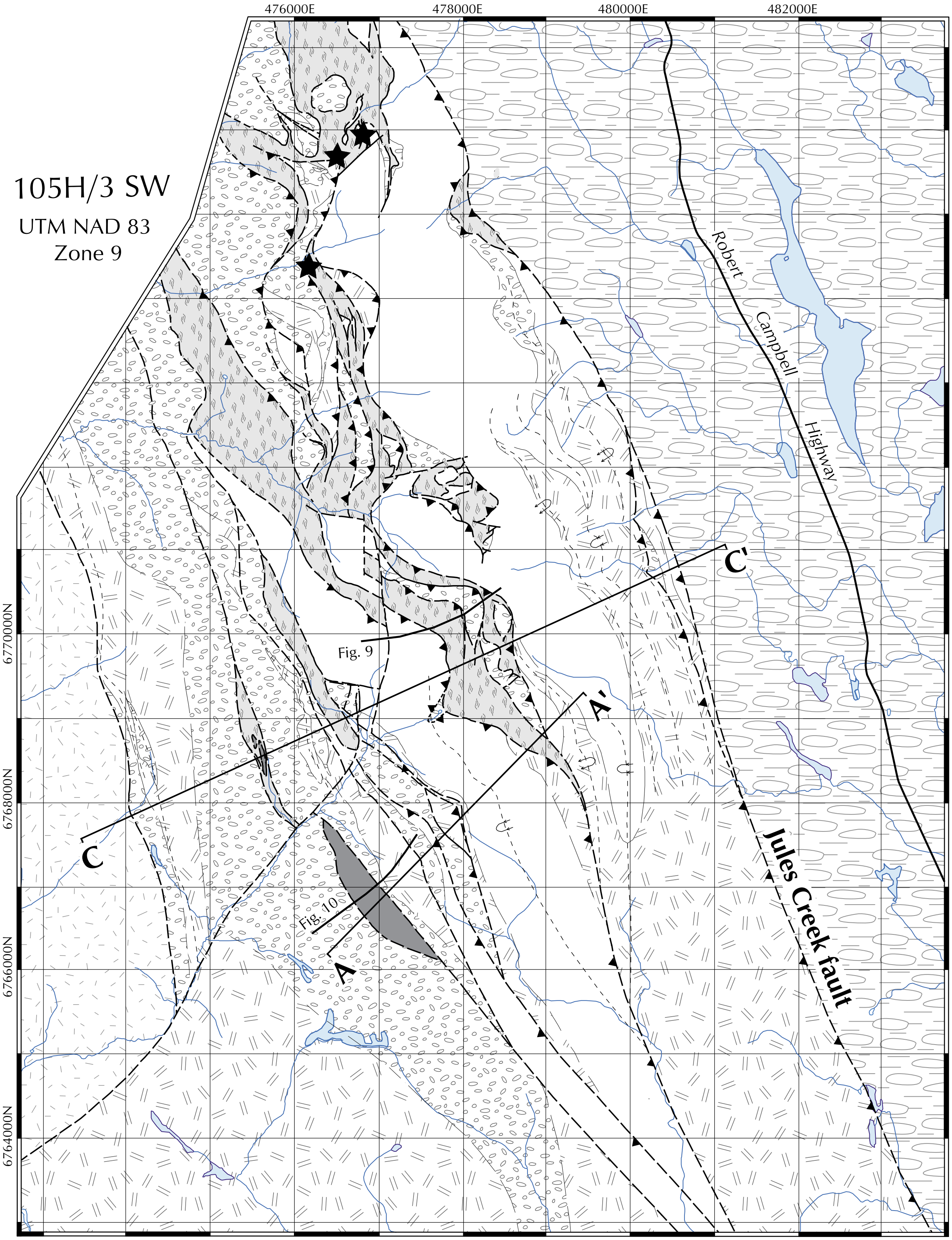

Figure 3a. *Geological map of the southern Campbell Range. The King Arctic jade mine is in the north of the area, where black stars mark nephrite jade occurrences. The locations of ridgelines in Figures 9 and 10 are shown as lines marked Fig. 9 and Fig. 10.*

LEGEND

serpentinite — massive dark to pale green with relict cumulate textures (euhedral bastite) in places.

Yukon-Tanana Terrane

Mississippian

coarse-grained metamorphic rocks — quartz-muscovite schist with clinozoisite-chlorite symplectic pseudomorphs after garnet and amphibole porphyroblasts; includes lenses of dark green epidote-amphibole metabasite (retrogressed eclogite).

Cleaver Lake thrust

Intrusive Rocks

Mississippian

metagranodiorite and metavolcanic rocks — medium-grained chlorite- and epidote-altered granodiorite and well foliated quartz-phyric chlorite-muscovite schist

Layered Rocks

Permian

Money Creek formation — black to grey chert-pebble conglomerate, blue quartz-eye bearing conglomeratic lithic wacke, carbonaceous phyllite. All metamorphosed to greenschist facies

Mississippian

Tuchitua River formation clastic rocks — homogeneous pale green chert-derived arenite and interbedded fine-grained dark grey argillaceous wacke. Metamorphosed to greenschist facies

Tuchitua River formation — green and pink chert and banded tuffaceous magnetite-bearing green chert with pale grey limestone locally interlayered with tuff. Metamorphosed to greenschist facies

Jules Creek fault

Slide Mountain Terrane

Layered Rocks

Carboniferous?

Fortin Creek (1) and Simpson Lake (2) groups —
(1) pale to dark chert-pebble conglomerate, quartz-arenite and argillite, all commonly vuggy and silicified
(2) polymictic conglomerate and sandstone

Symbols

fault — defined, approximate, assumed, with thrust or reverse motion

geological contact — defined, approximate, assumed

F_3 axial surface trace — overturned antiform, overturned synform

jade occurrence

line of cross-section

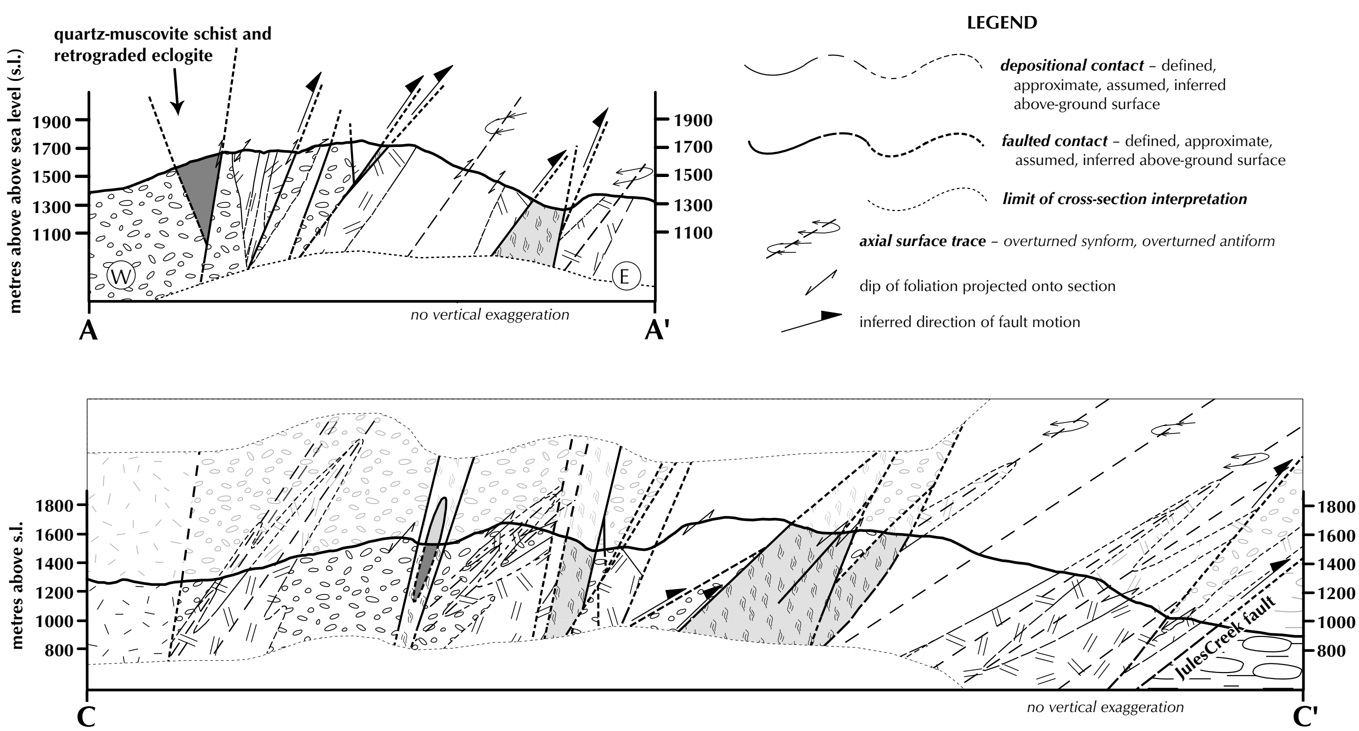

Figure 3b. *Geological cross-sections along lines A-A' and C-C'. The lines of section are shown on Figure 3a. The lightly shaded region above ground surface in cross-section line C-C' represents extrapolated above-surface geology.*

leucogabbro and coarse-grained metamorphic rocks including retrogressed eclogite. With the exception of the retrogressed eclogite and host rocks, all rocks in the area were metamorphosed under greenschist facies metamorphic conditions.

LITHOLOGY

The Tuchitua River formation chert, limestone and clastic rocks and unconformably overlying Money Creek conglomerates and lithic wacke are the most widespread units in the map area; both formations are metamorphosed to greenschist facies (Fig. 4). The Whitefish limestone, which is found above the Tuchitua River formation in other parts of the Finlayson Lake region, is only locally present. Fortin Creek group chert and argillite are found along the eastern side of the map area with minor outcrops of unconformably overlying Simpson Lake group conglomerate. Serpentinite is structurally interleaved with the Tuchitua River and Money Creek metasedimentary rocks and is host to both coarse-grained quartz-muscovite schists with lenses of retrogressed eclogite, and also nephritic jade.

Tuchitua River formation

The Tuchitua River formation is composed dominantly of intermediate volcanic and volcaniclastic rocks with lesser chert and limestone (Murphy, this volume). In the southern Campbell Range, only minor volcaniclastic rocks are present in a package composed of green and pink chert, limestone and an overlying chert-derived clastic package. Volcanic rocks of the lower Tuchitua River formation are not found in the field area but do occur approximately 50 km to the north and northwest. North of the study area near Alligator Lake, at the end of the 99 Mile Creek road, well foliated green lapilli tuff with 1-cm-sized chlorite aggregates along foliation planes (possible altered amphibole crystals) occurs with Tuchitua River formation chert. Chert, limestone and clastic rocks belonging to the Tuchitua River formation are found in the central geological domain in the field area. All units are polydeformed and metamorphosed to greenschist facies, but the following descriptions focus on sedimentary protoliths.

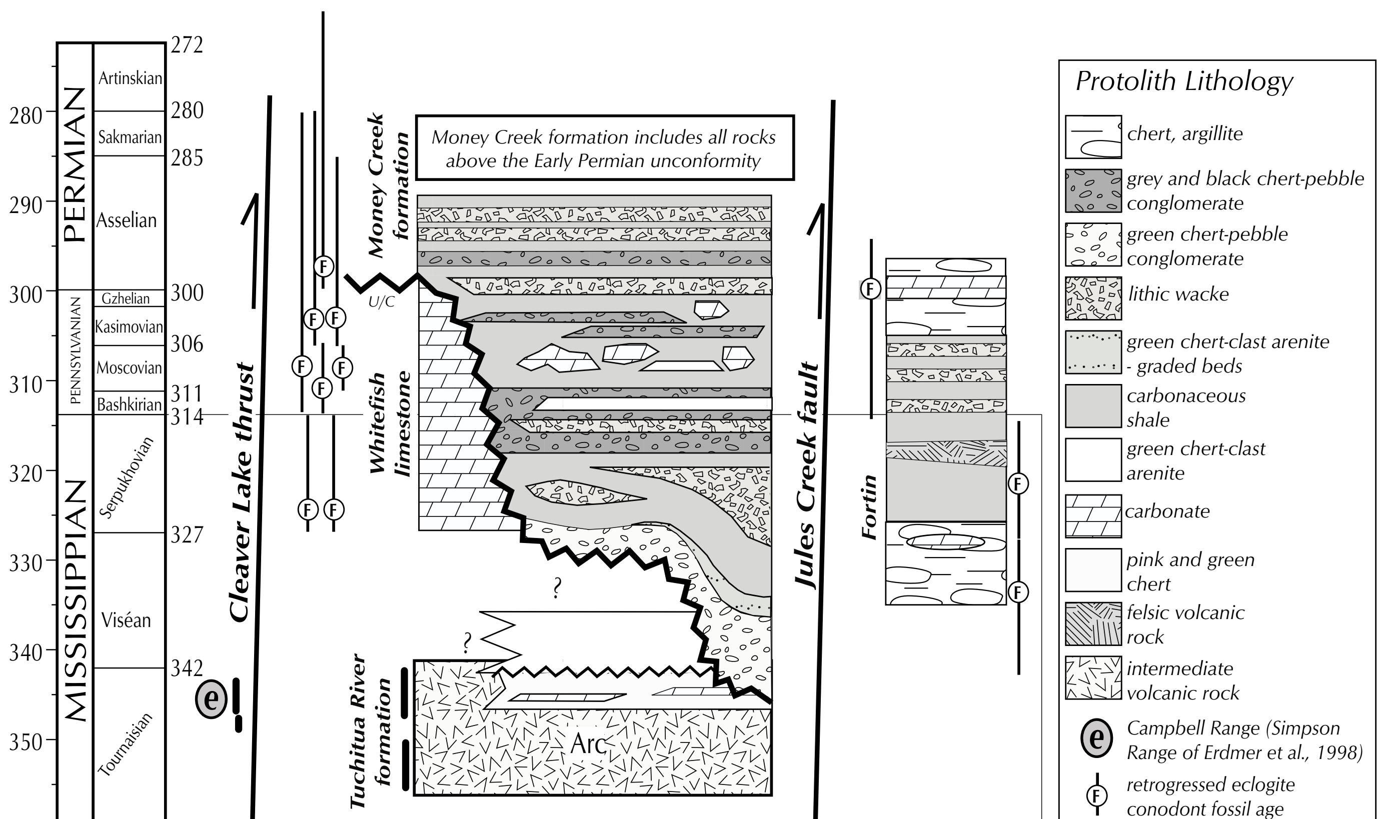

Figure 4. *Stratigraphic and structural relationships in the southern Campbell Range. Fortin Creek stratigraphy and fossil ages are from Murphy and Piercey (1999a,b,c; 2000) and Murphy (2001). E = 344 ± 1 Ma white mica ^{39}Ar-^{40}Ar cooling date on retrogressed eclogite (Erdmer et al., 1998). U/C = unconformity. Time scale after Okulitch (2001).*

Chert and limestone: Chert and limestone are the oldest stratigraphic units of the Tuchitua River formation found in the southern Campbell Range. A lower vari-coloured chert sequence is transitional upwards into limestone, which is overlain by a chert-clastic rock sequence. Relative ages are based on stratigraphic relationships. The entire package has a minimum thickness of 200 m and is bound by the unconformably overlying Tuchitua River clastic rocks.

The stratigraphically lowest chert unit contains interlayered translucent to opaque green, pink and white chert, which has gradational contacts in outcrop; red-pink- and green-dominant regions occur in layers up to 100 m thick. Ribbons 1 to 5 cm thick, with partings of pale green phyllite, are common in the green chert, which varies from highly contorted to relatively undeformed (Fig. 5a). Clastic interbeds are derived from both sedimentary and volcaniclastic sources. Fine-grained quartz-lithic sandstone beds occur within both the green and pink chert sequences. Plagioclase-chlorite lapilli-tuff beds up to 2 cm thick and the local occurrence of pale green phyllite interlayer are indications of volcaniclastic input.

Pale grey-weathering limestone occurs within the upper part of the pink and green chert succession. Siliceous interlayers up to 5 cm thick, with abundant pyrite boxwork, and interlayers of white to pale-green phyllite show the gradational relationship between the chert and the limestone. Carbonate-matrix siliciclastic interlayers with bedding on a cm-scale and crinoid fragments are present locally (Fig. 5b). Recessive-weathering of layers with low clastic content enhances bedding. Along the east side of the map area, the limestone is a discontinuous layer with a minimum thickness of 20 m. Elsewhere, although locally structurally thickened, the limestone is greater than 200 m thick, and is laterally continuous for at least 2 km. This thickness variation is likely due to original depositional variability, however, later structure also cuts the limestone in several places, and therefore only minimum thicknesses have been determined.

Well banded to laminated tuffaceous chert with variable clastic and volcaniclastic content gradationally overlies the pink and green chert (Fig. 5c). This unit is everywhere well banded with high silica content and locally contains pale to bright green opaque feldspar-dominant layers. White, bright yellow-green, and dark green layers are interbedded on a sub-mm- to cm-scale with sub-mm laminations. The pale layers locally have a characteristic black speckled appearance resulting from sub-mm weathering pits within the locally feldspar-

Figure 5. *Tuchitua River formation:* ***(a)*** *green ribbon chert,* ***(b)*** *bedded limestone with disseminated metamorphic chlorite and muscovite,* ***(c)*** *banded to laminated magnetite-bearing green chert.*

dominant tuffaceous matrix. Plagioclase-chlorite lapilli-tuff was sampled from this unit for U-Pb geochronology; results are pending for this work. Magnetite is concentrated in dark green to black chlorite-rich laminae. Pink, green and white chert is locally present and is also locally magnetite-bearing. Concentrated magnetite in this banded chert, along with the approximate late Tournaisian age of this unit, based on stratigraphic relationships with dated Tuchitua River volcaniclastic rocks elsewhere in the Finlayson Lake area (Murphy et al., 2002), supports correlation with siliceous barite-magnetite exhalative rocks above the Wolverine Lake deposit (Yukon MINFILE 2002, 105G 072, Deklerk, 2002). This suggests the presence of a regional hydrothermal system in the early Mississippian.

Clastic rocks: Clastic rocks of the Tuchitua River formation unconformably overlie the chert and limestone units and form the cliffs along the east side of the southern Campbell Range. Original thickness of the unit is at least 250 m, but with structural thickening the unit is up to 750 m thick. Green to dark grey fresh surfaces weather to a characteristic cm-scale 'mottled' texture; this may be due to variable clay content. Medium-grained green chert-clast arenite locally contains opaque sub-rounded to sub-angular white to pale green clasts that range up to pebble size. The unit changes gradationally upwards to fine-grained dark grey argillaceous wacke with the transitional region containing laterally continuous metre- to 10-m-scale interbedded layers of dark grey fine-grained lithic wacke and green chert-clast arenite. Dark grey to black argillite and argillaceous fine-grained wacke with 1-mm- to 1-cm-wide discontinuous green sandstone lenses becomes dominant upsection. The Tuchitua River clastic rocks, derived from immediately underlying Tuchitua River chert, are identified and distinguished from overlying clastic rock units based on clast lithology, widespread occurrence and weathering texture.

Whitefish limestone

The only exposure of the Whitefish limestone (unit Pc of Murphy, 2001) in the study area is a block of marble (25 m by 10 m exposed area) completely enveloped by serpentinite (UTM 478335E, 6771559N). A conodont age of Serpukhovian has been determined from this outcrop in the central field area, which is consistent with the age range of Serpukhovian to early Asselian determined for the unit in its closest in-place occurrence, approximately 50 km to the northwest (Murphy et al., 2002; Poulton et al., 1999). The pale grey- to buff-weathering bioclastic marble is foliated and contains dark grey crinoid fragments up to 2 mm in diameter within a pale grey recrystallized matrix. Orange-weathering diagenetic silica-replacement patches up to 5 cm thick are discontinuous and are concordant with foliation.

Money Creek formation

The Money Creek formation metaclastic rocks (unit 7 of Murphy and Piercey, 1999; unit PPcs of Murphy and Piercey, 2000a; unit Pcl of Murphy, 2001, Murphy, this volume) unconformably overlie the Tuchitua River formation rocks (Fig. 3 and 4). A basal unit derived from immediately underlying Tuchitua River formation chert is overlain, possibly unconformably, by a mixed clastic unit.

Basal conglomerate and sandstone: The basal conglomerate and sandstone of the Money Creek formation occur locally along the contact with underlying Tuchitua River formation rocks. The basal unit varies in thickness from 0 m to approximately 10 m, in part owing to deformation. Distinctive green-granule to -pebble conglomerate is dominated by sub-rounded clasts of green chert with subordinate limestone and pale green to white lithic clasts (Fig. 6a). Graded green chert-clast arenite beds up to 2 cm thick with granule-sized basal clasts occur in close association with the conglomerates and contain the same clast composition. Where the basal unit overlies Tuchitua River limestone, the matrix is commonly calcareous and the conglomerates contain well-rounded chert pebbles up to 2 cm in diameter.

The best exposures of the basal unit occur on hilltops in the northwestern part of the study area where it overlies limestone of the Tuchitua River formation (Fig. 3). Here the basal unit of the Money Creek formation comprises well foliated and lineated conglomerate and sandstone. The contact is an unconformity as clast content of the basal units reflects derivation from immediately underlying Tuchitua River formation chert and limestone. Although structural complexity precludes detailed lateral stratigraphic correlations, the basal conglomerate and sandstone are variable in thickness and are not always present along the unconformity at the top of the Tuchitua River formation, likely as a result of restricted deposition in areas of low paleotopography.

Mixed clastic rocks: Dark coloured clastic rocks of the Money Creek formation with variable clast content locally overlie the basal units. The unit contains dark grey to black rounded chert-pebble conglomerate (Fig. 6b), dark argillaceous chert, black carbonaceous phyllite and lithic

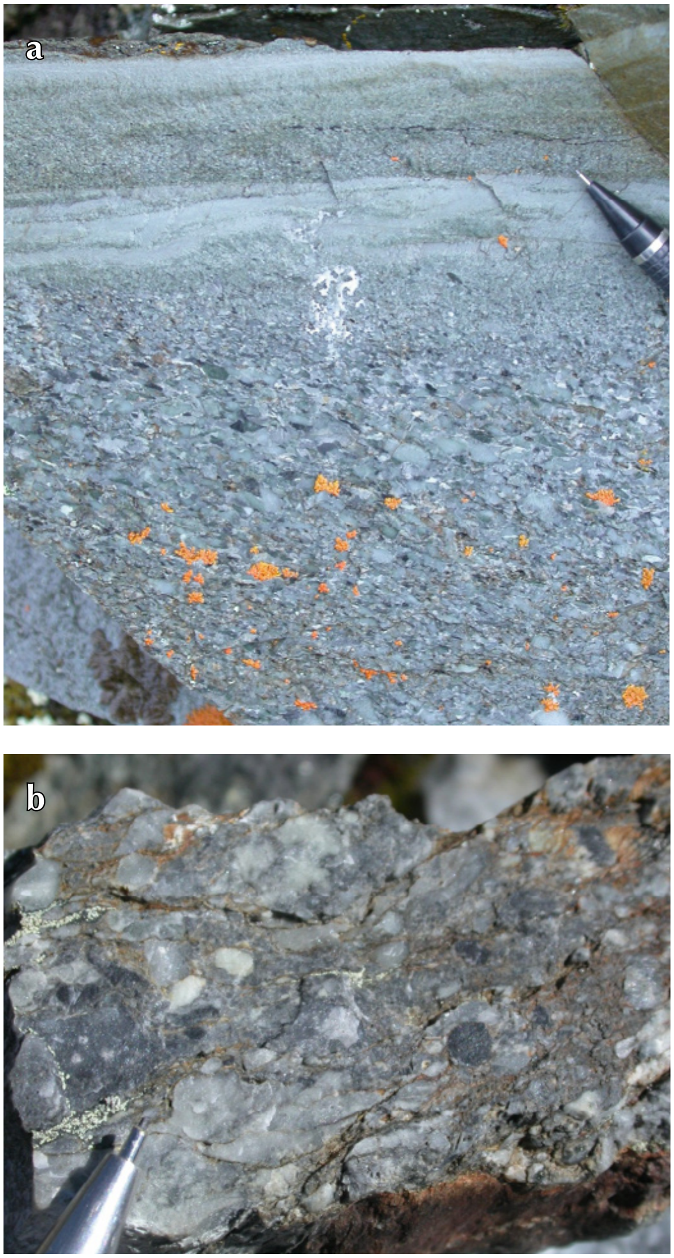

Figure 6. *Money Creek formation: **(a)** basal green-chert-pebble conglomerate and graded green chert-clast arenite, **(b)** dark chert-pebble conglomerate.*

wacke commonly with smoky blue quartz-eyes. The unit lacks stratigraphic continuity. Minor green to brown lithic arenite and lithic wacke are found in association with the phyllite and grit and compositionally reflect derivation from rocks of the underlying Tuchitua River formation. Blocks of crinoidal limestone up to 30 m long are found locally, within phyllite. Conodont age data are pending on these blocks, which are presumed to be Whitefish limestone. Limestone block trains in linear outcrop relationship within phyllite are evidence of debris-flow olistostromal deposition of parts of the Money Creek formation.

Fortin Creek group

To the east of the Jules Creek fault (Fig. 3a), in the poorly exposed lowlands on the eastern flanks of the Campbell Range, are rocks of the Fortin Creek group. They were previously known as the Finlayson group (Murphy et al., 2002) and have a regional basinal lithological character. Protolith lithologies of the unit in the field area include grey- to black-chert-pebble conglomerate, rusty-weathering medium-grained quartz-sandstone, and aphanitic rhyolite. All rocks are highly silicified and commonly display open quartz-lined vugs up to 2 cm in diameter. Aphanitic rhyolites display mm-scale flow-banding textures enhanced by later silicification.

Simpson Lake group

Conglomerate of the Permian to Triassic Simpson Lake group (Simpson Lake assemblage of Mortensen et al., 1997, 1999) rests unconformably on the Fortin Creek group. A single outcrop of angular to sub-rounded granule conglomerate containing clasts of ultramafic rock and Fortin Creek chert may be continuous under cover with more extensive exposures to the north. Along the road to the King Arctic jade mine, north of the field area, polymictic conglomerate includes subangular to well rounded clasts of chert, mica schist, quartzite, and various types of sandstone. Eclogite pebbles are found in exposures along the Robert Campbell Highway to the south (Mortensen et al., 1997, 1999).

Waters Creek formation and Simpson Lake plutonic suite

Poorly exposed metaintrusive and metavolcanic rocks occur along the western side of the map area in presumed fault contact with Money Creek formation rocks to the east (Fig. 3a); they include moderately foliated, fine- to medium-grained chloritized muscovite-amphibole granodiorite; chloritized, foliated, coarse-grained quartz-phyric amphibole granite-granodiorite, and well foliated quartz-phyric chlorite-muscovite schist. These rocks spatially and lithologically fit within the Waters Creek formation and Simpson Range plutonic suite (Mortensen and Jilson, 1985; Murphy, this volume) found in other parts of the Finlayson Lake area. A presumed fault contact with Money Creek formation rocks to the east is supported by the linear nature of the contact and the absence of lower Tuchitua River volcanic rocks, which would be present if the transition from Waters Creek formation rocks to upper Tuchitua River chert was stratigraphically intact.

Coarse-grained metamorphic rocks

Two occurrences of coarse-grained metamorphic rocks are found in the western part of the field area, in fault contact to both the east and west with greenschist facies clastic rocks of the Money Creek formation. Coarse-grained quartz-muscovite schist is the dominant lithology with quartz and muscovite content varying on the cm- to m-scale. Green chlorite and clinozoisite symplectic pseudomorphs after garnet and possibly amphibole have subhedral to anhedral shapes and are up to 1.5 cm in diameter (Fig. 7a). In places within the schist, the replaced porphyroblasts occupy up to 50% volume of the rock.

Rare discontinuous carbonate bands up to 10 cm thick, and lenses of very dense, heavy metabasite up to 20 m long and 10 cm to 5 m wide occur within the quartz-muscovite schist, and are concordant with foliation (Fig. 7b). Retrograded garnet porphyroblasts within the metabasite are present, up to 50% by volume, with minor relict garnet bound by fractures which are lined with the retrograde mineral assemblage. The garnet is the last remaining component of the peak metamorphic assemblage. A retrograde mineral assemblage of epidote and pale amphibole occupy the matrix and overprint the retrograded garnet domains. Titanite-rimmed rutile is present as 1- to 2-mm-long red crystals that are abundant in the metabasite only. These rocks have an N-MORB (normal mid-oceanic ridge basalt) geochemical signature (Creaser et al., 1999). White mica is late and interstitial to all other mineral assemblages and has a ^{39}Ar-^{40}Ar age of 344 ± 1Ma (Erdmer et al., 1998), interpreted to represent the cooling age of the unit through 350°C.

The metabasite has previously been interpreted as retrogressed eclogite (Erdmer et al., 1998; Mortensen and Jilson, 1985). We support this conclusion based on the retrograde mineral assemblage, textural similarity to well preserved eclogite, the presence of mafic lenses of basaltic composition within a quartz-muscovite schist host elsewhere in the Yukon-Tanana Terrane (YTT; similar to the Permian-aged eclogites in YTT), and the Mississippian age (Erdmer et al, 1998), which is similar to the age of preserved eclogite to the south in the Stewart Lake klippe (Fig. 1). Field relationships of the two occurrences of quartz-muscovite schist with retrogressed eclogite are discussed later in the paper with implications for tectonic development of YTT.

Serpentinite

Serpentinite in the area is commonly dark green, smooth and well foliated. Cumulate textures are preserved in places with bastite up to 1.5 cm in diameter. Where pale green bastites are preserved in a dark-green matrix, the rocks have a distinctive texture with the appearance of 'lizard-skin'. Local high-magnetite content is a result of olivine breakdown during serpentinization of the ultramafic protolith.

The serpentinite occurs across the map area as sheets with variable thicknesses ranging from less than 1 to

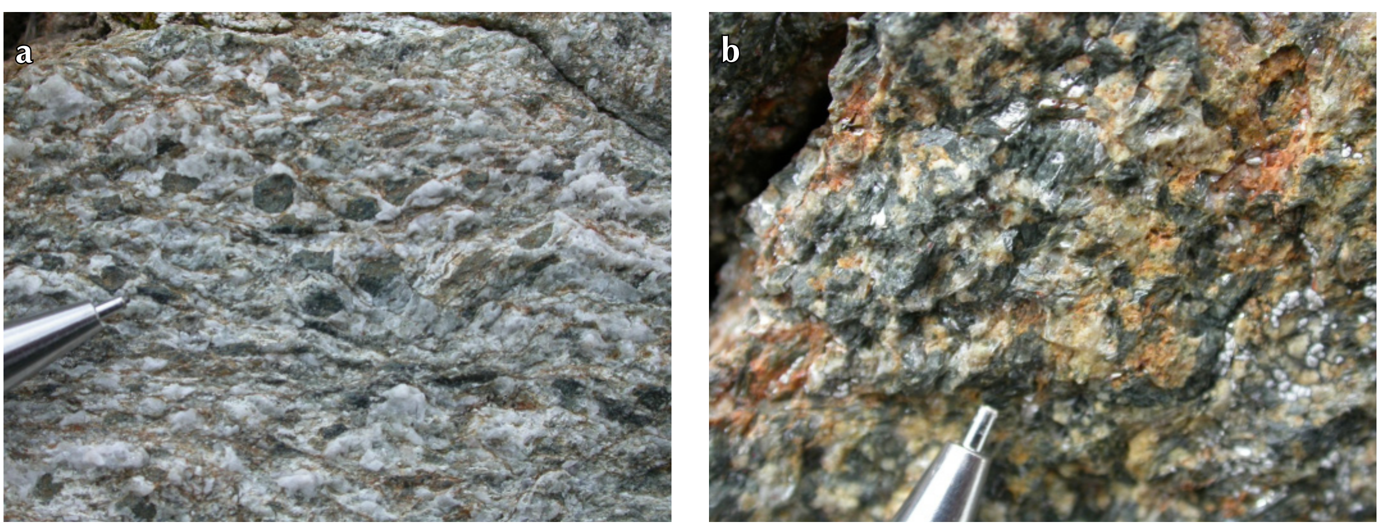

Figure 7. *Coarse-grained metamorphic rocks:* ***(a)*** *quartz-muscovite schist with symplectic chlorite and clinozoisite pseudomorphs after garnet porphyroblasts;* ***(b)*** *retrogressed eclogite with symplectic chlorite and clinozoisite pseudomorphs after garnet porphyroblasts in an epidote-amphibole matrix with interstitial, late white mica.*

200 m. One-metre-wide zones of talc-schist are developed along sheared contacts between serpentinite and metasedimentary sheets. Locally, the serpentinite contains blocks of various metasedimentary rocks, vari-textured leucogabbro, and coarse-grained quartz-muscovite schist with retrogressed eclogite.

Murphy et al. (2002) mapped similar serpentinite bodies along strike to the north of the field area. The serpentinite to the north is associated with Early Permian mafic volcanic and mafic plutonic rocks that occur on both sides of the Jules Creek fault (D.C. Murphy, pers. comm., 2003). Blocks of leucogabbro associated with the northern serpentinite have U-Pb zircon crystallization ages 274.3 ± 0.5 Ma (Mortensen, 1992) and 273.4 ± 2.1 Ma (D.C. Murphy, pers. comm., 2003). Similar leucogabbro blocks are associated with serpentinite in the east-central field area.

Jade

In the northern field area at the King Arctic mine (Yukon MINFILE 2002, 105H 014, Deklerk, 2002), nephrite jade (microcrystalline tremolite-actinolite) occurs in fault-controlled bands up to 3 m wide. It is located along faulted contacts of serpentinite and basal Money Creek formation chert-pebble conglomerates and sandstones (Fig. 8). The jade is generally heterogenous in colour, varying from white-green to very dark green. Variably foliated aggregates of tremolite-actinolite make up the pure nephrite with inclusions of epidote and bright-green serpentine. Fine-grained white-coloured rock is found associated with the jade occurrences, as blocks within serpentinite and as part of the nephrite package along faults. Macroscopically, this rock is similar to descriptions of white-rock, including rodingite, found associated with some nephrite deposits in British Columbia (e.g., Simandl et al., 2000) but has a mineralogy consisting dominantly of zoisite-clinozoisite, epidote and carbonate. No garnet has been found in petrographic analysis to date.

STRUCTURE

F_1, F_2 and F_3 folding

The oldest structures in the area are overturned open to tight similar folds of the Tuchitua River and Money Creek formations. Identification of the earliest folding event, F_1, is based on cross-cutting relationships, as structures from this event have been overprinted and reoriented by later structural events. Money Creek formation mixed clastic rocks are folded by F_2 and F_3 folds; however, on the

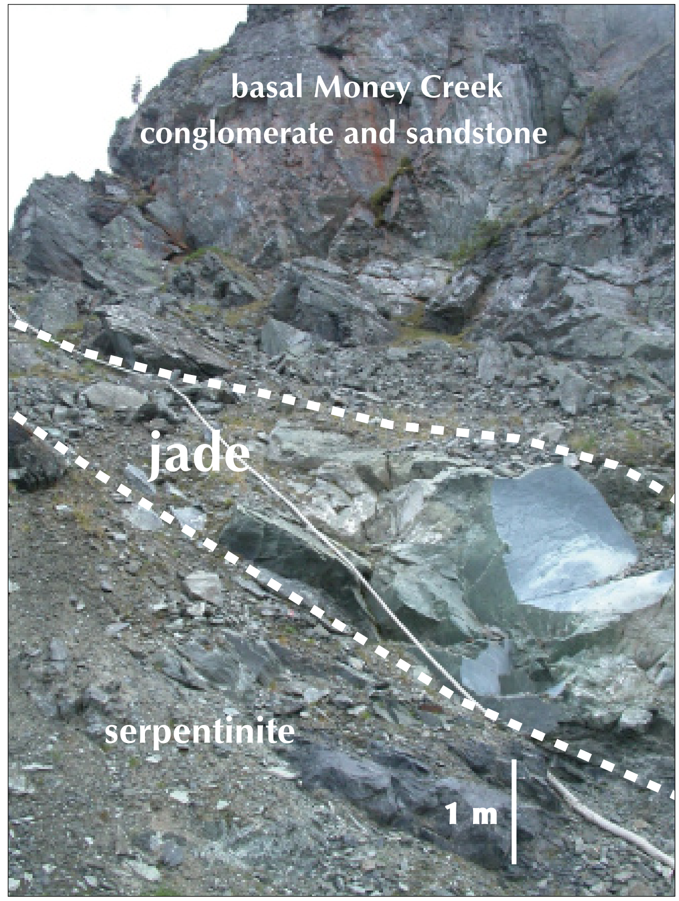

Figure 8. *Jade contacts near the working face at the King Arctic mine. Jade occurs along the faulted contact between serpentinite (below) and Money Creek basal metasedimentary rocks (above).*

eastern slopes of the southern Campbell Range, the mixed clastic rocks are interpreted to cross-cut previously folded Tuchitua River formation chert and clastic rocks. Similar fold-unconformable relationships are observed elsewhere in the southern Finlayson region (D.C. Murphy, pers. comm., 2003).

F_2 folds are folded by F_3 east-vergent folds and are identified in map pattern although not seen in outcrop (Fig. 3b). In the central part of the field area, Money Creek clastic rocks are wrapped around the fold hinge of an F_2 synform which plunges approximately 50° to the northwest. No S_2 axial planar fabric, that could be distinguished from S_3 structures, was observed in the field area.

D_3 structures are dominant in the rocks through the rest of the field area with F_3 folds of regional scale plunging between 30° to 50° northwest. The dominant foliation in the area strikes southeast with dips between 30° and 60°

southwest, and is axial planar to the F_3 folds. Minor folds in outcrop, most visible in Tuchitua River formation chert, mimic the regional F_3 fold orientation. F_3 strain can be variable; for instance, limestone ranges from relatively undeformed to highly-strained and boudinaged. It is likely that F_3 folds tightened earlier F_1 folds based on the synformal contact of Money Creek formation over an F_3 antiform along the east side of the southern Campbell Range (Fig. 3a).

All three folding events may be progressive with later F_2 and F_3 events having occurred synchronously with Money Creek formation deposition. This fits with tectonic models for YTT which describe northeast-directed shortening in Early Permian time (Murphy et al., 2003).

D_4 faulting

The northwest-southeast structural grain of the area is a result of D_4 reverse (present orientations) faulting. Rocks of the Tuchitua River and Money Creek formations are locally imbricated with serpentinite sheets that range in thickness from absent along the fault plane to up to 150 m (Fig. 9). The fault planes are curviplanar and locally show variations in dip orientation. Foliation parallel to the faults is well developed in the immediate hanging wall and footwall, and evidence of high strain is preserved in 'zebra-striped' mylonitic limestones. Along the boundaries of the serpentinite bodies, talc-schist zones up to 1 m thick are the result of shearing and fluid flow along the contacts with metasedimentary blocks. Slivers and blocks of local metasedimentary rocks are distributed through the serpentinite bodies. Limestone in close proximity to serpentinite commonly contains tremolite and magnetite porphyroblasts, possibly the result of mineralization during low temperature fluid circulation.

The reactivated Jules Creek fault marks the eastern limit of observed D_4 faulting as exposure drops off to the east. The dip of the D_4 faults is variable across the field area, but generally steepens to the west where the two most western serpentinite bodies are bound by near vertical faults. The original orientation and displacement direction along these faults is unknown. However, the fault planes commonly parallel bedding along F_3 fault limbs and, therefore, may originally have been low-angle thrusts controlled by folded bedding in Tuchitua River and Money Creek formation rocks. Regional tectonics suggest motion along these faults to be Jurassic to Cretaceous in age, as shortening of YTT and displacement along the Inconnu thrust occurred during this time (Murphy et al., 2003).

D_5 faulting

A high-angle brittle northeast-striking fault cuts D_4 structures; the trace of the fault curves northward in map view in the western half of the field area (Fig. 3a). The fault trace runs northeast along a valley that separates two parallel ridges. Hematitic silica-rich fault gouge is present along the exposed section of the slightly west-dipping, near-vertical fault. The offset along the fault is on the

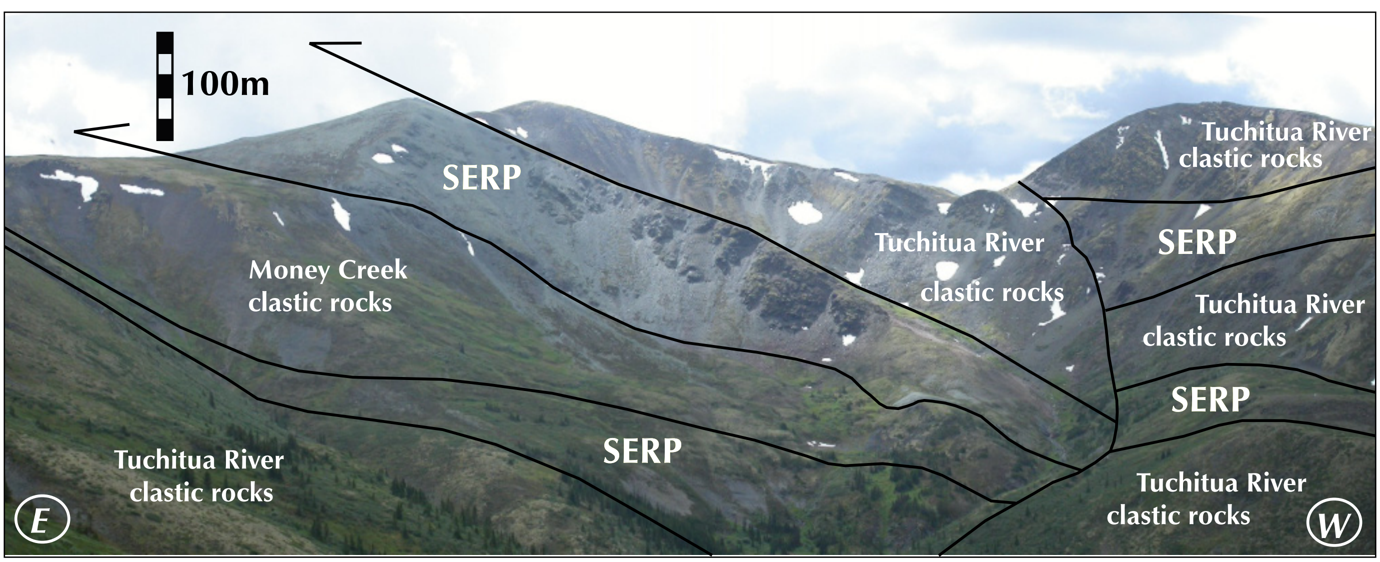

Figure 9. *View south to the southeastern field area along an oblique section through the metasedimentary and serpentinite fault-stacked sequence. The fault plane above the uppermost eastern serpentinite sheet in the photo dips to the southwest. SERP = serpentinite. All contacts are faulted.*

order of hundreds of metres based on the offset of high-angle D_4 faults that are mapped on either side.

Evidence of other late structure is seen as local slickenside preservation along fractures and joints in Money Creek rocks in the southern field area. Fibre-truncation lineations plunge steeply towards the west and preserve evidence of top-down-to-the-west sense of motion. It is not known whether these fabrics are related to the D_5 faulting event or later Cretaceous extension of YTT.

GEOLOGICAL SETTING OF RETROGRADED ECLOGITE

Quartz-muscovite schist ± retrogressed eclogite lenses occurs in two areas separated by the D_5 high-angle fault. The southern occurrence lies at the western edge of good exposure in the field area, well exposed along north- and south-trending spurs off the flanks of a northeast-trending ridge. Coarse-grained quartz-muscovite schist with lenses of retrograded eclogite occurs as a fault-bound block with greenschist facies upper Money Creek metasedimentary rocks on either side (Fig. 10). The eastern bounding fault is near vertical and well constrained, although not exposed. Similarly, to the west, the contact is not exposed and is presumed to be an east-dipping fault based on faulted contact relationships to the north.

The northern eclogite occurrence is roughly along strike from the southern occurrence, across the valley to the north in a low-lying saddle, which is underlain by poorly exposed blocks of quartz-muscovite schist, quartzite and chert. Resistant-weathering mounds up to 50 m long and 10 m wide show quartz-muscovite schist in float. Serpentinite is abundant in the creek gully draining south down the saddle; however, the top of the saddle is underlain by recessive dark argillite. The area is considered to be a fault-bound serpentinite mélange with a variable argillite matrix. Money Creek metasedimentary rocks occur on either side of the saddle in well-exposed cliff and rubbly outcrop.

DISCUSSION

THE ORIGIN OF THE QUARTZ-MUSCOVITE SCHIST, ECLOGITE AND SERPENTINITE

The occurrence of lenses of metabasite within quartz-muscovite schist and also the presence of rounded blocks of a variety of sedimentary and metamorphic rocks within serpentinite mélange in the southern Campbell Range support the formation and exhumation of the coarse-grained metamorphic rocks in a subduction zone. This is the only tectonic environment in which eclogite can be formed and exhumed that is compatible with regional tectonic models. In the Franciscan Complex of California, exhumed forearc subduction zone rocks, eclogite and various metasedimentary rocks occur as blocks within serpentinite- and shale-matrix mélange (Wakabayashi, 1992). Exhumation of intact eclogite facies metasedimentary sequences, now schists, containing

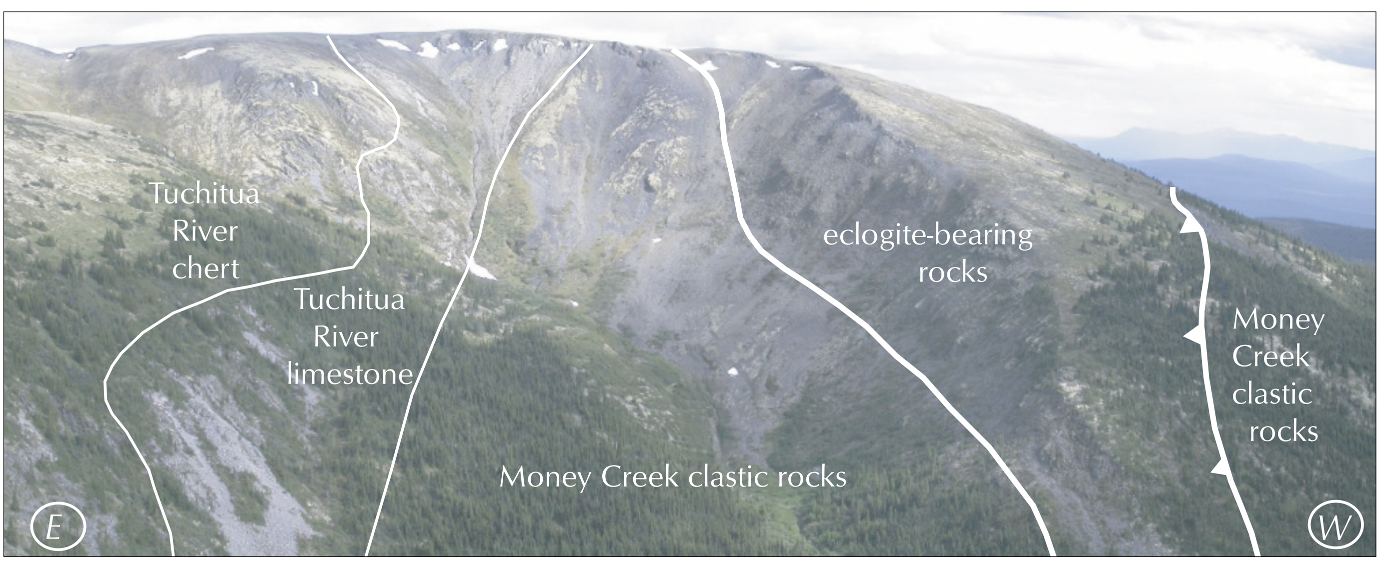

Figure 10. *View south to the southern occurrence of quartz-muscovite schist and retrograded eclogite. Heavy lines denote faulted contacts and thin lines indicate depositional contacts. The distance along the flat part of the ridge is approximately 1.5 km.*

lenses and blocks of eclogite is known from New Caledonia (Ghent et al., 1987). Both eclogite associations are present in the southern Campbell Range.

However, the origin of the serpentinite mélange at the northern occurrence is uncertain. It is possible that at least some of the serpentinite in the field area may be metaintrusive in origin. Regional relationships and age data have led D.C. Murphy (2001; pers. comm., 2003) to suggest that leucogabbro and associated serpentinite and mafic rocks to the north of the southern Campbell Range are a Permian mafic-ultramafic intrusive complex. Is some or all of the serpentinite in the field area part of this intrusive complex and Permian in age? The blocks of coarse-grained schist within serpentinite at the northern occurrence may be due to late (post-Permian) faulting which incorporated blocks of the Mississippian-aged coarse-grained rocks into a Permian-aged host serpentinite. The minimal displacement along the D_4 imbricate faults which placed similar local rock units on either side of serpentinite bodies is more compatible with this altered intrusive model for serpentinite origin. It is significant however that the quartzite blocks at the northern occurrence are not found elsewhere in the region and that the chert blocks are commonly pale in colour unlike dark Money Creek chert found locally. Geochemical study of the serpentinites in the field area will hopefully provide insight into the problem.

Regardless of the origin of the serpentinite mélange, the coarse-grained quartz-muscovite schist with lenses of retrogressed eclogite is foreign to the sedimentary rock units found in the area. These rocks alone provide evidence of a Mississippian-aged subduction zone-related component to the geology of the southern Campbell Range.

Tectonic setting

The presence of Mississippian cooling ages on retrograded eclogite along the eastern edge of Yukon-Tanana Terrane in the Finlayson region, at the southern Campbell Range and Stewart Lake localities, can be explained using current models for Yukon-Tanana Terrane tectonic evolution. The eclogites and associated rocks were formed and exhumed in a west-facing subduction zone along the west side of Yukon-Tanana Terrane in Mississippian-time. Although no date on the timing of peak metamorphism has been determined, using the mid-Mississippian ^{40}Ar-^{39}Ar cooling ages from the southern Campbell Range and Stewart Lake localities (Erdmer et al., 1998) as the age of formation is justified, as global examples show that high-pressure rocks may be exhumed rapidly; age constraints in the French Range of British Columbia show transition of blueschists from peak metamorphic conditions to erosion in potentially as little as 1 million years (Mihalynuk et al., 1999).

Early Permian regional thrust faults have been recognized in the Finlayson region (Murphy et al., 2003; Murphy, this volume). We propose that the eclogite and host rocks were carried from the forearc region along the Cleaver Lake thrust fault, and thrust over inboard arc and backarc rocks into their present position along the eastern margin of Yukon-Tanana Terrane. Folding of the Tuchitua River formation and deposition with progressive folding of the Money Creek formation was likely synchronous with this Early Permian shortening and erosional event. The faulted contacts of the eclogite and host rocks were likely modified by later structural events, including the Jurassic to Cretaceous D_4 event.

THE ORIGIN OF JADE

Jade formed by metasomatic replacement of the chert sand-pebble conglomerate and possibly serpentinite along the D_4 reverse faults that imbricate metasedimentary rocks with serpentinite in the area (Fig. 8). It is possible to see the gradational metasomatic reaction zone in outcrop where the distance from protolith metaconglomerate to serpentinite is approximately 5 m, with an intervening jade seam of approximately 2 m (Fig. 11). Focused fluid flow along the faults likely facilitated the exchange of chemical species between protoliths: Fe, Mg and Ca from the serpentinite, and SiO_2 and Ca from the highly soluble chert-pebble conglomerate. Jade sealed the faulted contacts of the conglomerate and serpentinite implying late syn-faulting jade formation, however it is not possible to determine whether late fault movement was accommodated by shearing in adjacent serpentinite, post-jade formation.

CONCLUSIONS

Early Permian regional shortening of Yukon-Tanana Terrane resulted in polydeformation of Mississippian to Early Permian volcaniclastic and metasedimentary rocks of the Tuchitua River and Money Creek formations. These rocks were imbricated with sheets of serpentinite in the southern Campbell Range, possibly in post-Late Triassic time. Nephrite jade occurs along these imbricate faults, as a result of metasomatic replacement of siliceous

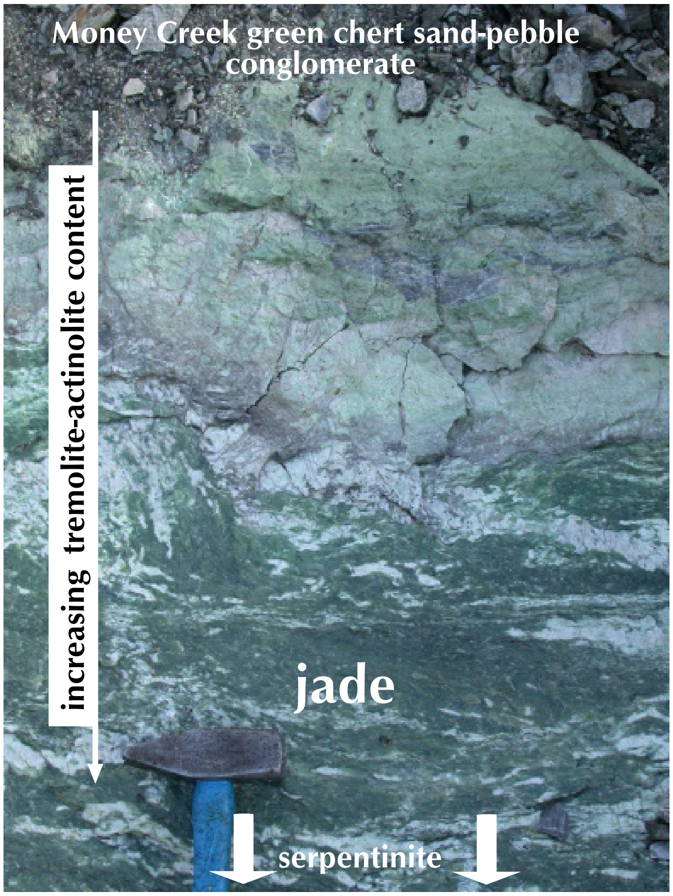

Figure 11. *Nephrite jade contacts in outcrop. Over a distance of approximately 2 m, basal Money Creek chert-clast sandstone and conglomerate is gradationally replaced by nephritic jade. Serpentinite underlies the jade seam. Fluid flow within late high-angle reverse faults facilitated metasomatic replacement of the conglomerate and serpentinite by microcrystalline tremolite-actinolite (nephrite).*

metasedimentary rocks and serpentinite by tremolite-actinolite.

Fault-bounded blocks of quartz-muscovite schist with lenses of Mississippian-age retrograded eclogite occur in the western field area in association with serpentinite-mélange of undetermined origin and are surrounded by greenschist facies metasedimentary rocks. Regional Early Permian thrust faults carried the former high-pressure rocks, from their position above an east-facing arc along the western margin of Yukon-Tanana Terrane, to their present position near the eastern contact with the North American miogeocline.

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Permafrost and landslide activity: Case studies from southwestern Yukon Territory

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ABSTRACT

Five case studies of recent landslides in southwestern Yukon Territory illustrate the role of permafrost in landslide processes of the region. In the Marshall Creek basin, permafrost degradation after recent forest fires caused numerous debris flows near the valley bottom. Similarly, on Haeckel Hill, fire-related deepening of the active layer has facilitated active layer detachment slides on upper hillside slopes. In the Kluane Range, the interface between frozen and unfrozen ground appears to control the depth of movement for active layer detachment slides and debris flows along Silver Creek. The failure mechanism on Mount Sumanik is controlled by a frozen substrate, which contributes to a reduction in drainage and elevated pore-water pressure. Lastly, thawing of segregated ice has caused a thaw slump of fine-grained sediment in lacustrine terraces along Takhini River.

RÉSUMÉ

Cinq études de glissements de terrain récents illustrent le rôle du pergélisol dans les processus de glissement dans la région. Dans le bassin du ruisseau Marshall, la dégradation du pergélisol après des feux de forêt récents a provoqué de nombreuses coulées de débris dans le fond de la vallée. Dans une situation analogue, sur la colline Haeckel, le creusement du mollisol causé par le feu a fait glisser le mollisol sur le haut des collines. Dans le chaînon Kluane, l'interface entre le sol gelé et le sol non gelé semble régir la profondeur du mouvement des glissements par détachement du mollisol et les coulées de débris le long du ruisseau Silver. Le mécanisme de rupture sur le mont Sumanik est régis par un substrat gelé qui contribue à une réduction du drainage et à une pression interstitielle élevée. Enfin, le dégel de la glace de ségrégation a créé des glissements de sédiments à grain fin dans les terrasses lacustres longeant la rivière Takhini.

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INTRODUCTION

A series of case studies of recent landslides within and adjacent to the Alaska Highway corridor were undertaken during the summer field season of 2003 as part of the Yukon Geological Survey's Alaska Highway corridor landslide hazard study. Within the western portion of the project area, between Whitehorse and the Yukon-Alaska border, many landslides relate to permafrost, either due to the degradation of ground ice or the influence of frozen ground on soil drainage. By describing the geologic and climatic controls of five cases of permafrost-related landslide activity, the aim of this paper is to highlight the role of permafrost in landslide processes in this section of the Alaska Highway corridor and introduce the potential influence that climate change has on these processes.

SETTING

PHYSIOGRAPHY

The Alaska Highway corridor between Whitehorse and the Alaska-Yukon border spans nearly 425 km and is a critical region for transportation, settlement, tourism, and resource development. Geology divides the region into two broad physiographic regions: Yukon Plateau and St. Elias Mountains (Fig. 1). Broad upland areas with rounded summits 1500-2000 m a.s.l. (above sea level) characterize Yukon Plateau. Incised into these upland areas are a number of deep valleys with elevations near 600 m a.s.l. The Alaska Highway corridor between Haines Junction and Whitehorse follows one such valley. Shakwak Trench divides Yukon Plateau from St. Elias Mountains and is the physiographic expression of Denali Fault. It is a broad 8- to 20-km-wide valley with a gently undulating floor underlain by thick deposits of till and outwash from a number of glaciations, as well as Holocene alluvium and aeolian material. The Kluane Range (Fig. 1) rises abruptly to 2000 m above Shakwak Trench as a narrow band of steep glaciated peaks.

CLIMATE AND PERMAFROST

The study area has a sub-arctic continental climate with long, cold winters, short mild summers, low relative humidity and low to moderate precipitation (Table 1). The area southeast of Kluane Lake has a more moderate continental climate than to the north due to its relative proximity to the Pacific Ocean. Local relief modifies climate throughout the entire region; for example, cold air trapped in the valleys of Yukon Plateau frequently causes temperature inversions (Wahl et al., 1987).

The Alaska Highway corridor is underlain by discontinuous permafrost. For much of its length, it lies within the transition from sporadic discontinuous permafrost to extensive discontinuous permafrost (Fig. 1; Heginbottom et al., 1995). Local climate, vegetation cover, and terrain (aspect, material type, drainage condition) are the primary controls on the distribution of permafrost. Rampton et al. (1983) described the distribution and character of ground ice along the proposed Alaska Highway gas pipeline route based on geotechnical drillhole data. They found the percentage of ground underlain by permafrost varied considerably, comprising 80% of valleys and lowlands north of Kluane Lake, <50% of the area between Kluane Lake and Takhini River, and <20% of the Takhini River valley. By contrast, the distribution and character of permafrost is less constrained on the hillslopes, plateaus and summits adjacent to the corridor. At these locations, temperature inversions and variations in snow depth complicate altitudinal trends in permafrost distribution. Nonetheless, permafrost is generally thicker and more widespread on north-facing slopes where thick vegetative mats, tree canopy, and poor drainage conditions exist.

MASS MOVEMENTS

A number of studies of mass movements within the Alaska Highway corridor have been completed. These include investigations of rock glaciers (Blumstengel, 1988),

Table 1. *Environment Canada climate normals for period 1971-2000.*

Station	Daily mean temperature °C			Mean precipitation (mm)		
	January	July	Annual	January	July	Annual
Beaver Creek	-26.9	14.0	-5.5	13.5	97.2	416.3
Burwash Landing	-22.0	12.8	-3.8	9.6	66.2	279.7
Whitehorse	-17.7	14.1	-0.7	16.7	41.4	267.4

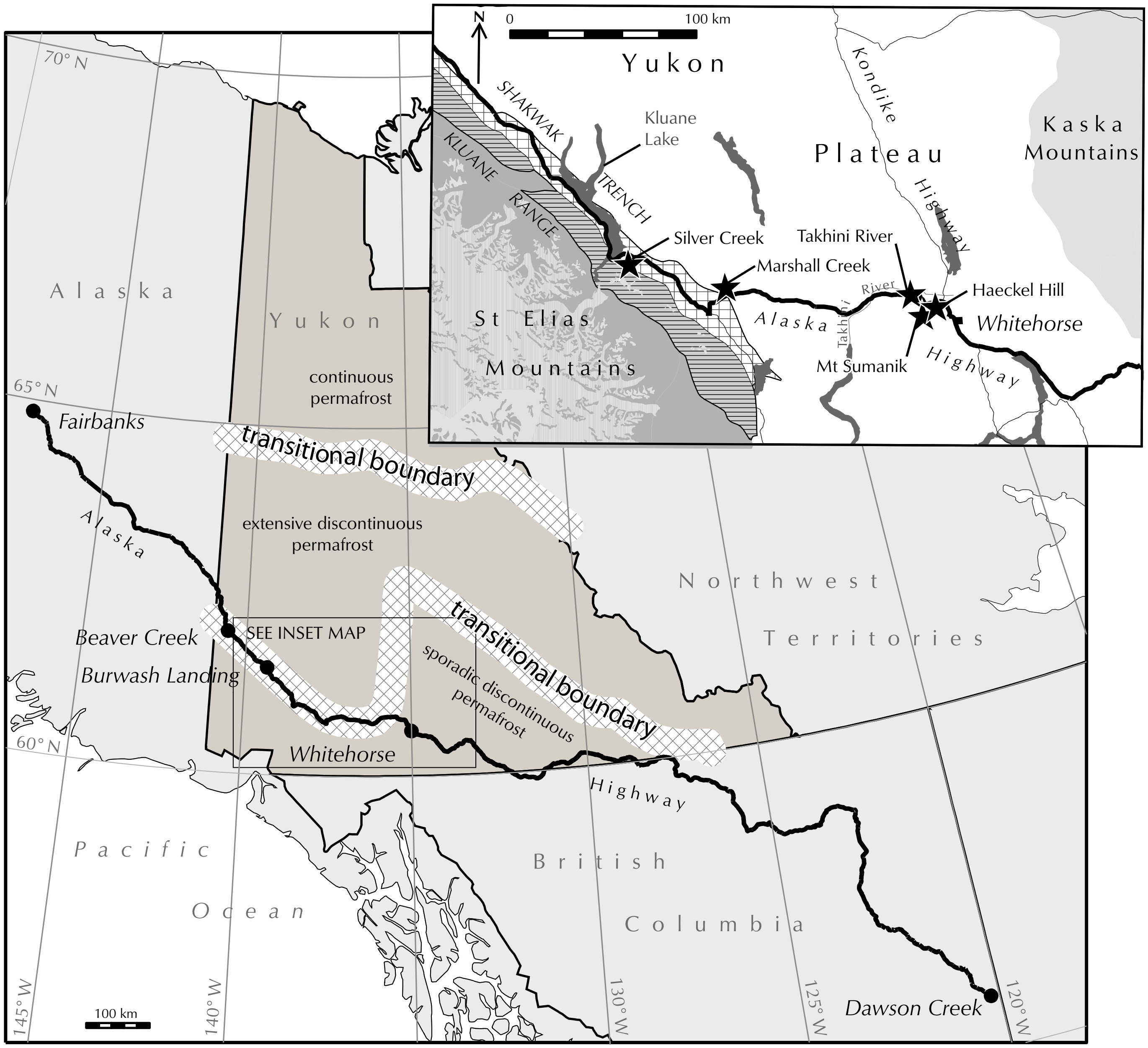

Figure 1. *The Alaska Highway and permafrost distributon of Yukon Territory (after Heginbottom et al., 1995). Inset map displays locations discussed in the text and selected physiographic regions (after Mathews, 1986).*

debris flow fans (Clague, 1981; Harris and McDermid, 1998), large rock slides (Clague, 1981; Everard, 1994), rain-storm-triggered debris flows (Evans and Clague, 1989), and 1:100 000-scale terrain hazard mapping (Gerath and Smith, 1989). These studies focus on activity in the Kluane Range, and do not describe the influence of permafrost on landslide processes in the corridor.

Permafrost-related landslide hazards are explored by three studies. Hugenholtz (2000) describes the morphology of six active-layer detachment slides on an alpine plateau south of Kluane Lake. Based on a ground-heating experiment, he proposed that rapid snowmelt and/or intense pluvial events are required to trigger a detachment. Harris and Gustafson (1993) studied activity on debris flow fans along the Slims River valley, a tributary at the south end of Kluane Lake. They found that debris flows often occur in warm weather, not always as a result of heavy rainfall events, and therefore, speculated that ground ice thaw may contribute water to the failure process. Harris and Gustafson (1988) proposed that retrogressive slumps of icy, unconsolidated sediments produce material for debris flows in the Kluane Range. However, they do not provide a description of the failures or the permafrost conditions that may have contributed to their initiation.

CASE STUDIES

MOUNT SUMANIK

Landslide setting and morphology

A series of ten debris flow channels in a basin draining Mount Sumanik demonstrate how the presence of a shallow frozen substrate may predispose an alpine slope to debris flow activity (Figure 2). Mount Sumanik is located 15 km west of Whitehorse. The basin containing the landslides drains westward. Instabilities are confined to the southwest facing slopes of the drainage basin, and occur on the apex of convex alpine slopes in silty till deposits and colluvium. The failures were initiated on moderately steep slopes (24°-29°) and traveled down the more moderate mountain side (15°-25°) scouring gullies up to 47 m wide and 13 m deep, commonly to bedrock (Figure 3). Continued retrogression is evident in the headwalls and on some of the sidewalls. The flows

Figure 2. *Oblique aerial view of Mount Sumanik debris flow channels. View is to the northeast.*

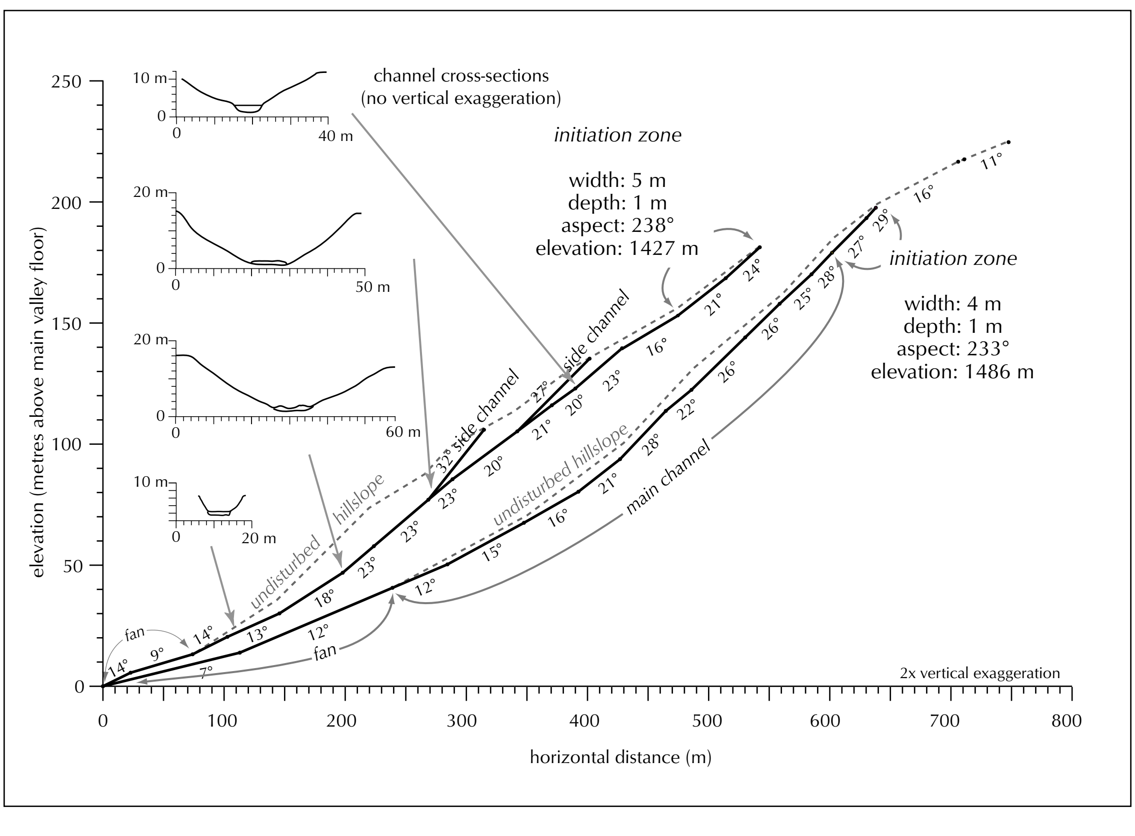

Figure 3. *Profile and cross-sections of debris flow channels and deposits on Mount Sumanik.*

traveled up to 680 m to valley bottom and produced fans containing boulders up to 2 m in diameter. Individual deposits are less than 2 m thick. The source material was a colluviated till composed of subrounded granules to boulders in a sandy silt matrix.

The frequency with which the debris flows occur was not ascertained. However, the oldest willows growing on the freshest flow deposits are two years old. Aerial photographs of the debris flow gullies from 1986 display well vegetated, subdued, v-shaped forms, indicating that the hill sides had not failed recently. Finally, a lack of vegetation within the landslide debris indicates that failures since 1986 occur with enough frequency to inhibit vegetation growth within the gully systems.

The basin or creek system of the Mount Sumanik debris flow channels do not contain any infrastructure such as roads or buildings. Nevertheless, the impact of the debris flows on the main creek is readily observed. The debris flows and their deposits contribute a large supply of sediment ranging from clay to large boulders to the creek system. Multiple abandoned channels mark the resultant lateral instability of the creek during flood up to 3 km downstream from the debris flow fan.

Failure mechanism

Shallow slumping and evidence of poor drainage is widespread on the slope above each debris flow headscarp. Soil pits reveal that within this area, frozen ground lies approximately 1.65 m below the surface in late summer. A 60-cm saturated soft plastic layer with low bearing strength was discovered on top of the permafrost table. This stratigraphy suggests that the presence of permafrost promotes poor drainage and may lead to the elevated pore pressures that trigger initial slumping. Once failures initiate in the upper alpine slopes, shallow bedrock beneath the lower gullies concentrates water and facilitates long runout distances into the valley bottom. The structure and ice content of permafrost in the initiation zone could not be ascertained because of pit collapse and inundation at the bottom of the active layer.

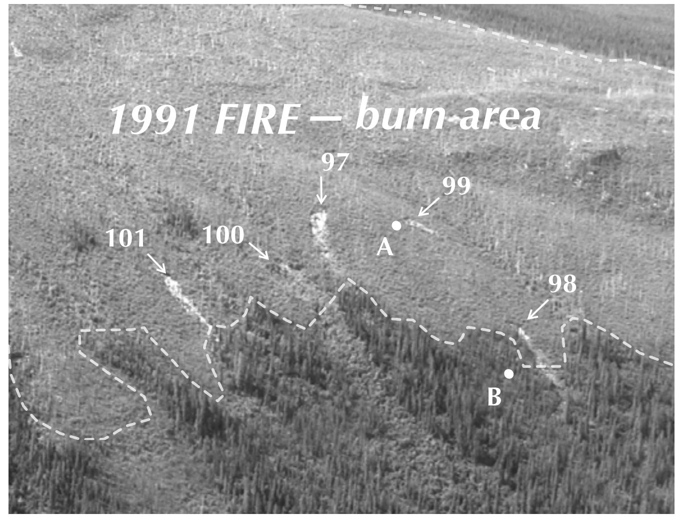

Figure 4. *Oblique aerial view of fire-related active layer detachment slides and secondary debris flow scars on the north-facing slope of Haeckel Hill, stations 97 to 101. Location A and B are hand-dug trenches.*

HAECKEL HILL

Landslide setting and morphology

Five debris slide scars occur in an area burned by a 1991 forest fire on the mid-slopes of Haeckel Hill (Fig. 4). Haeckel Hill is located 7.5 km northwest of Whitehorse and 2 km south of the Alaska Highway. Comparison of soil organic horizons and canopy cover inside and outside of the burned area indicate that the forest fires burned most of the organic mat and forest canopy. The debris slide scars are located on the north-facing slope of the hill at approximately 1000 m a.s.l. The source material was till and colluviated till composed of granules to cobbles with few boulders and a sandy silt matrix. Table 2 describes the morphological characteristics of the landslide scars.

Table 2. *Morphological characteristics of landslides on Haeckel Hill.*

Station	Elevation (m)	Aspect	Initiation slope	Scar length (m)	Scar width (m)	Scar depth (m)
03AH097	1104	46°	20°	167	14	1.3
03AH098	1098	349°	19°	51	15	1.2
03AH099	1041	27°	21°	105	9	1.5
03AH100	1080	352°	24°	-	10.5	2
03AH101	1077	14°	18°	-	10	1

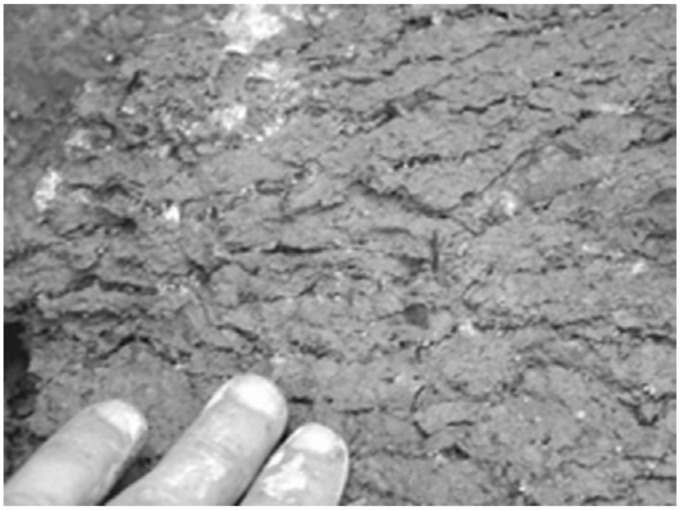

Figure 5. *Photograph of frozen soil with stratified ice veins (1-3 mm thick) from Location B, the unburned forest site in Figure 4.*

Transverse compression ridges were commonly observed at the toe and along the sides of the scars. These features indicate that sliding was the initial failure mode. Flow levees up to 1 m in height commonly flank the landslide track and suggest that the slides translated into debris flows. As well, sloughing beneath intact forest mat and fans of debris overlying compression ridges attest to retrogressive secondary failures. Aerial photographs taken in 1995 demonstrate that three of the five landslides had occurred within four years of the fire.

Permafrost conditions

In order to gain insight into the depth and character of permafrost within the burned area, a trench adjacent to the headscarp of landslide 99 was excavated in late August (Location A, Fig. 4). However, permafrost was not encountered within the 1.35-m-deep trench. A second pit was dug in the unburned white spruce forest directly below the slide scars (Location B, Fig. 4). Here, permafrost was uncovered at a depth of 70 cm, beneath 25 cm of organic mat and 45 cm of unfrozen mineral soil (Fig. 5). The permafrost contained stratified segregated ice veins, 1-3 mm thick, composing 15% (by volume) of the soil.

Failure mechanism

Comparison of scar depths and the active layer depths in the unburned site suggests that the landslides occurred along a thawing ice-rich zone at the base of the active layer. Elevated pore water pressure in this zone may have resulted from thawing ice lenses, in combination with snowmelt and/or rainfall. Maintenance of high pore pressure was facilitated by poor drainage due to the presence of a frozen substrate. Finally, the presence of a substantial amount of segregated ice suggests that the strata would undergo significant volume and strength reductions as thawing occurred. Three of the five landslide scars appear to have experienced secondary debris flows associated with thaw since the initial failure. These flows travelled much farther than the initial slides. The timing of the failures suggests that the thawing is attributable to the 1991 forest fire.

SILVER CREEK

Landslide setting and morphology

As Silver Creek flows eastward from the glaciated peaks of the Kluane Range and enters Shakwak Trench, it incises 80 m into an undulating and fluted plain composed of till, lacustrine and outwash sediments from a number of glaciations (Denton and Stuiver, 1966). Evidence for four recent shallow debris slides was found along the northwest-facing slope of Silver Creek during field surveys in 2003 (Fig. 6). The largest slide (landslide 1) occurred in 1988, according to aerial photos taken in 1989 and the age of willows in the landslide scar. The remaining three slides occurred between 1989 and 2003. All four slides initiated on middle to upper planar slopes that displayed indications of only minor concentration of runoff or groundwater flow when they were examined during 2003 fieldwork. The source material was a grey colluviated silty till with minor boulders and common cobbles. The scar of

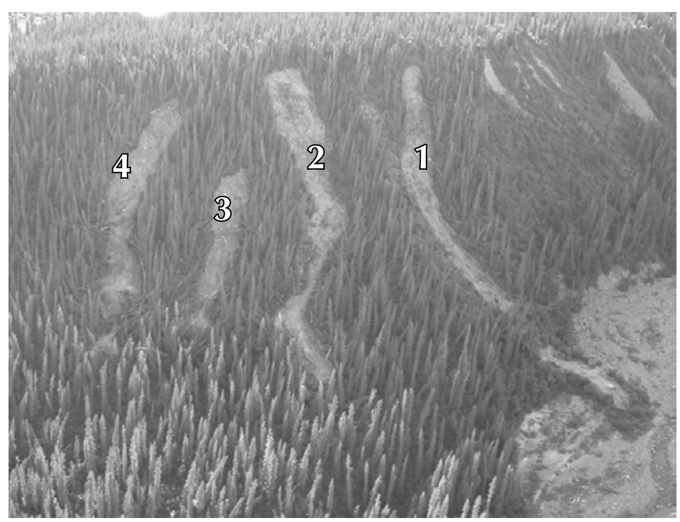

Figure 6. *Oblique aerial view of Silver Creek debris slides. Landslide scars are numbered 1 through 4.*

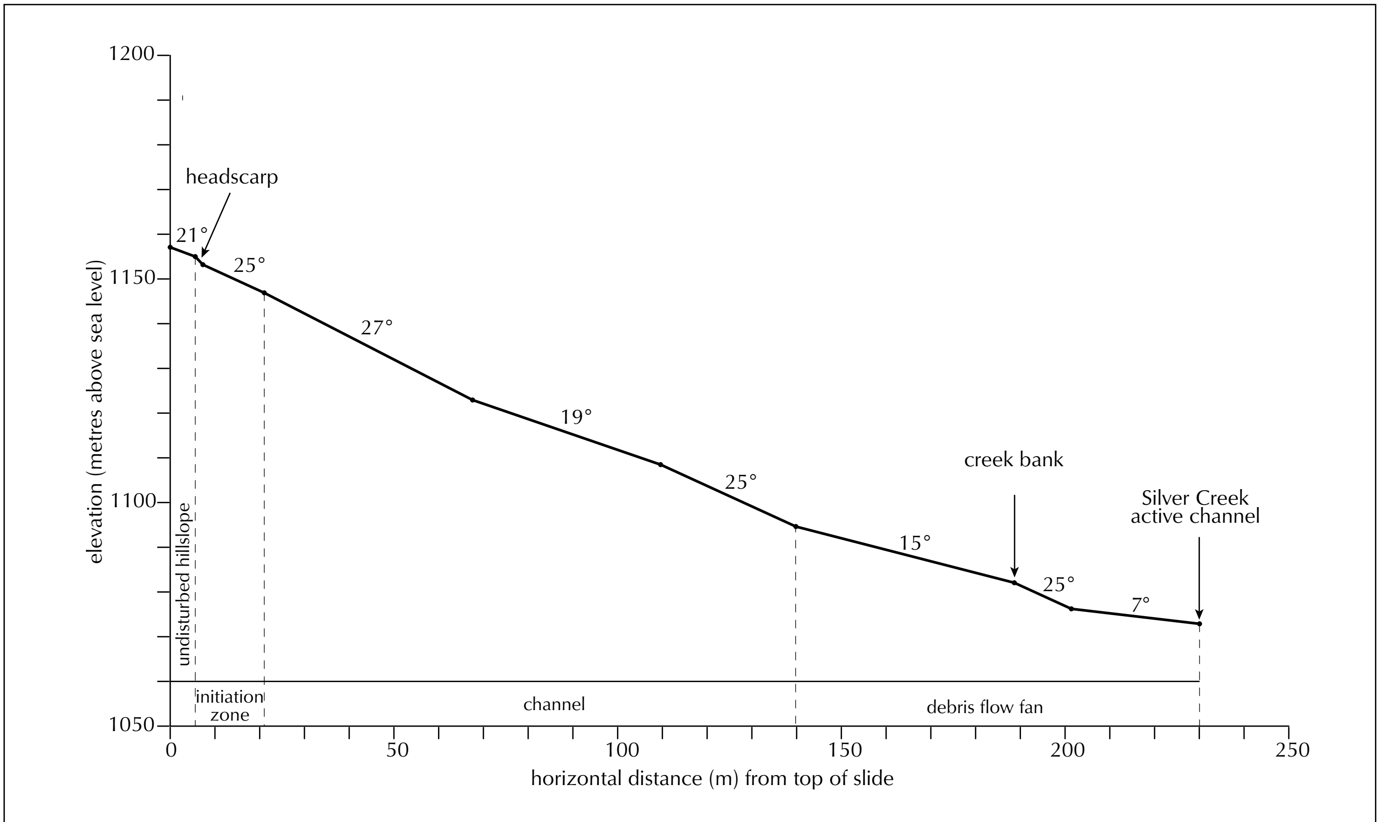

Figure 7. *Longitudinal profile of Silver Creek debris flow (to scale, no vertical exaggeration).*

landslide 1 was surveyed in detail (Fig. 7). The maximum depth of the scar is 1 m. The width of this scar ranges between 10 m at its headscarp to 26 m across its fan. Overlapping flow lobes and flow levees are common features within the deposits in both the headscarp area and the channel. A thick mat of organic material overhangs much of the headwall.

Permafrost conditions

Apart from the areas disturbed by landsliding, the southern bank of Silver Creek is occupied by mature white spruce forest. Typically, the ground is covered by lichens and feather mosses ranging from 25 to 30 cm thick. Frozen soil was encountered in mid-August at a depth of approximately 40 cm below the mineral soil surface. The top 15 cm of the frozen soil contained visible clear ice coatings on clasts, ice grains, and ice veins up to 1 mm thick. The visible ice content was estimated to be less than 10% by volume.

Failure mechanism

In July 1988, heavy rainfall triggered numerous failures, some severing the Alaska Highway, in the Kluane Lake area (Evans and Clague, 1989). From July 1-17 of that year, Burwash Landing received 209% of its normal rainfall for that period, and 42% of its annual total precipitation (Evans and Clague, 1989). These rainstorms are suspected to have triggered landslide 1 as the 1989 aerial photograph and dendrochronology investigations suggest. Permafrost is very shallow in the undisturbed slope adjacent to the failure. The presence of a shallow frozen substrate likely led to the elevation of pore water pressure to the point of failure. Comparison of the depth of the landslide scar and the depth of permafrost on the undisturbed slope suggests that the permafrost table also controlled the depth of failure. Sloughing from beneath the organic mat and the presence of overlapping flow lobes in the landslide debris suggests that the present depth of the scar (1 m) has been modified by thaw and reactivation since the initial failure. A triggering event for landslides 2, 3 and 4 has not been established, although a similar mechanism is speculated.

MARSHALL CREEK BASIN

Landslide setting and morphology

Evidence for 41 recent debris flows exists within terraces and valley sides of the Marshall Creek basin, 14 km northeast of Haines Junction. The vast majority of the instabilities were initiated within an area burned by forest fires during the summer of 1998 (Fig. 8). The fires affected an area of approximately 37 km^2 and bordered Marshall Creek for 9 km.

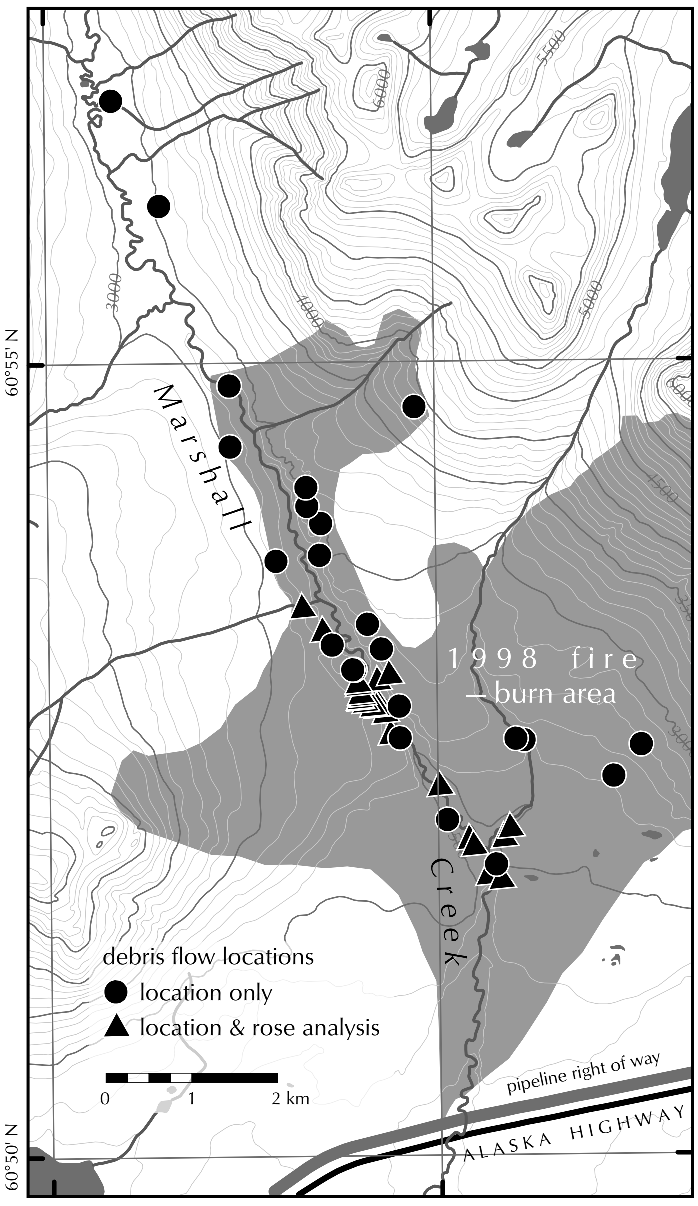

Figure 8. *Topographic map of debris flow locations and areal extent of burn along Marshall Creek. (Contour elevations in feet.)*

The debris flows of the Marshall Creek basin can be divided into two groups based on the landform within which they originated. The majority of the landslides (36) developed on the scarp of high-level terraces composed of glacial and fluvioglacial material (Fig. 9). In comparison, a lesser number (5) of the landslides occurred on gentle till-blanketed valley sides. Much of the valley fill was deposited as ice advanced and retreated from the Marshall Creek valley during the late Wisconsinan McConnell Glaciation. During this advance and subsequent retreat, silt-rich till blankets were deposited on valley sides and a thick fill of silt-rich till and glaciolacustrine and glaciofluvial strata was deposited in the valley bottom.

Figure 10 describes the aspect of the debris flow initiation zones that were surveyed by helicopter and on foot. The average aspect of the debris flow headscarps in the high-level terraces was northerly.

The impact of the debris flows includes burial of mining equipment at an unoccupied camp and mining access roads by up to a metre of debris in several locations. Many debris flows traveled directly into Marshall Creek and contributed sediment ranging in size from clay to boulders. The creek is still actively eroding this material. The Alaska Highway and the proposed Alaska Highway pipeline right-of-way cross Marshall Creek 3 km downstream from the failures. These crossings remained unaffected by the failures.

Permafrost conditions

In order to compare the depth and character of permafrost within and outside of the burned area, soil pits

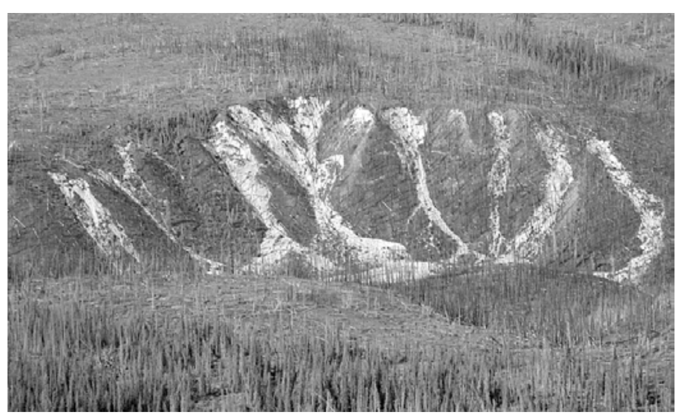

Figure 9. *Oblique photograph of debris flow scars originating from scarp of terraces formed in glacial material along Marshall Creek.*

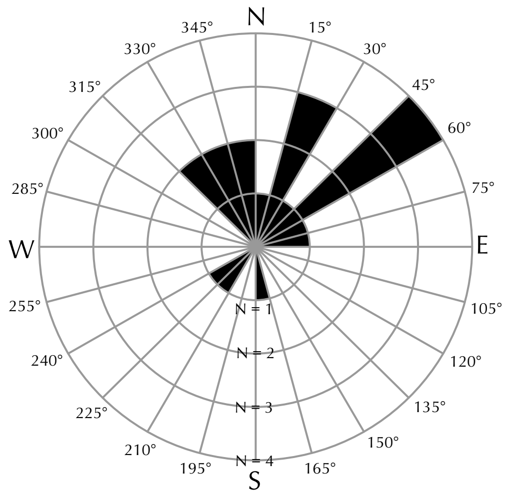

Figure 10. *Rose diagram displaying aspect of visited landslide headscarps in Marshall Creek valley. N is number of samples.*

were dug in burned and unburned terrace gully walls of similar aspect and geometry. At the unburned site, ice was found at a depth of 60 cm, beneath 25 cm of moss and lichen, 20 cm of black humic organic soil, and 15 cm of unfrozen soil in late summer. Within the frozen soil, ice coatings up to 3 mm thick were observed on granules and pebbles within a silty sand matrix. In total, excess ice is estimated to compose 10% (by volume) of the soil. That is, there may be 10% (by volume) more ice in the sediment than the filling of natural pore space can account for. In contrast, at the burned site, ground temperatures were 6.4°C at 1.05 m depth.

Failure mechanism

Comparison of soil organic horizons and forest canopy cover inside and outside of the burned area indicate that the forest fires burned most of the organic mat and canopy. Removal of the vegetative cover has led to changes in surface energy balance and caused the active layer to increase in thickness. Examination of the northerly aspect of the landslide initiation zones, as well as comparison of scar depths and the active layer depths in the unburned site, suggests that the landslides occurred along a shallow ice-rich zone at the base of a deepening active layer. Thawing of ice lenses in combination with snow melt and/or rainfall may have contributed water to elevate pore pressure in this zone. High pore pressure was then likely maintained by poor drainage due to the presence of a shallow frozen substrate. Finally, the locally ice-supported structure of permafrost in the Marshall Creek basin suggests that the strata experienced significant strength reduction as thawing occurred.

TAKHINI RIVER

Landslide setting and morphology

A retrogressive thaw slump is located adjacent to the Alaska Highway, 25 km west of Whitehorse. The failure occurred in a terrace composed of laminated silt and clay, and is representative of eight other failures that have occurred within 6 km of this location. The terrace's surface lies 11 m above the river, is locally ice-rich, and hosts numerous thermokarst lakes. The slump has an approximately 7-m-high, 107-m-wide, semi-circular headscarp. During field visits in the summer of 2003, the western portion of the headscarp was near vertical, and the remainder of the headscarp exhibited a slope of 25° with fresh terracettes extending back to the embankment of the Alaska Highway. These features indicate recent retrogressive activity. From the headscarp area, a 132 m, low angle (7°) tongue extends into Takhini River (Fig. 11). The river has eroded the fine-grained material leaving a 1.7 m stream cut at the landslide toe. The volume of the failure is on the order of 40 000 m^3.

At the position of the thaw slump, 1971 aerial photographs indicate that stream erosion had removed the vegetative cover on the bank of Takhini River. By 1979,

Figure 11. (a) *Oblique aerial photograph taken in 2003 of Takhini River retrogressive ground ice slump.* ***(b)*** *Inset aerial photograph taken in 1987 of Takhini River retrogressive ground ice slump.*

slumping had caused the terrace scarp to recede approximately 25 m. Between 1979 and 1986, further slumping had caused the headscarp to retreat an additional 112 m to near its present position. Since 1986, the headscarp has retreated several metres and decreased its slope substantially.

Permafrost conditions

Extensive forest fires during the summer of 1958 burned most of the vegetation and soil organic horizon in the area surrounding the slump. Burn (1998) found that the active layer is 1.4 m thick in unburned sites, whereas at burned locations 39 years after the fire, the permafrost table may be more than 3.75 m below the ground surface. Burn (1998) also found that the excess ice content of permafrost in the valley ranges between 10% and 50%, and averages 24%.

Failure mechanism

River erosion-related thawing of ice-rich sediment caused the failure of fine-grained lacustrine terraces along Takhini River. The morphology of the thaw slump is characteristic of bi-modal flows (McRoberts and Morgenstern, 1974). It has a semi-circular, amphitheatre-like headscarp and biangular profile. The flow has a low-angle tongue (7°) and, when active, had a steep headscarp (Fig. 11). In general, retrogressive thaw slump development is initiated when the vegetation or active layer materials are removed causing thaw of icy material. The thaw slump under investigation is on the cut bank of a migrating meander of the river; the meander is propagated by a tributary alluvial fan entering Takhini River on the opposite bank.

The Takhini River thaw slump illustrates how thaw-related landsliding can impact infrastructure and streams. In addition, it illustrates the longevity of thaw-related failures. Firstly, highway fill is subsiding and causing the roadbed to slope towards the slump. Cracks in the road surface are also propagating parallel to the scarp as the headscarp stabilizes and utility cables have been routed above-ground where disrupted by the movement. Finally, the flow of fine-grained material into Takhini River has contributed more fine-grained material to its already high sediment load.

DISCUSSION

IMPLICATIONS OF FUTURE CLIMATE CHANGE

The triggering events in each case study relate to river migration, intense summer rainfall and/or rapid snowmelt, as well as permafrost degradation caused by forest fires. Therefore, any climate change leading to an increase in the frequency and/or magnitude of these events in southwestern Yukon will similarly lead to an increase in the frequency and/or magnitude of periglacial landslides in the region, at least in the short term. Under any change in climate, slopes will be required to re-establish an equilibrium with new conditions.

The range of projections of climate change over the next 50 years for southern Yukon is summarized in Figure 12 and Table 3. Although each scenario projects a slightly different set of future conditions, all projections share several common themes. Firstly, there will be an increase in temperature, more so in the winter than in the summer. There will also be an increase in precipitation. The seasonal timing of this increase is inconsistent between scenarios, but most project that it will occur in winter and

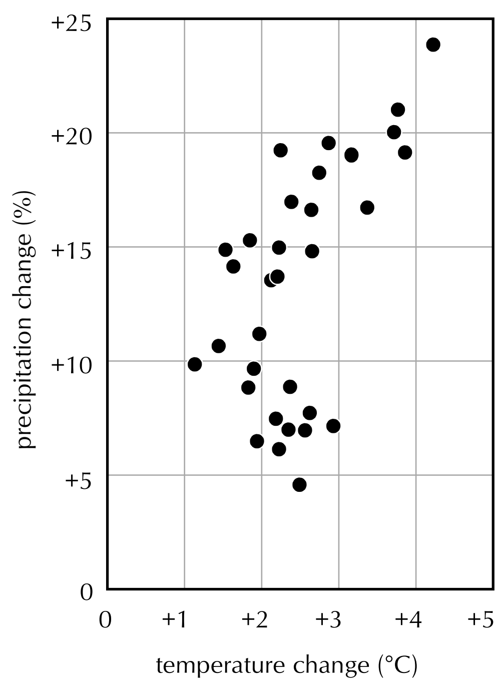

Figure 12. *Projected precipitation and temperature increases (relative to present) for southern Yukon (60.75°N, 135°W) for 2050s. Data provided by the Canadian Institute for Climate Studies, the Canadian Centre for Climate Modelling and Analysis (CCCma) and the IPCC Data Distribution Centre (DDC).*

spring. Although these generalizations may be meaningful at a large regional scale, projections for specific locations are less certain. Many climatic factors important for determining the stability of permafrost or rainfall patterns are dependant on local conditions that are quite complex and poorly modeled. For example, the geometry and orientation of individual valleys influence the local effect of winds on snow depth and the establishment of temperature inversions.

In its third Assessment Report, the Intergovernmental Panel on Climate Change (IPCC, 2001) undertook a systematic analysis of the predicted changes in extreme weather and climate events over the 21st century. The panel determined that more intense precipitation events

Table 3. *Projected increase (relative to present) in seasonal and annual temperature and precipitation, southern Yukon (60.75°N, 135°W), for the decade 2050. Data for seven general circulation models (GCMs) using IPCC (2000) Special Report on Emission Scenarios. Data provided by the Canadian Institute for Climate Studies, the Canadian Centre for Climate Modelling and Analysis and the IPCC Data Distribution Centre.*

	Projected temperature increase (°C)					Projected annual precipitation increase (%)
Experiment	**Winter**	**Spring**	**Summer**	**Fall**	**Annual**	
cgcm2 a21	3.9	3	3.2	1.5	2.9	7
cgcm2 a22	3	2.4	2.9	1.1	2.4	9
cgcm2 a23	3.9	2.2	3	1.1	2.6	7
cgcm2 b21	2	1.8	2.6	1.4	1.9	7
cgcm2 b22	3.3	1.8	2.4	1.2	2.2	8
cgcm2 b23	4.1	2	2.6	1.3	2.5	5
csiromk2b a11	3.5	4.7	4.4	4.2	4.2	24
csiromk2b b11	3.4	4.2	4	3.2	3.7	20
csiromk2b a21	3.1	3.2	4.1	3	3.4	17
csiromk2b b21	3.1	4.5	4.1	3.7	3.8	19
hadcm3 a21	0.6	1.4	2.8	2.4	1.8	9
hadcm3 a22	2.2	1.1	2.4	3.8	2.4	17
hadcm3 a23	2.3	0.8	2.6	3	2.2	15
hadcm3 b21	0.1	0.6	1.8	2	1.1	10
hadcm3 b22	1.6	1.1	2.1	3	1.9	11
hadcm3 b11	1	0.5	1.9	2.4	1.5	11
hadcm3 a1fi	2.8	1.5	2.6	3.6	2.6	15
ccsrnies a21	2.6	2	1.9	2.5	2.2	19
ccsrnies b21	3.2	2.5	2.6	3.1	2.9	20
ccsrnies a11	4.5	3.6	3.1	3.8	3.7	21
ccsrnies b11	1.4	1.1	1.5	2.1	1.5	15
ccsrnies a1fi	2.8	2.2	2.2	3.2	2.6	17
ccsrnies a1t	3.8	2.7	2.7	3.4	3.1	19
echam4 a21	2.2	0.8	2.3	2.1	1.8	15
echam4 b21	2.6	0.6	2.7	2.8	2.2	14
gfdlr30 a21	2.9	2.5	2.1	3.6	2.8	18
gfdlr30 b21	3.2	2.1	2.2	1.9	2.3	7
ncarpcm a21	2	1.9	1.4	2.1	1.9	10
ncarpcm b21	2.4	1.4	1	1.7	1.6	14
cgcm2 a2x	3.6	2.5	3	1.3	2.6	8
cgcm2 b2x	3.1	1.9	2.5	1.3	2.2	6
hadcm3 a2x	1.7	1.1	2.6	3.1	2.1	14

are very likely over many areas around the world. In the study area, this may cause more cyclonic activity in the Gulf of Alaska to penetrate the St. Elias Mountains.

An estimate of how future global atmospheric conditions relate to site-level slope stability requires transcendence of multiple levels of uncertainty and complexity. Therefore, estimates of how landslide processes in the study area will respond to climate change are necessarily qualitative. With this in mind, several suggestions can be made based on the inferred failure mechanisms of the landslides discussed in this paper. Firstly, an increased incidence of forest fire with climate change, and fire-related deepening of the active layer, will certainly lead to more debris flows analogous to those in the Marshall Creek Basin and on Haeckel Hill. Furthermore, the vulnerability of these settings to fire-related ground warming illustrates their susceptibility to thermal disturbance from other causes. Increased annual air temperature or winter snow cover may similarly lead to more widespread deepening of the active layer, and given the local importance of ice near the top of the permafrost zone for soil strength, this ground warming will likewise increase the frequency of debris flows and slides. In addition, an increase in the magnitude or frequency of extreme summer precipitation events will result in an increase in debris flow activity analogous to that near Silver Creek and Mount Sumanik. Finally, increased precipitation may also lead to more runoff, increased river migration and thaw slumps in ice-rich terrain similar to that near the described thaw slump in the Takhini Valley.

SUMMARY

Along the Alaska Highway corridor, various types of landslides relate to the presence and/or degradation of permafrost. The presence of permafrost and its thaw, in various hill slope settings, influences landslide processes via its control on soil drainage and soil strength. The series of debris flow channels on Mount Sumanik demonstrate how poor drainage due to the presence of a shallow frozen substrate may predispose alpine slopes to failure. The recent active layer debris slides and debris flows on Haeckel Hill and in the Marshall Creek basin illustrate the influence of fire-related ground ice thawing on slope stability in valley bottom and mid-slope positions. At these locations, the thaw of soils with moisture contents in excess of saturation caused a reduction of soil strength. Four debris slides along Silver Creek provide examples of permafrost-related failures in an undisturbed, forested setting. At this location, intense rainfall likely induced elevated pore pressures over the permafrost table, thereby reducing the shear strength of the active layer, and triggering at least one of the flows. Finally, a thaw slump within glaciolacustrine silts and clays on the bank of Takhini River initiated when river erosion exposed the icy sediment to thaw, underlining the vulnerability of ice-rich terrain to erosion.

In each case study, failures are induced by thermal disturbance due to river erosion or fire-related removal of vegetation as well as extreme snowmelt and/or precipitation events. If global warming leads to an increased incidence of these events, an increase in landslide frequency and/or magnitude can also be expected within the settings described in this paper.

ACKNOWLEDGEMENTS

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Evidence for a late-McConnell readvance of the Cassiar Lobe in Seagull Creek, Pelly Mountains, central Yukon

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ABSTRACT

Drift prospecting in high relief areas of the Cordillera requires consideration of paleo-ice-flow reversals. This means rethinking the manner and degree to which glacial ice eroded, transported and deposited surficial sediments. The regional context, geomorphic landforms and sediment stratigraphy identified in the Seagull Creek valley suggest that late-glacial up-valley ice flow, although relatively short in duration, may have been the controlling process for glacial transport and deposition in this area. This interpretation has important implications for mineral exploration programs that utilize glacially transported materials for various forms of geochemical analysis. Geomorphic landforms and glacial dynamics responsible for reverse (up-valley) ice flow in Seagull Creek valley have important implications for mineral exploration on the Ross River Minerals Tay LP gold-copper property.

RÉSUMÉ

La prospection des sédiments glaciaires dans les zones montagneuses de la Cordillère exige une analyse des inversions de paléo-courant glaciaire. En d'autres termes, il s'agit de repenser la façon dont la glace a érodé, transporté et déposé les sédiments superficiels et réévaluer son importance. Le contexte régional, les formes de relief et la stratigraphie des sédiments de la vallée du ruisseau Seagull font supposer que l'écoulement tardiglaciaire vers l'amont, même s'il a été de courte durée, a pu être le processus de contrôle du transport et de la sédimentation glaciaire dans cette zone. Cette interprétation a des répercussions importantes sur les programmes de prospection minérale qui utilisent les matériaux transportés par les glaciers pour effectuer diverses analyses géochimiques. Les formes de relief et la dynamique glaciaire qui sont responsables de l'écoulement glaciaire inverse (amont) dans la vallée du ruisseau Seagull ont des conséquences de taille sur l'exploration minérale dans la propriété d'or-cuivre Tay LP de la société Ross River Minerals.

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INTRODUCTION

Till geochemistry and ice-flow reconstruction have been used in regions of thick glacial deposits to trace mineral occurrences in underlying bedrock (Shilts, 1993). This type of 'drift prospecting' is generally straightforward in regions where the dominant ice flow was relatively constant and unidirectional. Due to the nature of deglaciation in the Cordillera, however, drift transport in mountainous regions may be more complex than previously thought. The possibility of reverse (up-valley) ice flow in Seagull Creek valley has significant implications for ongoing mineral exploration, particularly on the Ross River Minerals Tay LP property. The objective of this paper is to document the late glacial history of Seagull Creek and relate this to the present search for mineralization in the valley.

Quaternary deposits obscure much of the bedrock in Seagull Creek valley (Fig. 1), and the nature of underlying mineralization is not fully understood (Tolbert, 2000). Surface exposure of bedrock occurs primarily within Seagull Creek and above the upper limit of till preservation at approximately 1300 m elevation on the surrounding hillsides. Samples containing some of the highest gold values on the property are from mineralized float boulders found along the valley sides and bottom (Tolbert, 2000). Historically, exploration in the valley bottom has focused on geochemical investigations. Although soil sampling programs, limited drilling, and electromagnetic surveys undertaken by a number of exploration programs have located some gold-bearing rocks, the source of high-grade mineralization observed in float has yet to be discovered. It is proposed that a possible error in interpreting this data is the assumption of

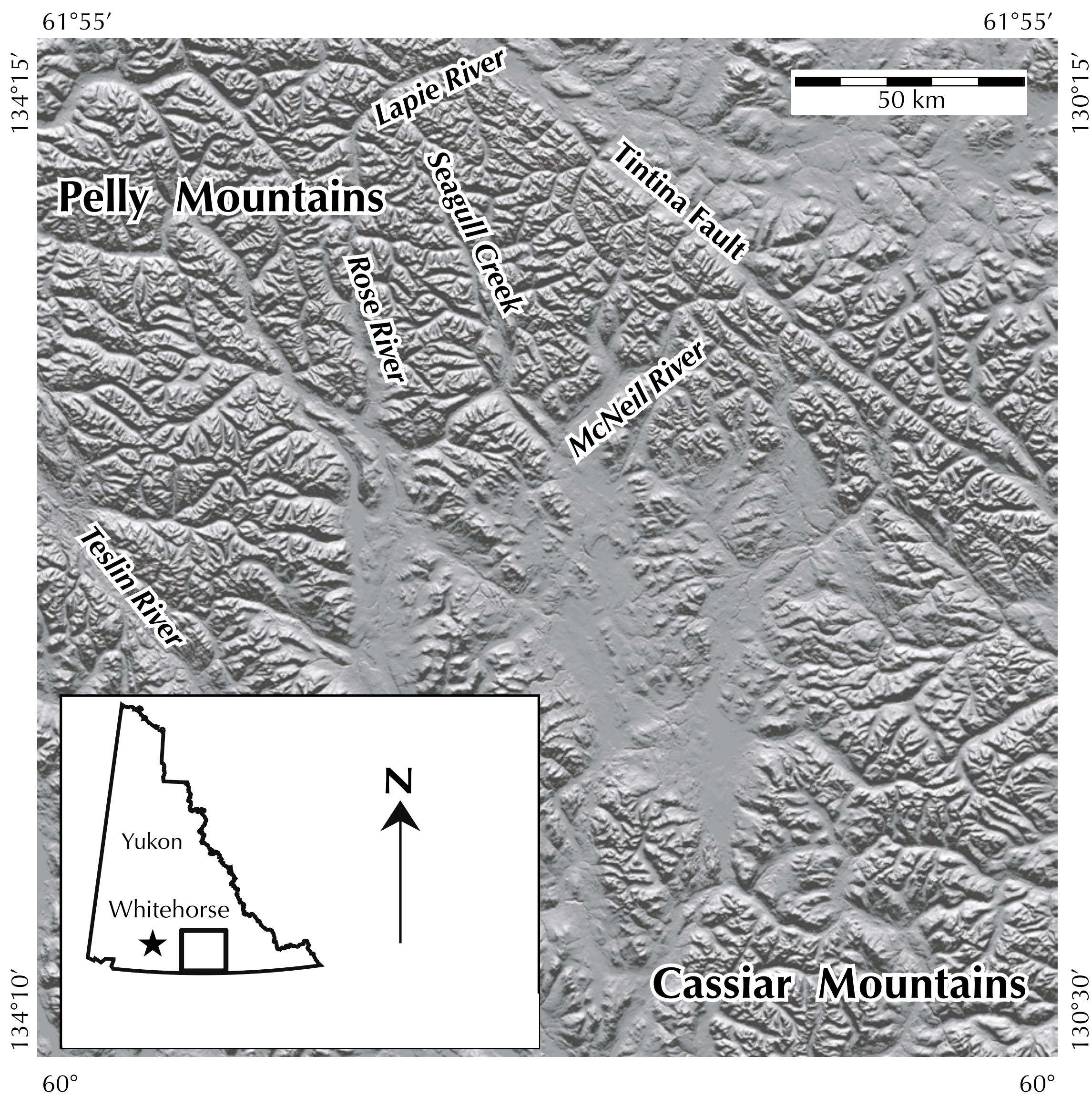

Figure 1. *Seagull Creek is located along the continental divide of the Pelly Mountains in central Yukon.*

down-valley ice flow as the dominant transport mechanism of valley-bottom sediments.

The importance of drift prospecting in glaciated terrain in mountainous regions of central Yukon has been well established by till geochemistry programs conducted in the nearby Anvil, Finlayson and Glenlyon regions (Bond, 1999, 2001; Bond and Plouffe, 2002, 2003). However, before applying this methodology, some basic assumptions relating to the nature and history of glacial transport need to be verified. Previous research near Lapie River (Plouffe and Jackson, 1992) and Anvil Range (Bond, 1999), as well as ongoing investigations in the Wheaton River valley by the authors have shown that reversals of ice flow in mountainous regions have occurred during the late-glacial phase of the McConnell Glaciation and can be the dominant sedimentation-controlling event for some valleys. The regional context, topographic landforms and sediment stratigraphy of Seagull Creek suggest that up-valley ice flow was likely the controlling process on glacial transport of surficial materials.

PHYSIOGRAPHY AND BEDROCK GEOLOGY

Seagull Creek is located in the St. Cyr Range of the Pelly Mountains in central Yukon (Fig. 1). The physiography of this region is characterized by high (up to 2162 m) cirques, arêtes and horn peaks above broad, sediment-filled valley bottoms ranging in elevation from 900-1200 m. Tertiary drainage trended to the southwest and is preserved only in major valleys such as the Ross and Nisutlin (Jackson, 1994). Narrower northwest-trending valleys follow the orientation of ice expansion during the Pleistocene.

The Tay LP gold-copper property is located within the Pelly-Cassiar Platform, a region of northwest-trending platform carbonates ranging in age from Cambrian through Mississippian (Gordey and Makepeace, 1999). This shallow marine miogeoclinal sequence has been folded and faulted into the 70-km-wide and 600-km-long massif of the Pelly Mountains. Mid-Cretaceous granitic rocks extensively intrude the entire foreshortened assemblage, and Late Cretaceous right-lateral movement of 450 km along the Tintina Fault has displaced tectonic elements relative to each other. In the Seagull Creek valley garnet-diopside skarn rocks are found in close association with limestone and intrusions of quartz monzonite (Tolbert, 2000). Known mineralization on the property consists of veins and replacement of calcareous schists with variable amounts of tourmaline, pyrrhotite, pyrite and chalcopyrite, and trace to minor amounts of marcasite, arsenopyrite, galena, bismuthinite, tellurobismuth, bismuth and gold (Tolbert, 2000).

Falling within the 'Tintina Gold Belt' (British Columbia and Yukon Chamber of Mines, 2000) of the Cordillera, there has been active mineral exploration in Seagull Creek valley since the 1970s. The 9524-hectare Tay-LP claims were staked in 1984 and have been optioned to both Cominco Ltd. and Comox Resources Ltd. before Ross River Minerals Ltd. acquired interest in 1999. Thick glacial deposits in the valley bottom have hindered prospecting, and the scarcity of basal till has made traditional drift prospecting techniques ineffective. In 1999, a reconnaissance program of selective leach soil sampling was undertaken to test the viability of this method for locating mineralization beneath deep, transported overburden (Tolbert, 2000). Although this more sensitive analysis improved soil geochemistry results, high-grade mineralization in Seagull Creek has yet to be located.

GLACIAL HISTORY

The last glaciation to affect central Yukon is the late Wisconsinan McConnell Glaciation, which began sometime after 26 ka BP (Jackson and Harington, 1991; Matthews et al., 1990). The Pelly Mountains acted as a regional divide for the northern sector of the Cordilleran Ice Sheet, supporting numerous divides and ice-cap complexes that shed ice north-northeast to the Selwyn Lobe, and south-southwest to the Cassiar Lobe. It is likely that an ice divide or ice cap existed near the current hydrological divide at the headwaters of Seagull Creek. Ice sheet thickness in this region never greatly exceeded relief and the radial flow from the Pelly Mountain ice complexes remained topographically controlled throughout the McConnell Glaciation (Jackson, 1994).

Deglaciation of the Pelly Mountains likely began by a rapid rise in the equilibrium-line altitude causing thinner ice in high mountains and cirques to stagnate and melt before the thick accumulations in adjacent valleys (Jackson, 1994). This pattern of downwasting and stagnation is common in much of the Cordillera and is responsible for blockages to down-valley drainage and extensive ice-stagnation landforms in cirques and valley bottoms (Fulton, 1991). Deglaciation of the Pelly Mountains was complete by around 10 ka BP (Jackson, 1994).

Late-glacial readvances in Yukon are evidenced primarily by depositional and erosional landforms indicative of ice surface gradients and flow directions. Up-valley ice flows have been documented in many areas of central Yukon. In the Anvil Range district, Bond (1999) used flights of valley-bottom kame terraces and laterally continuous meltwater channels and moraines to provide evidence of invading ice fronts from down-valley sources. Closer to Seagull Creek valley, at the confluence of the Lapie and Pelly rivers, Plouffe and Jackson (1992) supplemented geomorphic evidence with detailed till fabrics and erratic tracing to infer a late-glacial readvance of the Selwyn Lobe up-gradient into the Lapie River valley. Current work by the authors in the Wheaton and Watson river valleys near Whitehorse has revealed a similar scenario for the coast mountain transitional zone. A six-phase model has been developed to explain the regional glacial dynamics of up-valley ice flow for mountainous regions (Fig. 2):

Stage 1: Onset of glaciation and the initial advance of ice from high-elevation accumulation zones.

Stage 2: Continued advance of ice out of the mountainous regions into low-lying plains.

Stage 3: Development of a regional ice sheet, marking glacial maximum.

Stage 4: Initial retreat of ice at the onset of deglaciation. The reduction in ice is most noticeable in the mountainous areas where ice was relatively thin.

Stage 5: Readvance of glaciers during a period of climatic deterioration. Ice sheets advance readily into the already deglaciated mountains. This allows for 'up-valley ice flow'.

Stage 6: Final ice retreat and the end of the glaciation.

EVIDENCE OF LATE GLACIAL READVANCE

Baseline information for interpreting glacial history in Yukon can be provided by reconnaissance-level surficial geological mapping and an understanding of the processes of deglaciation in the Cordillera. A 1:50 000-scale surficial mapping project of the Tay LP property was undertaken in the summer of 2003 to identify the most reliable areas for geochemical sampling. In general, colluviated bedrock and till above valley bottom stagnation landforms have short transport paths and are reliable sampling mediums for drift prospecting. The degree of transport in valley bottom sediments, however, is not as easily determined and can vary widely.

The evidence for a regionally sourced readvance in Seagull Creek valley consists primarily of lateral meltwater channels and depositional ice-stagnation features. Meltwater channels from the receding alpine glaciers are preserved by erosional troughs descending down-valley from north to south at elevations above 1350 m in upper Seagull Creek (Fig. 3). The longitudinal gradients of meltwater channels approximate that of the former ice-surface profile and are indicative of down-gradient ice flow (Ryder, 1994; Bennett and Glasser, 1996).

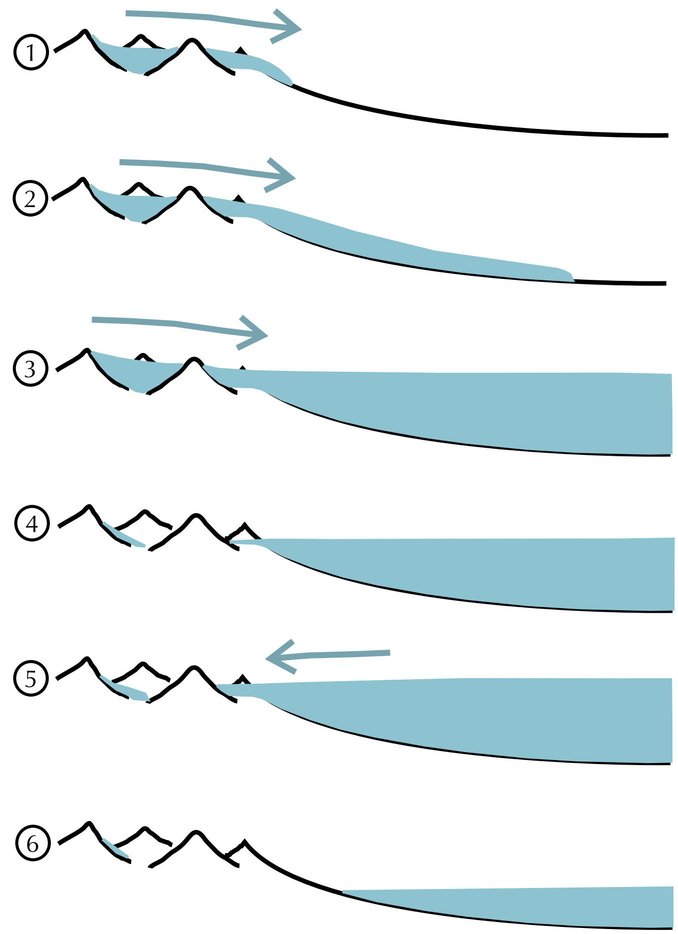

Figure 2. *A six-phase model is used to explain the regional glacial dynamics of up-valley ice flow for mountainous regions. Stage (1) is the onset of glaciation and initial ice advance from high elevations, (2) continued ice advance from mountains into low-lying plains, (3) glacial maximum and development of a regional ice sheet, (4) onset of deglaciation, initial retreat is most noticeable in high mountains where ice is thin, (5) climatic deterioration causes a readvance of the ice sheet into already deglaciated mountain valleys (up-valley ice flow), and (6) final ice retreat at the end of the glaciation.*

During retreat, while thick valley-bottom ice accumulations persisted to some extent, renewed nourishment of the Cassiar Lobe caused an expansion of the ice sheet margin and forced ice up-valley into the Pelly Mountains (Fig. 4). By contrast, local ice re-accumulation was limited in cirques of the Seagull Creek drainage. This apparent precipitation deficit in the Pelly Mountains may have been caused by the Cassiar Lobe intercepting moisture from Pacific air masses and thus enabling Cassiar ice to flow freely up the southward draining Pelly Mountain valleys.

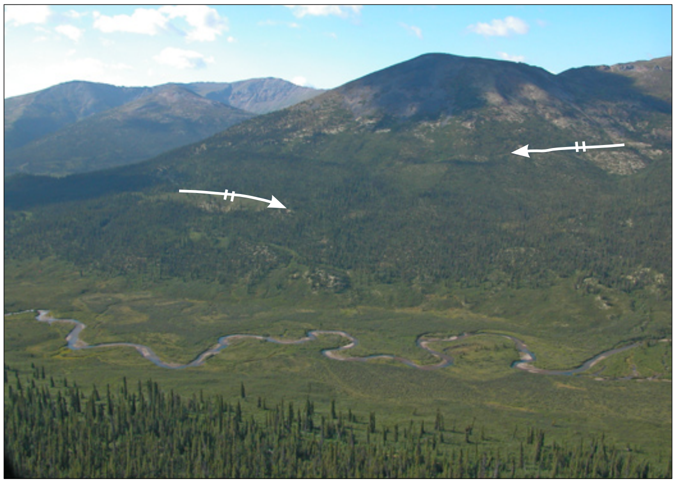

Figure 3. *Upper meltwater channels, descending from right (up-valley) to left (down-valley), preserve the profile of retreating alpine ice after glacial maximum. Lower meltwater channels, descending from left (down-valley) to right (up-valley), represent the ice surface profile during the Cassiar readvance.*

Previously stagnating ice tongues in the Rose, Seagull and McNeil valleys (Fig. 1) would have been reincorporated into the northward-advancing Cassiar valley glaciers. Ice flow advanced up to, and in places breached, alpine divides. In the study area, Cassiar ice reached its maximum limit at the south end of Seagull Lakes (Fig. 4). The northward ice movement is well documented by up-valley descending, lateral ice-marginal channels (Fig. 3) and the outlet channel at the Seagull Lakes divide. Similar meltwater channels were mapped in the Rose and McNeil drainages (Jackson, 1994) and include correlative ice-stagnation deposits in the low divides.

The recessional phase of the ice lobe is marked by periods of dynamic equilibrium between up-valley flow and ice-front ablation. This step-wise retreat is noted at a number of locations in the valley and best displayed at the kame deposit in Figures 5 and 6. The well developed

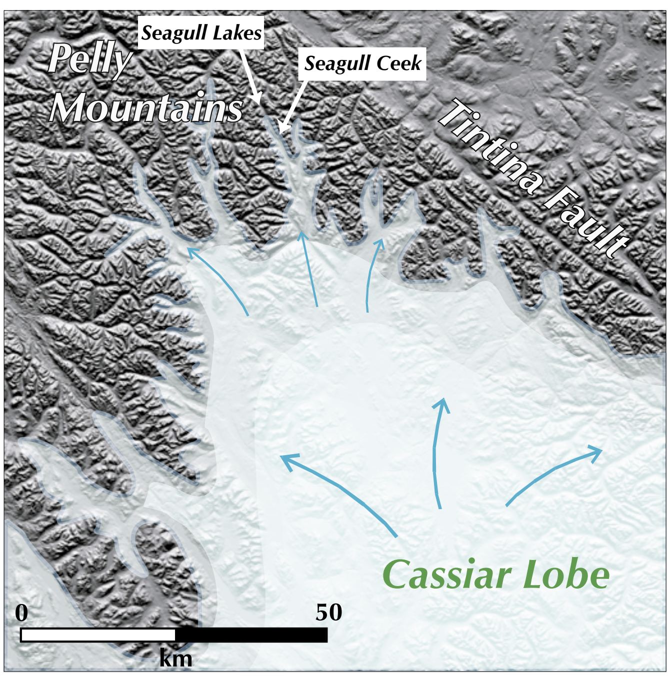

Figure 4. *Expansion of the Cassiar Lobe forced ice up-valley into the Pelly Mountains. Local alpine accumulations were not significant enough to interfere with the regional readvance. The Selwyn Lobe, located north of the Tintina Fault, is not shown in this diagram.*

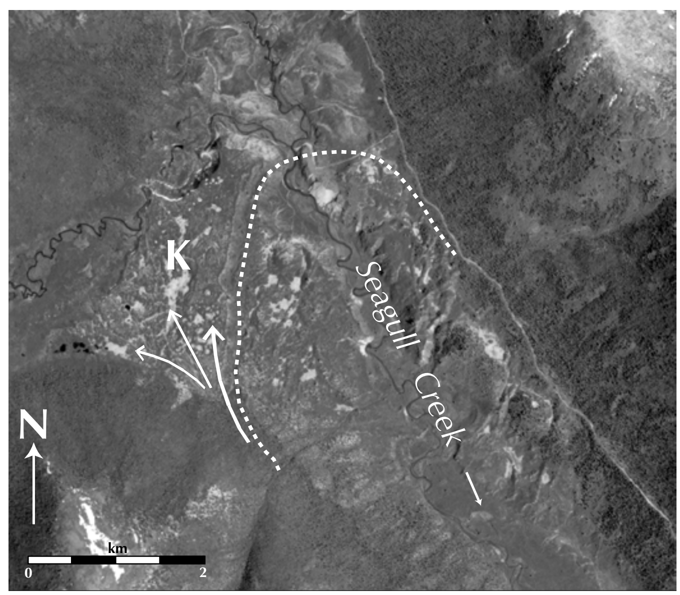

Figure 5. *An aerial view of the confluence of an unnamed tributary valley with Seagull Creek shows the former ice front (dashed line) preserved on the south side of the kame terrace (K). The shape of the ice front and the direction of meltwater flow over the kame (arrows) indicate up-valley flow. Seagull Creek is presently flowing south-southeast.*

Figure 6. *Nearly 50 m of glaciofluvial sand and gravel were deposited along the ice front (dashed line) during the recessional pause that created the kame terrace. View is down-valley toward the southeast.*

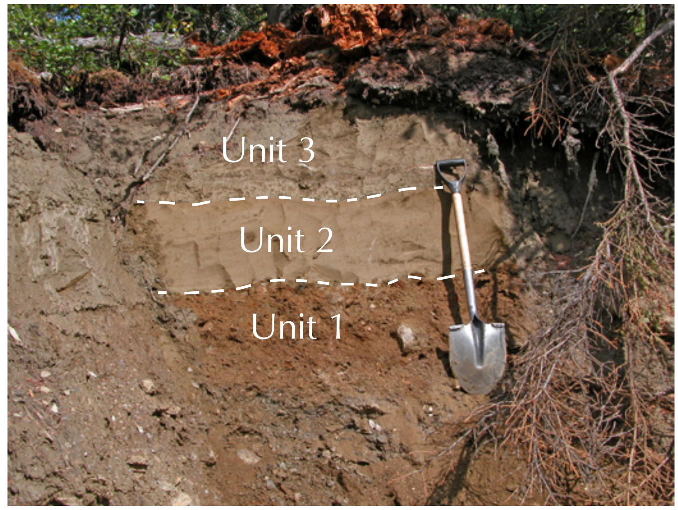

Figure 7. *The valley-bottom stratigraphy of the study area is well preserved in this hillslope section above the valley floor. Unit 1 is an angular, clast-dominated ablation till. Unit 2 is a medium-fine sand that grades upward into a thin (~ 5-10 cm) silty clay bed. This unit represents the short-lived lacustrine event between the kame and the southward-retreating ice front after maximum readvance into Seagull Creek. Unit 3 is composed of Holocene ash and colluviated hillslope sediments.*

morphology of this kame, and the associated deposition in the adjacent tributary valley, signifies a considerable standstill. The rapid rate of up-valley transport and sedimentation at this ice front is inferred by nearly 50 m of stratified coarse sand and gravel exposed in section on Seagull Creek (Fig. 6). Lateral extension of the kame sediment into a proglacial lake north of the ice front is suspected according to the elevation of the outlet channel near Seagull Lakes. However, there is very little evidence of glaciolacustrine sedimentation preserved north of the kame deposit. This, and the lack of northward continuity of the kame front, suggests that deposition beyond the active ice front may have occurred onto buried or stagnating ice.

Following the deposition of the kame terrace, deterioration of valley ice was relatively rapid and characterized by stagnation and in-situ downwasting of the ice surface. Before southward drainage of Seagull Creek resumed, ponding of supra-glacial meltwater was limited and short-lived. Approximately 30 cm of a discontinuous sandy lacustrine unit overlies valley bottom sediments south of the kame terrace (Fig. 7). The extent of this glacial lake would have been restricted between the kame terrace to the north and the retreating ice front to the south. As the ice mass melted, down-valley drainage of Seagull Creek resumed, creating a series of paraglacial terraces below the kame, as sediment was reworked toward baselevel (Fig. 8).

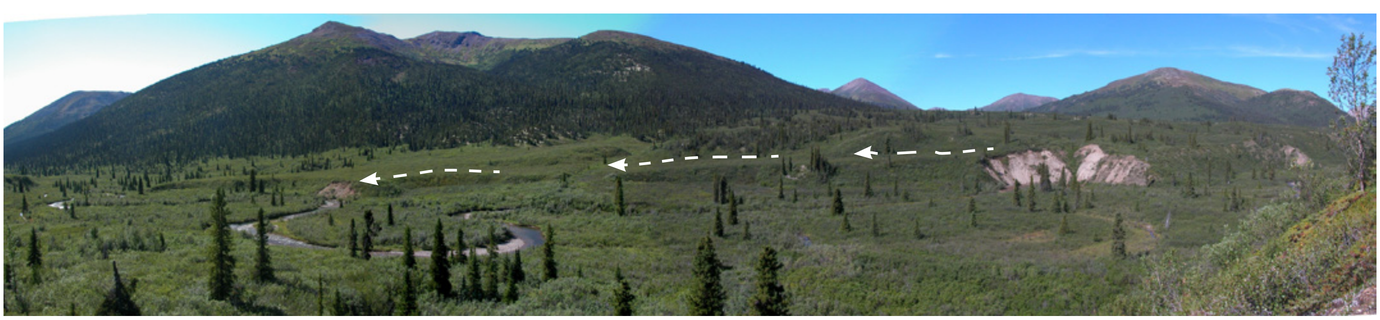

Figure 8. *The resumption of down-valley drainage in Seagull Creek created a series of downstream-descending paraglacial terraces (dashed line).*

IMPLICATIONS FOR DRIFT PROSPECTING

The ice-flow reversal and nature of sedimentation recorded in the Seagull Creek valley has profound implications for drift prospecting in the area. All previous studies assumed a dominantly down-valley ice flow in regard to the origin of mineralized float. Also, the ubiquity of glacio-fluvial sediments makes most soil survey techniques impractical. Down-valley of the kame deposit, where glacial drift is thick, care must be taken to sample from till that has a relatively high silt and clay fraction. This is best found at elevations above 1150 m and also at depth below ablation material in the valley bottom (Fig. 9).

The rapid stagnation of ice in Seagull Creek valley resulted in extensive and well-washed ablation till overlain by somewhat chaotic glaciofluvial deposits. Although ablation till is not ideal for geochemical analysis, it is a closer derivative of bedrock than glaciofluvial sediments and therefore can provide a more reliable geochemical signal. Till deposition in this region is relatively thin, and it is likely that a readvancing ice front from the Cassiar Lobe was able to remobilize the majority of valley bottom sediments and further eroded bedrock in Seagull Creek.

The spatial characteristics of a dispersal train in Seagull Creek may exhibit both down-valley and up-valley indicators depending on the degree of reworking by the later phase ice flow. A basic ribbon-shaped dispersal train would have developed during the onset of glaciation and glacial maximum conditions (d_1) when down-valley ice flow dominated (Fig. 10a). A reversal of ice movement (d_2) would have partly re-entrained the initial dispersion train and established a new up-valley-trending geochemical anomaly from the mineralized outcrop (Fig. 10b). This of course assumes the readvancing glacier erodes to and incorporates the mineralized bedrock. The length of transport associated with d_2 ice movement may be shorter due to a decrease in basal sliding associated with up-gradient ice flow. The remnant d_1 dispersion train will have a diluted geochemical signature.

__Figure 9.__ Approximately 13 m of basal till (Tb) is exposed in section below a glaciofluvial complex (Gx) of water-washed sand and gravel along a tributary to Seagull Creek (view is southeast).

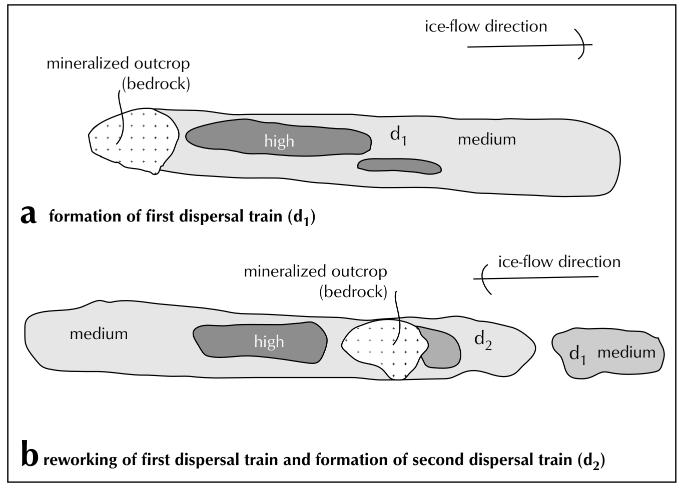

__Figure 10.__ Spatial characteristics of a dispersal train in Seagull Creek may exhibit both down-valley and up-valley indicators: __(a)__ down-valley ice flow and __(b)__ up-valley ice flow. High and medium indicate level of hypothetical geochemical concentration.

CONCLUSIONS

The distribution of sediments in Seagull Creek is determined primarily by late-glacial recessional processes. Therefore, geoscientists cannot rely on overly simplistic models of high-to-low elevation, down-valley ice flow when drift prospecting in high relief areas of Pelly Mountains. Future exploration should work with a deglacial model that incorporates the possibility of large magnitude late-glacial ice-flow reversals at the margins of the Cassiar ice lobe. Ice-flow directions near a receding ice margin can differ considerably from flow directions during earlier stages of a glaciation. Thus, investing the resources to properly interpret surficial landforms can aid in creating a sound till geochemistry program reflective of the most recent mechanism of glacial transport.

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Preliminary lithostratigraphy of the Laberge Group (Jurassic), south-central Yukon: Implications concerning the petroleum potential of the Whitehorse Trough

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ABSTRACT

The Whitehorse Trough, a Mesozoic sedimentary basin in south-central Yukon that has potential for gas and oil, consists of the Lewes River Group (Triassic), the Laberge Group (Jurassic), and the Tantalus Formation (Jura-Cretaceous). The Laberge Group in the Carmacks (115I) and Laberge (105E) map areas is subdivided into four informal lithostratigraphic units: the Richthofen, Tanglefoot, Conglomerate and Nordenskiold formations. The Richthofen formation, distinguished by siltstone to very fine sandstone and mudstone couplets, is exposed in the southern part of the Laberge map area where it rests unconformably to conformably on the Lewes River Group and is unconformably and/or conformably overlain by the Tanglefoot formation. The Tanglefoot formation, distinguished by coal-bearing, interbedded sandstone and mudstone, is exposed in the northern part of the Laberge map area and the southern part of the Carmacks map area where it rests unconformably on the Lewes River Group, and is overlain by the Tantalus Formation. The Conglomerate (conglomerate) and Nordenskiold (dacite tuff) formations occur as minor units within the Tanglefoot formation. The Richthofen-Tanglefoot formation unconformity and/or conformity is a potential petroleum play in the central Whitehorse Trough, whereas the Lewes River Group-Tanglefoot formation unconformity is a potential petroleum play in the northern Whitehorse Trough.

RÉSUMÉ

La cuvette de Whitehorse, bassin sédimentaire mésozoïque du centre-sud du Yukon ayant un potentiel en gaz et pétrole, se compose du Groupe de Lewes River (Trias), du Groupe de Laberge (Jurassique) et de la Formation de Tantalus (Jurassique-Crétacé). Dans les zones cartographiques de Carmacks (115I) et de Laberge (105E), le Groupe de Laberge est subdivisé en quatre unités lithostratigraphiques informelles : les formations de Richthofen, Tanglefoot, Conglomerate et Nordenskiold. La formation de Richthofen, qui se distingue par un siltstone passant à des couplets de grès très fin et de mudstone, est exposée dans la partie sud de la région cartographique de Laberge où elle repose en discordance sur le Groupe de Lewes River et est surmontée en discordance ou concordance par la formation de Tanglefoot. Cette dernière, qui se distingue par un grès et un mudstone interstratifiés houillers, est exposée dans le nord de la zone cartographique de Laberge et dans le sud de la zone cartographique de Carmacks où elle repose en discordance sur la Groupe de Lewes River et sous la Formation de Tantalus. Les formations de Conglomerate (conglomérat) et de Nordenskiold (tuf dacitique) forment des unités de moindre importance dans la formation de Tanglefoot. La discordance ou la concordance de la formation de Richthofen-Tanglefoot représente une zone pétrolière possible dans le centre de la cuvette de Whitehorse tandis que la discordance de Groupe de Lewes River – formation de Tanglefoot représente une zone pétrolière possible dans le nord de la cuvette de Whitehorse.

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INTRODUCTION

The Whitehorse Trough is a Mesozoic sedimentary basin that extends from just north of Carmacks, 650 km southward to Whitehorse and into northern British Columbia (Fig. 1). It is interpreted to have originated in Middle to Late Triassic time as a forearc basin, with the ancient North American margin on the east and the volcano-plutonic Stikinia arc on the west, undergoing oblique convergence (Tempelman-Kluit, 1979). The National Energy Board (2001) describes the Whitehorse Trough as an immature, mainly gas-prone basin in which potential source rocks (i.e., Triassic carbonates and Jurassic mudstones), reservoirs (i.e., Jurassic sandstones), seals (i.e., Jurassic mudstones) and traps (i.e., anticlines) have been identified. Koch (1973) estimates that 25 to 116 billion cubic metres (0.9 to 4.1 trillion cubic feet) of gas, and possibly some oil, occur within the basin. However, petroleum exploration is hampered by a poor understanding of the stratigraphy. Hence, the Yukon Geological Survey initiated a long-term study of the stratigraphy of the Whitehorse Trough, the aim of which is to better assess the hydrocarbon potential of this frontier basin. This report summarizes some of the results from the first field season of this study.

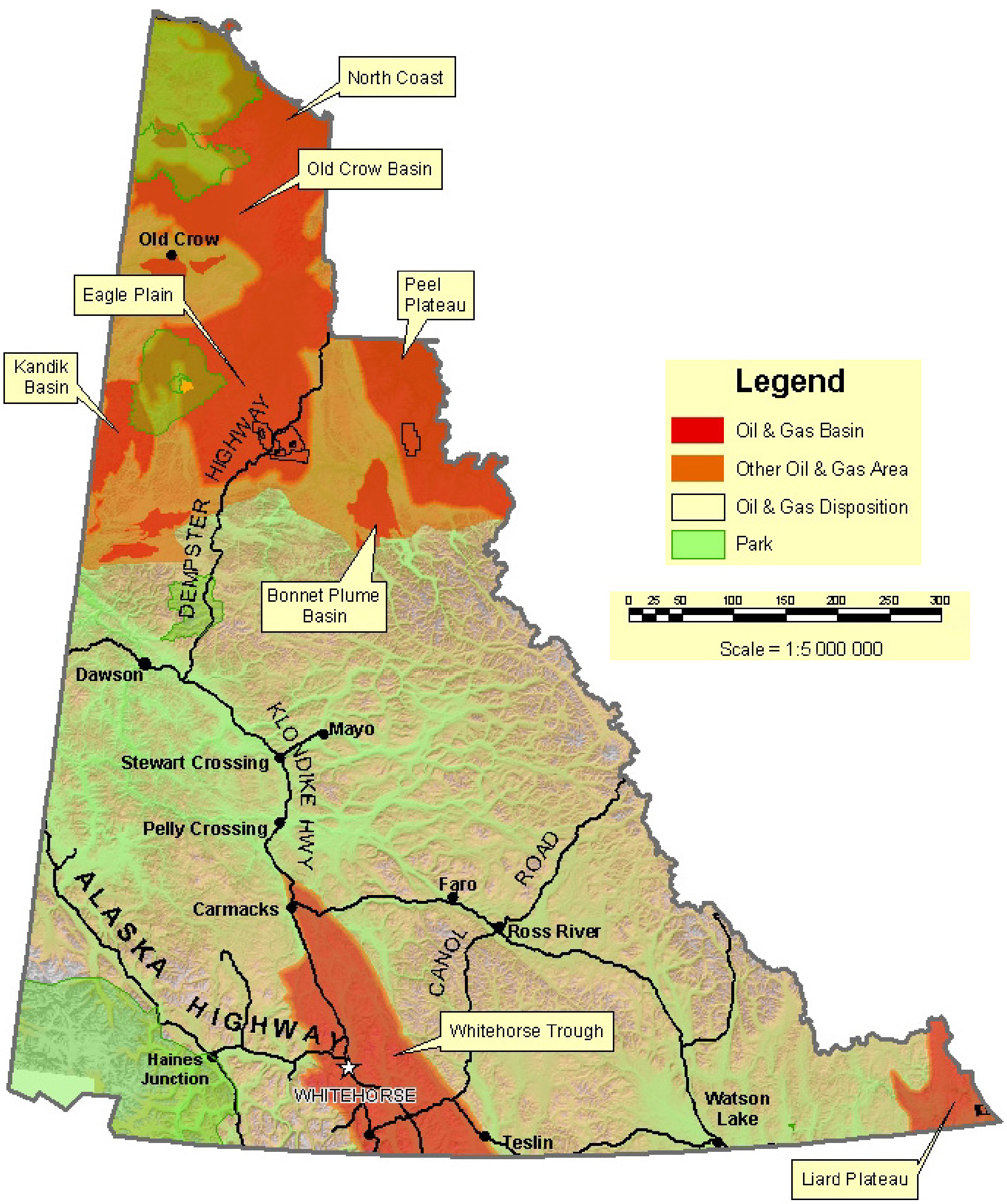

Figure 1. *Oil and gas basins in the Yukon showing the location of the Whitehorse Trough (Energy, Mines and Resources, August, 2002).*

PROBLEMS, PURPOSE AND PREVIOUS WORK

Wheeler (1961) proposed the name 'Whitehorse trough' and recognized three main stratigraphic units: 1) Triassic volcanic, volcaniclastic, siliciclastic and carbonate rocks of the Lewes River Group; 2) Jurassic siliciclastic rocks of the Laberge Group; and 3) Jura-Cretaceous siliciclastic rocks of the Tantalus Formation. Laberge strata were originally described by Cairnes (1910) in the Lewes and Nordenskiold coal district (Fig. 2); and Lees (1934), working in the Laberge map area, and Bostock (1936) working in the Carmacks map area, adopted this nomenclature. Bostock and Lees (1938) subsequently described the Nordenskiold unit as a lithostratigraphic unit, as did Wheeler (1961) for the Laberge unit. Souther (1971), working in the Tulsequah map area northern British Columbia, subdivided the Laberge Group into the relatively coarser-grained Takwahoni Formation and the relatively finer-grained Inklin Formation; and Tempelman-Kluit (1984), working in the Carmacks and Laberge map areas, subdivided the Laberge Group (from oldest to youngest) into the 'Richthofen Formation', 'Conglomerate Formation', 'Nordenskiold Dacite' and 'Tanglefoot Formation'. According to the North American Stratigraphic Code (North American Commission on Stratigraphic Nomenclature, 1983), the formations proposed by Tempelman-Kluit (1984) should be considered informal units and the term 'formation' not capitalized. This report follows the guidelines of the Code. In addition, the term 'Nordenskiold formation' proposed by Bostock and Lees (1938) is a more proper lithostratigraphic name than 'Nordenskiold Dacite' proposed by Templeman-Kluit (1984); hence this report uses Nordenskiold formation. The purpose of this paper is to properly define the units of the Laberge Group in the Carmacks (115I) and Laberge (105E) map areas of south-central Yukon as lithostratigraphic units.

Previous reports discussing the stratigraphy of the Laberge Group in the Carmacks (115I) and Laberge (105E) map areas include Cairnes (1910), Lees (1934), Bostock (1936), Bostock and Lees (1938), Tempelman-Kluit (1974, 1975, 1978, 1980, 1984), Lowey and Hills (1988), Dickie (1989), Dickie and Hein (1988, 1992, 1995), and Allen (2000). Campbell (1967) briefly mentioned the stratigraphy of the Laberge Group in the Glenlyon (105L) map area. Previous

N Carmacks	Laberge	Whitehorse	Tulsequah S
--------- (Cairnes, 1910) -------------- Laberge series Nordenskiold dacites			
	(Lees, 1934) Laberge series Nordenskiold dacites		
(Bostock, 1936) Laberge series			
--------- (Bostock and Lees, 1938) --------- Nordenskiold formation Laberge series			
		(Wheeler, 1961) Laberge group	
			(Souther, 1971) Laberge Group Takwahoni Formation Inklin Formation
--------- (Tempelman-Kluit, 1984) ----- Laberge Group Tanglefoot Formation Conglomerate Formation Nordenskiold Dacite Richthofen Formation			

Figure 2. *History of stratigraphic nomenclature of the Laberge Group.*

reports discussing the stratigraphy of the Laberge Group in the Whitehorse (105D) map area include Cockfield and Bell (1926, 1944), Wheeler (1961), Dickie (1990), Dickie and Hein (1988, 1992, 1995), Hart and Pelletier (1989), Hart and Radloff (1990), Hart and Brent (1993), Hart and Hunt (1994, 1995), and Hart (1997), whereas Palfy and Hart (1995), Clapham (2000), and Clapham et al. (2002) discuss the biostratigraphy. Previous reports discussing the lithostratigraphy of the Laberge Group in northern British Columbia include Souther (1971), Bultman (1979) and Mihalynuk (1999), whereas Smith et al. (1988), Johannson (1993, 1994) and Johannson et al. (1997) discuss the biostratigraphy. In addition, the Yukon Geological Survey has an unpublished manuscript by D.J. Tempelman-Kluit describing the geology of the Carmacks and Laberge map areas, including the stratigraphy of the Laberge Group, made available from the Geological Survey of Canada.

SUSPECT STRATIGRAPHY

The stratigraphy of the Laberge Group is suspect because published reports (e.g., Hart, 1997; Mihalynuk, 1999; Tempelman-Kluit, 1978, 1984) refer to the formations comprising it as map, lithostratigraphic, and/or chronostratigraphic units. Tempelman-Kluit (1978) expressed difficulty in distinguishing the Lewes Group from the Laberge Group and apparently mapped 'individual conglomerate, sandstone, shale and limestone bodies by composition and texture'. Hart (1997, p. 23) used nomenclature for classes of stratigraphic units that is no longer accepted, and confused 'time-rock' (i.e., lithostratigraphic) and time-stratigraphic (i.e., chronostratigraphic) units. He stated "formations and members created by Tempelman-Kluit (1984) are largely facies-representative, and not time-stratigraphic units"(p. 23), and that formations and members "cross time-stratigraphic horizons and make the use of rock-stratigraphic units impractical"(p. 40). Mihalynuk (1999) described the Takwahoni and Inklin formations as lithostratigraphic units and then defined the units by age.

Furthermore, the current distribution of the mapped strata comprising the Laberge Group in the Yukon may partly be due to confusion over what these units are and to misidentified units; the thickness of the units is based mostly on calculations from a map and not from measured sections (e.g., Hart, 1997; Wheeler, 1961); and the age of the units is not the simple 'layer cake' geology as commonly portrayed. According to the North American Commission on Stratigraphic Nomenclature (1983, Article 22) a "lithostratigraphic unit is a defined body of sedimentary, extrusive igneous, metasedimentary, or metavolcanic strata distinguished and delimited on the basis of lithic characteristics and stratigraphic position." Furthermore, lithostratigraphic units are not defined on the basis of age, inferred geologic history, depositional environment or fossil zones; they generally cut across time horizons (i.e., they are diachronous), and any particular formation may be a different age in a different area (Schoch, 1989). Lithostratigraphic units are important because several mineral deposits, such as placer gold and base metal sedimentary exhalative (SEDEX) deposits, and of course hydrocarbon deposits, are commonly facies controlled, particularly in siliciclastic sedimentary rocks. Hence, in the search for petroleum, lithostratigraphic units such as sandstone are of interest because they may be potential reservoirs for oil and gas.

REVISED STRATIGRAPHY

LITHIC CHARACTERISTICS

Richthofen formation

No type section, or stratotype, for the Richthofen formation has been described, but Tempelman-Kluit suggested that the type area is the west shore of Lake Laberge (Fig. 3). The Richthofen formation is described as 'silty shale' (Fig. 4) and apparently all mappable shale, regardless of stratigraphic position was included in this unit (Tempelman-Kluit, 1984). However, rocks exposed in

Figure 3. *Type area for the Richthofen formation, west shore of Lake Labege (view looking north).*

Figure 4. *Typical exposure of the Richthofen formation along Lake Laberge (rock hammer, circled, for scale).*

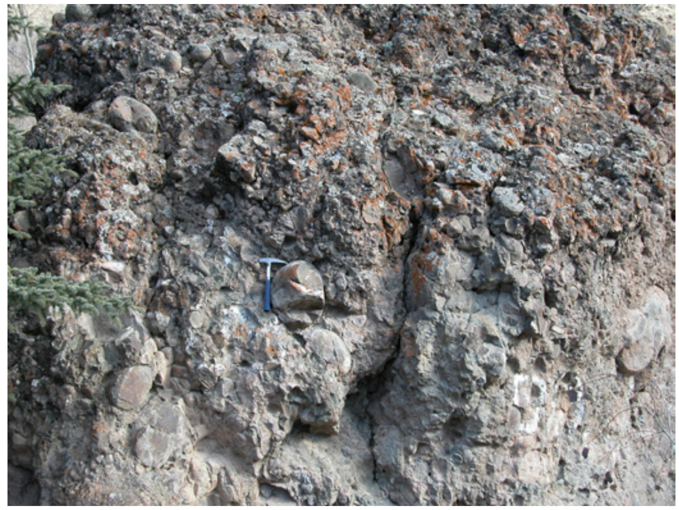

Figure 6. *Typical exposure of the Conglomerate formation at Conglomerate Mountain (rock hammer for scale).*

the type area are more properly described as a succession of graded siltstone to very fine-grained sandstone and mudstone couplets, or thin-bedded turbidites. Also occurring in the Richthofen formation and associated with these couplets are conglomerate, pebbly sandstone, sandstone, volcaniclastic rocks, pelagic fauna and relatively deep-water trace fossils such as *Zoophycos*. Lithologically then, the Richthofen formation is distinguished by siltstone-sandstone and mudstone couplets.

Conglomerate formation

No stratotype for the Conglomerate formation has been described but Tempelman-Kluit indicated the type area is Conglomerate Mountain north of Lake Laberge (Fig. 5). The Conglomerate formation is described as framework- to matrix-supported conglomerate (Fig. 6), and apparently all mappable conglomerate, regardless of stratigraphic position, was included in this unit (Tempelman-Kluit, 1984). Also occurring in the Conglomerate formation are pebbly sandstone and sandstone. Lithologically though, the Conglomerate formation cannot be distinguished by conglomerate because this rock type also occurs in other formations. Therefore, the stratigraphic position of conglomerate must be determined before it can be assigned to a formation.

Figure 5. *Type area for the Conglomerate formation, Conglomerate Mountain north of Lake Laberge.*

Nordenskiold formation

No stratotype for the Nordenskiold formation has been described, but Tempelman-Kluit suggested that the type area is the valley of the Nordenskiold River near Montague Mountain and Conglomerate Mountain north of Lake Laberge (Fig. 7). The Nordenskiold formation is described as massive dacite tuff (Fig. 8), and apparently all tuff was included in this unit (Tempelman-Kluit, 1984). Also occurring in the Nordenskiold formation are well preserved crystal tuffs. Lithologically though, the Nordenskiold formation cannot be distinguished by tuff because this rock type also occurs in other formations. Therefore, the stratigraphic position of tuff must be determined before it can be assigned to a formation.

Figure 7. *Type area for the Nordenskiold formation, valley of the Nordenskiold River near Montague Mountain and Conglomerate Mountain north of Lake Laberge.*

Figure 9. *Type area for the Tanglefoot formation, Tanglefoot Mountain (on left foreground) north of Lake Laberge and east of Chain Lakes.*

Figure 8. *Typical exposure of the Nordenskiold formation at Montague Mountain.*

Figure 10. *Typical exposure of the Tanglefoot formation, Robert Campbell Highway east of Carmacks (Jacob's staff is 1.5 m long).*

Tanglefoot formation

No stratotype for the Tanglefoot formation has been described but Tempelman-Kluit suggested the type area is Tanglefoot Mountain, north of Lake Laberge and just west of Chain Lakes (Fig. 9). The Tanglefoot formation is described as arkose and feldspathic sandstone (Fig. 10), and apparently all mappable sandstone regardless of stratigraphic position was included in this unit (Tempelman-Kluit, 1984). However, based on this study, the Tanglefoot formation is characterized by interbedded sandstone and mudstone. Also occurring in the Tanglefoot formation and associated with the interbedded sandstone and mudstone are conglomerate, pebbly sandstone, volcaniclastic rocks, coal, abundant terrestrial plant fossils and marginal marine fossils. Lithologically then, the Tanglefoot formation is distinguished by coal-bearing interbedded sandstone and mudstone.

DISTRIBUTION

Five Finger Rapids

Tempelman-Kluit (1984) mapped a thin band of Richthofen formation and Conglomerate formation at Five Finger Rapids, 20 km north of Carmacks (Fig. 11). However, the shale mapped as 'Richthofen formation' is a carbonaceous sequence of mudstone with carbonate concretions (Fig. 12), and not the siltstone-sandstone and mudstone couplets characteristic of the Richthofen formation; whereas the conglomerate mapped as the 'Conglomerate formation' is a sequence of coal-bearing conglomerate, pebbly sandstone, sandstone and mudstone (Fig. 13). In addition, immediately up-river from Five Finger Rapids is the historic Five Finger coal mine, in

Figure 12. *Tanglefoot formation mudstone at Five Finger Rapids incorrectly mapped as 'Richthofen formation' (carbonate concretions on right side of photograph are approximately 20 cm in diameter).*

Figure 11. *Part of the geologic map for the Carmacks map area (from Tempelman-Kluit, 1984).*

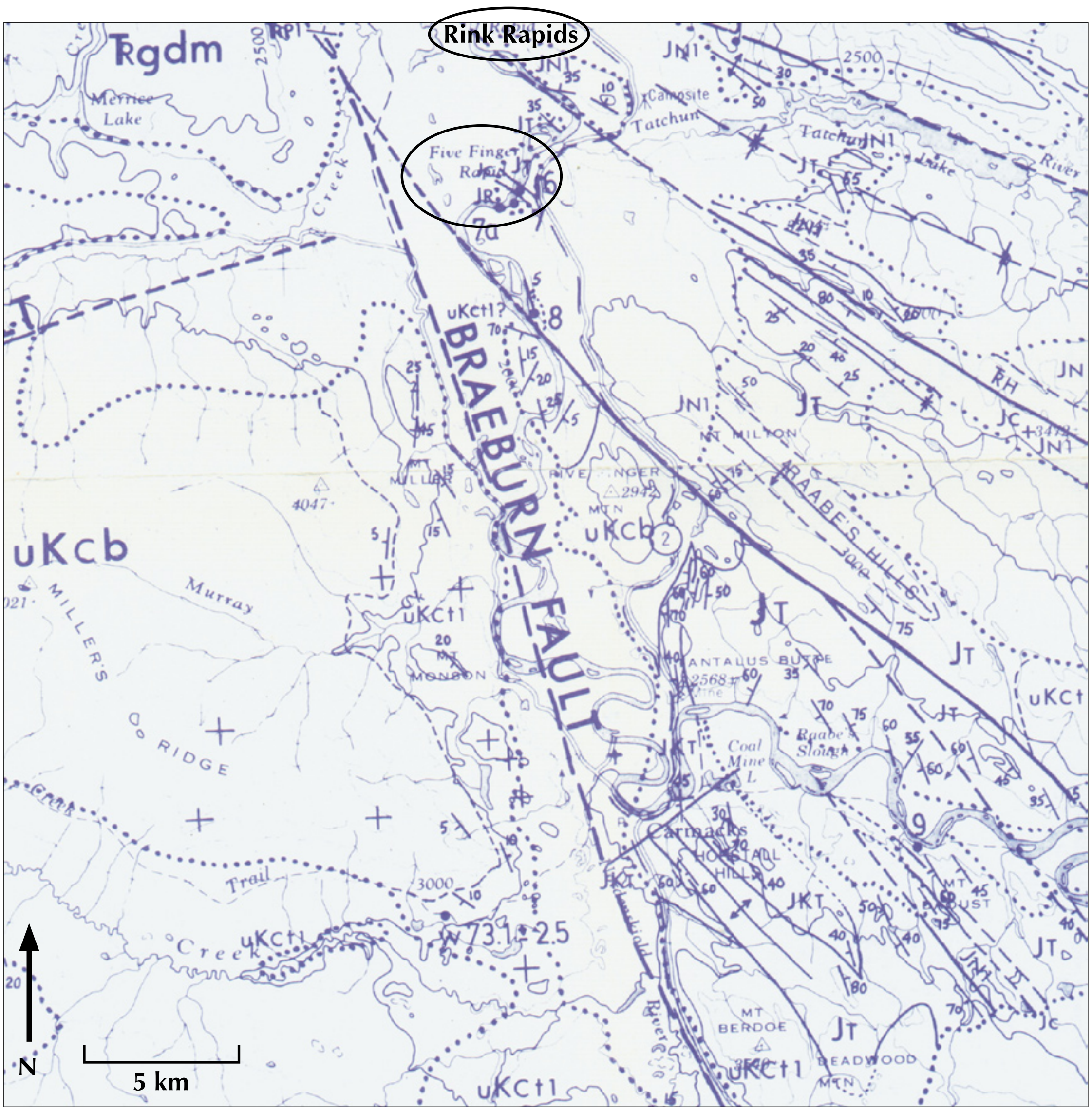

Figure 13. *Tanglefoot formation conglomerate at Five Finger Rapids incorrectly mapped as 'Conglomerate formation'.*

Figure 15. *Tanglefoot formation interbedded conglomerate and sandstone near Eagle's Nest Bluff incorrectly mapped as the 'Conglomerate formation' (Jacob's staff is 1.5 m long).*

which coal was extracted from strata of the Laberge Group (Hunt, 1984; Deklerk, 2002). Hence, the entire section exposed at Five Finger Rapids belongs to the Tanglefoot formation.

Rink Rapids

The Nordenskiold formation was mapped by Tempelman-Kluit (1984) as outcropping along the Yukon River near Rink Rapids, 25 km north of Carmacks (Fig. 11). However, the tuff mapped as 'Nordenskiold Dacite' is a sequence of interbedded sandstone and mudstone (Fig. 14). Although several of the sandstone beds appear tuffaceous, carbonaceous laminae and terrestrial plant fossils are locally present. Therefore, this carbonaceous section of interbedded sandstone and mudstone is part of the Tanglefoot formation.

Figure 14. *Tanglefoot formation interbedded sandstone and mudstone at Rink Rapids incorrectly mapped as the 'Nordenskiold (Dacite) formation' (rock hammer for scale).*

Eagle's Nest Bluff

Tempelman-Kluit suggested that a section of conglomerate and sandstone unconformably overlying carbonates of the Lewes River Group near Eagle's Nest Bluff, 20 km east of Carmacks, are part of the Conglomerate formation. However, these rocks consist of a sequence of conglomerate, pebbly sandstone, sandstone and mudstone (Fig. 15). In addition, several of the lowermost sandstone beds are tuffaceous, terrestrial plant fossils and coal seams are present up section, the rocks display a consistent dip to the west, and they are mapped by Tempelman-Kluit (1984) as the Tanglefoot formation in the Carmacks map area (115I). Therefore, the section exposed near Eagle's Nest Bluff represents the basal part of the Tanglefoot formation.

Joe and 'Fossil' creeks

Tempelman-Kluit (1984) mapped sandstone and shale exposed along Joe and 'Fossil' creeks, 25 km northwest of the north end of Lake Laberge as the Richthofen formation (Fig. 16), and Allen (2000) also mapped the rocks along Joe Creek as the Richthofen formation. However, rocks exposed along these creeks consist of a succession of interbedded sandstone and mudstone that

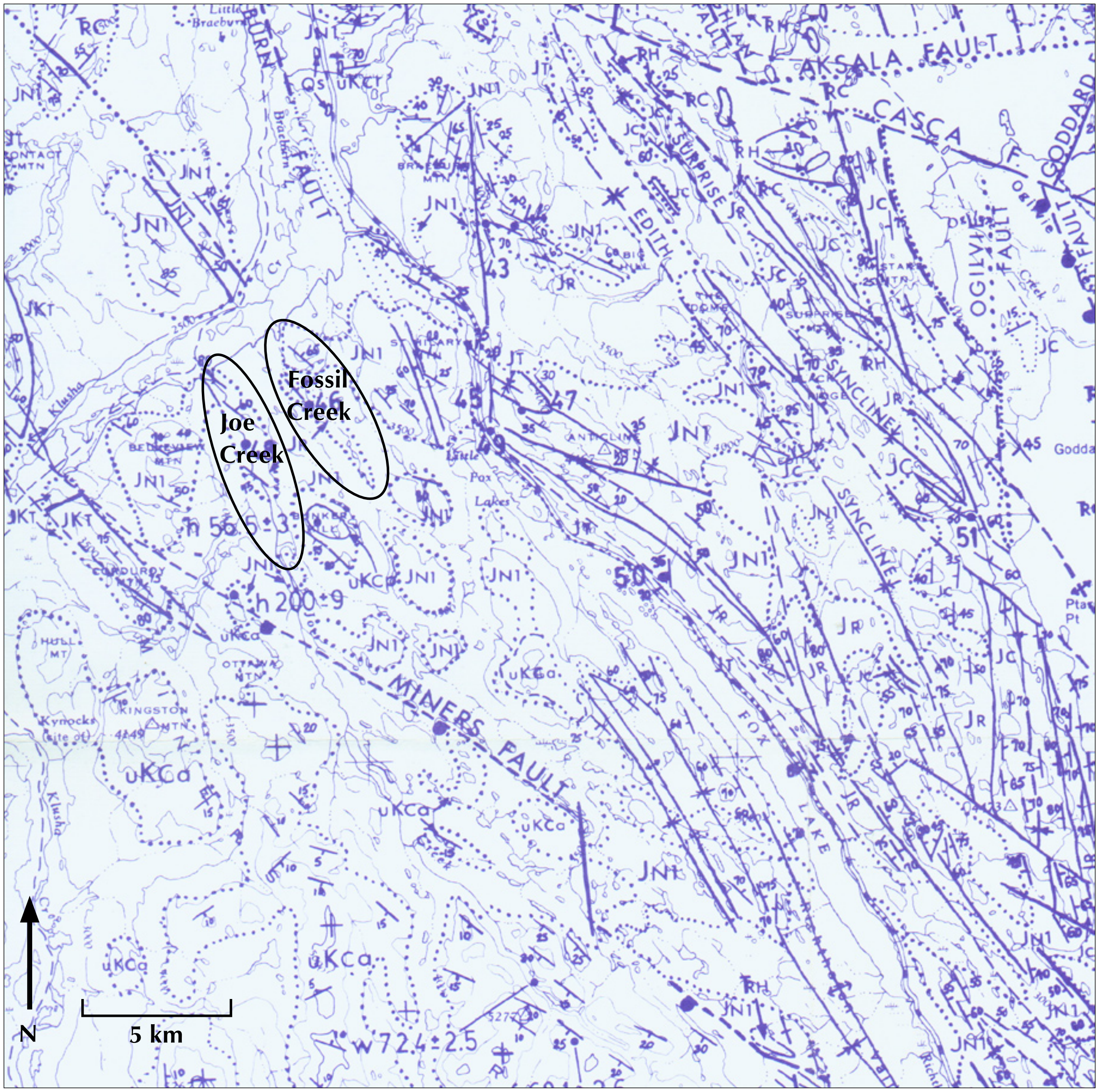

Figure 16. *Part of the geologic map for the Laberge map area (from Tempelman-Kluit, 1984).*

Figure 17. *Tanglefoot formation interbedded sandstone and mudstone at Joe Creek, incorrectly mapped as 'Richthofen formation' (sandstone beds are up to 1 m thick).*

contain thin coal seams and abundant terrestrial plant fossils (Fig. 17). Hence, these rocks belong to the Tanglefoot formation and not the Richthofen formation.

Therefore, either the Richthofen formation was completely removed by erosion in the northern part of the Laberge map area and the Carmacks map area, which seems unlikely, or the Richthofen formation was not deposited in this area, which is a more plausible interpretation. Also, most of the conglomerate now assigned to the Conglomerate formation and most of the tuff now assigned to the Nordenskiold formation can be reassigned to other formations (i.e., the Richthofen and Tanglefoot formations).

THICKNESS

Most of the stratal architecture of the Whitehorse Trough, including the Laberge Group, is based on Hart and Radloff (1996) and Hart (1997). However, the thicknesses they present are mainly estimates or calculations from a map and not from measured stratigraphic sections. Even the original work by Wheeler (1961) on the Whitehorse Trough is based on calculations from a map, and although this provides an initial framework, measured stratigraphic sections are required to properly determine the stratigraphy of the Laberge Group.

Although some sections have been measured, their location is poorly recorded, they may be 'composite' sections, or they may have been measured incorrectly. The section locations in Dickie (1989) are only to the nearest degree and several are erroneous (i.e., latitude and longitude coordinates do not correspond to NTS map numbers); and section 3 in Dickie (1989) was apparently measured from the base to the top of Conglomerate Mountain, but bedding consistently dips southward and so a properly measured section section would go from north to south across the mountain front.

REVISED AGE

Figure 18 is a plot of fossil ages for formations in the Laberge Group in the Carmacks and Laberge map areas based on Tempelman-Kluit (1984), showing a 'layer-cake' geology with the Richthofen formation ranging from Hettangian to Pliensbachian in age, the Conglomerate and Nordenskiold formations ranging from Sinemurian to Toarcian in age, and the Tanglefoot formation ranging from Toarcian to Bajocian in age. Figure 19 is a revised plot of the same fossil ages based on reassigning misidentified units to other formations. Note that the Richthofen and Tanglefoot formations span almost the same age — since these formations represent the same basin fill, and possibly, at least in part, a facies change — whereas the Conglomerate and Nordenskiold formations are now restricted in age.

IMPLICATIONS

The revised stratigraphic architecture of the Whitehorse Trough for the Carmacks and Laberge map areas is shown in Figure 20. Note that in the southern part of the Laberge map area, the Richthofen formation rests unconformably and/or conformably on the Lewes River Group, and it in turn is overlain unconformably and/or conformably by the Tanglefoot formation. In contrast, in the northern part of the Laberge map area and in the southern part of the Carmacks map area, the Tanglefoot formation rests unconformably on the Lewes River Group, and the Conglomerate and Nordenskiold formations occur as minor units — perhaps best described as members — within the Tanglefoot formation. Hence, this diagram shows the stratigraphic position of the formations of the Laberge Group, which can be used to delimit these lithostratigraphic units in the Carmacks and Laberge map areas. This revised lithostratigraphy has important implications in the search for gas and oil in the Whitehorse Trough.

An important process in the exploration for gas and oil is the definition of the 'play' and the mapping of its 'fairway'. A play is a group of related petroleum prospects or pools having similar geologic conditions of source rock, reservoir, seal and trap, and the fairway is the geographic distribution of these geologic controls (Allen and Allen, 1990; White, 1988). Although further work is required before play-fairway maps can be constructed for the Whitehorse Trough, the National Energy Board (2001) described eight conceptual plays (i.e., three gas with minor oil, and five solely gas). However, one of these plays (i.e., the Conglomerate-Richthofen stratigraphic conceptual gas and oil play) is based on the assumption that the Richthofen formation and Conglomerate formation interfinger, but this contact relationship probably does not occur in the Carmacks and Laberge map areas; and a second play (i.e., the Hancock-Conglomerate structural conceptual gas and oil play) only briefly mentions the Tanglefoot formation as a possible reservoir.

Based on the revised lithostratigraphy presented in this report, two new conceptual plays are possible.

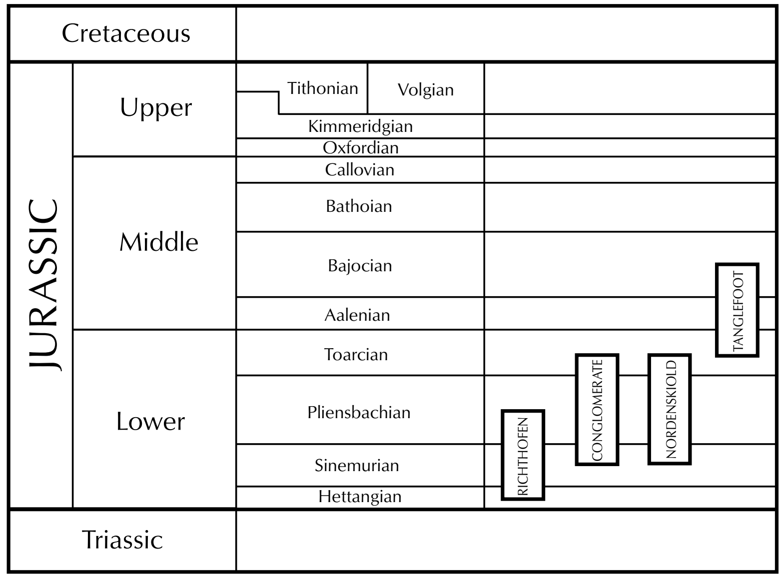

Figure 18. *Plot of fossil ages for the Laberge Group in the Carmacks and Laberge map areas (from Tempelman-Kluit, 1984; Jurassic time scale from Palfy et al., 2000).*

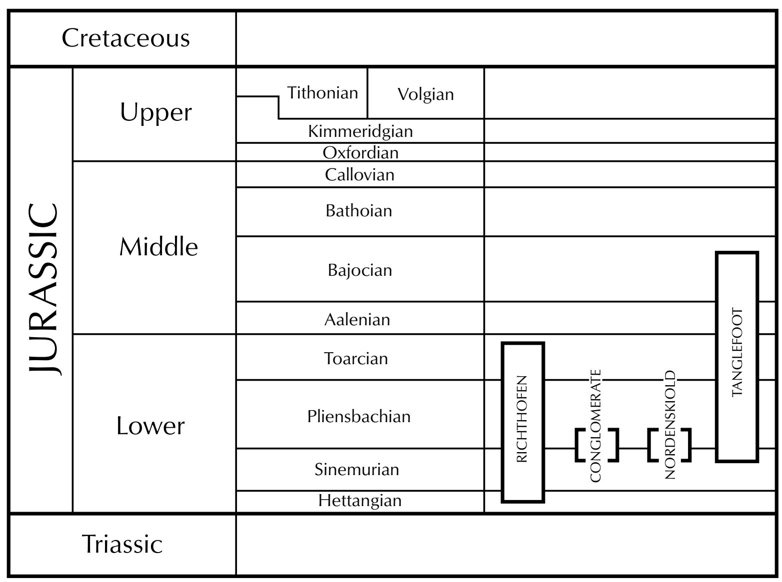

Figure 19. *Revised plot of fossil ages based on reassigning misidentified units to other formations (age chart from Palfy et al., 2000).*

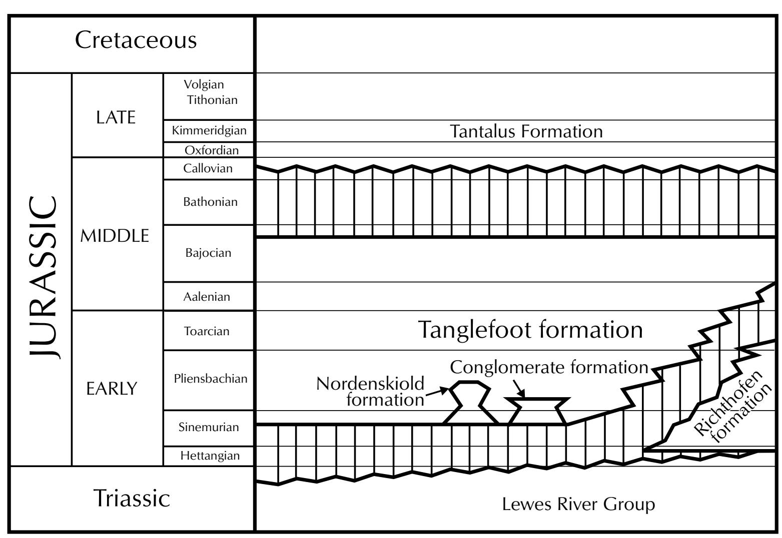

Figure 20. *Revised lithostratigraphy of the Laberge Group in the Carmacks and Laberge map areas (age chart from Palfy et al., 2000). Vertical bars indicate a period of non-deposition.*

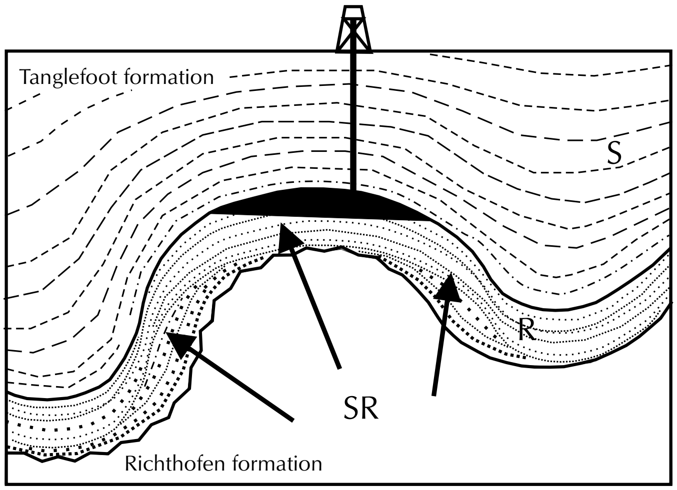

Figure 21. *Conceptual petroleum play #1, southern part of the map areas (R=reservoir, S=seal, SR=source rock).*

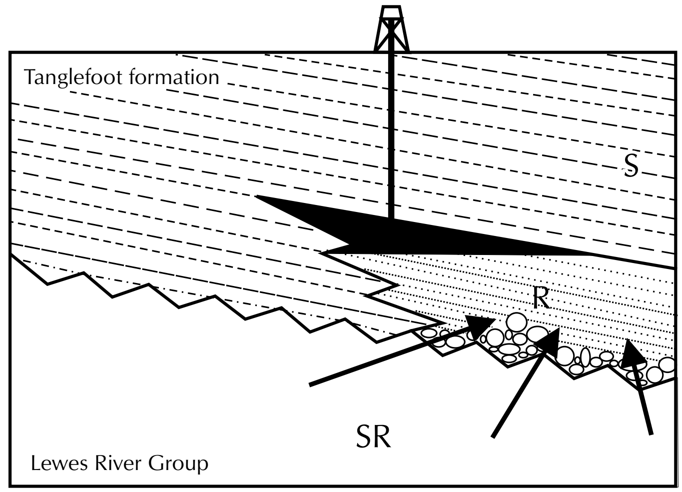

Figure 22. *Conceptual petroleum play #2, northern part of the map areas (R=reservoir, S=seal, SR=source rock).*

Figure 21 is a conceptual petroleum play developed for the Richthofen formation-Tanglefoot formation unconformity and/or facies change. This play requires the primary migration of petroleum from source rocks of Richthofen formation siltstone-sandstone and mudstone couplets, and accumulation in reservoirs of Tanglefoot formation sandstone. Regional topseals (or cap rock) of Tanglefoot formation mudstone would prevent further migration of petroleum with trapping in structural anticlines. The play is restricted to the southern part of the Laberge map area. Figure 22 is a conceptual petroleum play developed for the Lewes River Group-Tanglefoot formation unconformity, assuming that the Richthofen formation was not deposited in the northern part of the map areas. This play requires the primary migration of petroleum from source rocks of Lewes River Group carbonates, and accumulation in reservoirs of Tanglefoot formation sandstone. Regional topseals of Tanglefoot formation mudstones would prevent further migration of petroleum with stratigraphic trapping in pinchouts. The play is restricted to the northern part of the Laberge map area and the southern part of the Carmacks map area (i.e., the northernmost part of the Whitehorse Trough).

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The Early Tertiary Sifton Range volcanic complex, southwestern Yukon

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ABSTRACT

The early Tertiary magmatic episode in the northern Canadian Cordillera is linked to the restructuring of the Kula-North American plate system from orthogonal to oblique convergence. Resultant volcanism was widespread, and remnant successions outcrop along the eastern margin of the Coast Plutonic Complex (CPC). The Sifton Range volcanic complex of southwestern Yukon is a member of the Paleogene Sloko-Skukum Group, and comprises a 900-m thick, shallow-dipping, volcanic succession dominated by intermediate to evolved lava and pyroclastic rocks deposited in a northwesterly trending half-graben. Locally, the volcanic sequence is intruded by alkali-feldspar granites of the CPC's Nisling Plutonic Suite dated at 57.5 Ma. Felsite sills radiate from the main intrusive body, and together with numerous basaltic to dacitic dykes traverse the volcanic package. Both the felsic volcanic rocks and epizonal granitoids exhibit anomalous enrichments in large-ion lithophile elements indicating crustal contributions during the late-stage petrogenesis of the complex. In addition, the Sifton Range intrusive rocks exhibit modal mineralogy reflective of lower ambient pressures relative to the compositionally similar Annie Ned granites along the Alaska Highway between Stony Creek and Mendenhall, 20 km south of the complex. The amount of post-Eocene uplift (ca. 30 m/Ma) that exposed the contact between the intrusive and corresponding volcanic rocks is constrained by the presence of a calc-silicate bed at an elevation of 1830 m within the upper volcanic stratigraphy.

RÉSUMÉ

Le changement d'orientation des plaques Kula-Nord américaine, passant d'un système orthogonal à oblique, est responsable de l'épisode magmatique du début du Tertiaire dans le nord de la Cordillère canadienne. Cet épisode est associé à du volcanisme largement étendu, et les successions volcaniques préservées affleurent tout au long de la bordure Est du Domaine Côtier Plutonique (DCP). Le complexe magmatique de Sifton Range situé dans le sud-ouest du Yukon constitue le centre volcanique du groupe Sloko-Skukum du Paléogène. Les dépôts volcaniques du Sifton Range sont situés dans un hémi-graben d'orientation Nord-Ouest et forment une succession de 900 m d'épaisseur faiblement inclinée. La succession est dominée par des laves et des dépôts pyroclastiques de compositions intermédiaires à évoluées. La section volcanique est recoupée par des granites à feldspath alcalin appartenant à l'intrusion Nisling du DCP (57.5 Ma). Des sills felsiques se propagent du centre intrusif principal et, tout comme plusieurs dykes basaltiques et dacitiques, coupent les dépôts volcaniques. Les similitudes géochimiques entre la succession volcanique felsique et les granitoïdes epizonaux sont interprétées comme le résultat d'un système magmatique riche en silice remplie périodiquement. Les roches intrusives du Sifton Range sont caractérisées par une minéralogie modale indiquant de basses pression ambiantes par rapport aux granites Annie Ned de composition similaire, exposées le long de l'autoroute d'Alaska entre Stony Creek et Mendenhall à 20 km au sud du complexe. La quantité de soulèvement post-Eocène (ca 30 m/Ma) qui a exposé le contact entre les roches intrusives et les roches volcaniques associées est contrainte par la présence d'un lit de marbre à 1830 m d'altitude à l'intérieur de la stratigraphie volcanique supérieure.

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INTRODUCTION

Despite numerous studies of continental calc-alkaline volcanic sequences and subduction-related granitoid plutons, few studies have addressed the relationships between the two. This lacuna is partly a problem of exposure because where intrusive rocks outcrop, the associated volcanic suite is commonly lost to erosion, whereas preserved volcanic remnants tend to conceal their intrusive component. However, in the Sifton Ranges of the eastern Coast Plutonic Complex (CPC) of southwestern Yukon, an uplifted batholith is in direct contact with its contemporaneous volcanic equivalents, thus representing an exceptional natural setting for such an integrated study (Fig. 1). This paper reports the initial results of a study of the Sifton Range volcanic complex (SRVC), located at 61°00' N 136°10' W, 75 km northwest of Whitehorse, Yukon (Fig. 2).

Regional mapping by Kindle (1953), Tempelman-Kluit (1974) and Wheeler and McFeely (1991) had variously assigned the Sifton volcanic package to the Triassic Mush Lake Group, the compositionally similar Mount Nansen felsic volcanics, and the Upper Cretaceous Carmacks Group, respectively. Following a reconnaissance survey by D. Francis and C. Hart in 1995, the calc-alkaline character of the complex was established, and equivalence to the Sloko-Skukum volcanics was proposed.

Here we report the results of detailed geological mapping and sampling conducted within the Sifton Range complex, and along a traverse across the Annie Ned pluton that outcrops by the side of the Alaska Highway between Stony Creek and Mendenhall (southeastern corner of Aishihik (115H), and northeastern corner of Dezadeash (115A) map areas). The 2002 and 2003 field seasons involved documentation of volcanic stratigraphy and collection of over 150 specimens for the purpose of petrographic, geochemical and geochronological analyses.

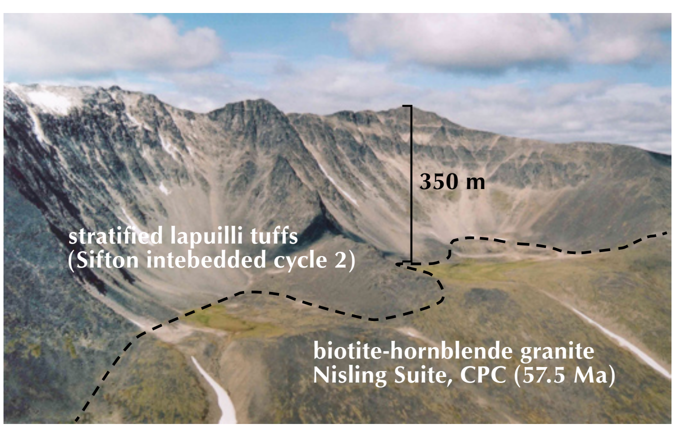


Figure 1. *Granite of the Nisling Plutonic Suite forms the base of two cirques in the western Sifton Ranges (location in Figure 2). The intruded coeval volcanic sequence consists of gently-dipping lapilli tuffs and volcanic breccias.*

GEOLOGICAL FRAMEWORK

With an axial length of 1800 km, the Coast Plutonic Complex (CPC) is the largest exposed continental-margin batholith in the world. It is a complex accumulation of orthogneisses, migmatites and I-type plutons intruded along the western margin of the Intermontane Superterrane during Mesozoic and early Cenozoic times (Armstrong, 1988). The final phase of widespread plutonism within the CPC of the northern Canadian Cordillera occurred during the Early Tertiary (62 to 48 Ma). This magmatic episode is linked to a change in the motion of the Kula plate relative to the North American plate, from dominantly orthogonal to oblique subduction (Engebretson et al., 1985; Gabrielse et al., 1992). Contemporaneous uplift (ca. 5 to 30 km) and erosion exposed the plutons to increasing depths westward across the CPC, and resulted in a transition from the tonalites of Skagway (Alaska) through the central granodiorites of Summit Lake and Clifton (British Columbia), into subcircular alaskites and rhyolite stocks to the east (Barker, 1986).

Simultaneously with the plutonism, volcanic activity was pervasive, and remnant volcanic sequences outcrop along the length of the western Intermontane (Fig. 2). In southern Yukon, major Eocene volcanic complexes occur at Sekulmun Lake, Mount Skukum and Bennett Lake, and are all assigned to the Skukum Group (Wheeler, 1961), while in northern British Columbia, equivalent Eocene volcanic rocks occur south of Atlin Lake and are referred to as the Sloko Group (Aitken, 1959; Figure 2). Collectively, this episode of calc-alkaline volcanism is referred to as the Sloko epoch (Hart, 1995).

SIFTON RANGE VOLCANIC COMPLEX

Together with the Miners Range to the east and the Ruby Range to the west, the Sifton Range marks a physiographic transition from the high peaks of the Coast Mountains to the flat Kluane Plateau further north. At an average elevation of 1700 m, it is an area of rugged topography with numerous cliff-faces exceeding 300 m in height. Approximately three-quarters of the outcrops are above tree line, while the lowermost stratigraphy is discontinuously exposed along stream banks and bluffs. The principal structural feature of the Sifton Range volcanic complex (SRVC) is a west-northwesterly trending half-graben that resulted in a 10 km-long, linear juxtaposition of the Early Tertiary volcanic rocks with the Paleozoic basement southwest of the complex (Fig. 3). Large-scale normal and rotational (block) faulting locally created over 100-m offsets between corresponding volcanic units. The bulk of the SRVC is underlain by green, biotite-muscovite-quartz-feldspar schists, and felsic, chlorite-biotite orthogneisses assigned to pre-400-million-year-old Nisling Assemblage of the Yukon-Tanana Terrane (Tempelman-Kluit, 1974). The Early Jurassic Aishihik Suite granodiorites, and the Late Triassic, augite-phyric Povoas basalts comprise the basement below its western and easternmost sections, respectively.

The Sifton Range complex exhibits a striking complementary relationship between its volcanic and plutonic components. The volcanic rocks span a continuum from basaltic andesite to rhyolite, with the bulk of compositions being classified as dacites (Fig. 4). A decrease in abundance of more SiO_2-rich compositions is matched by simultaneous emergence of evolved pyroclastic rocks and granitic plutonism.

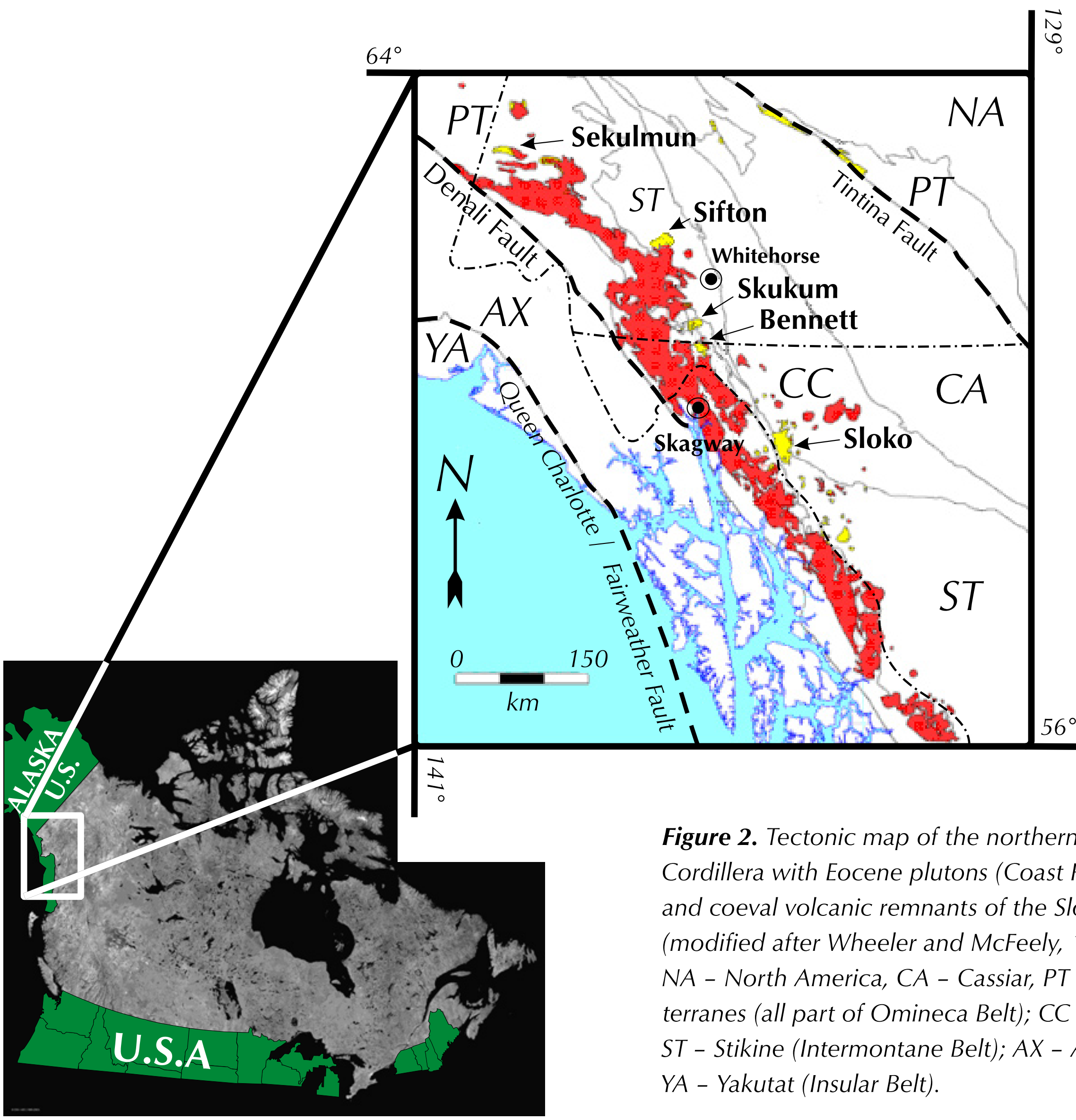


Figure 2. *Tectonic map of the northern Canadian Cordillera with Eocene plutons (Coast Plutonic Complex), and coeval volcanic remnants of the Sloko-Skukum Group (modified after Wheeler and McFeely, 1991). Terranes: NA – North America, CA – Cassiar, PT – pericratonic terranes (all part of Omineca Belt); CC – Cache Creek, ST – Stikine (Intermontane Belt); AX – Alexander and YA – Yakutat (Insular Belt).*

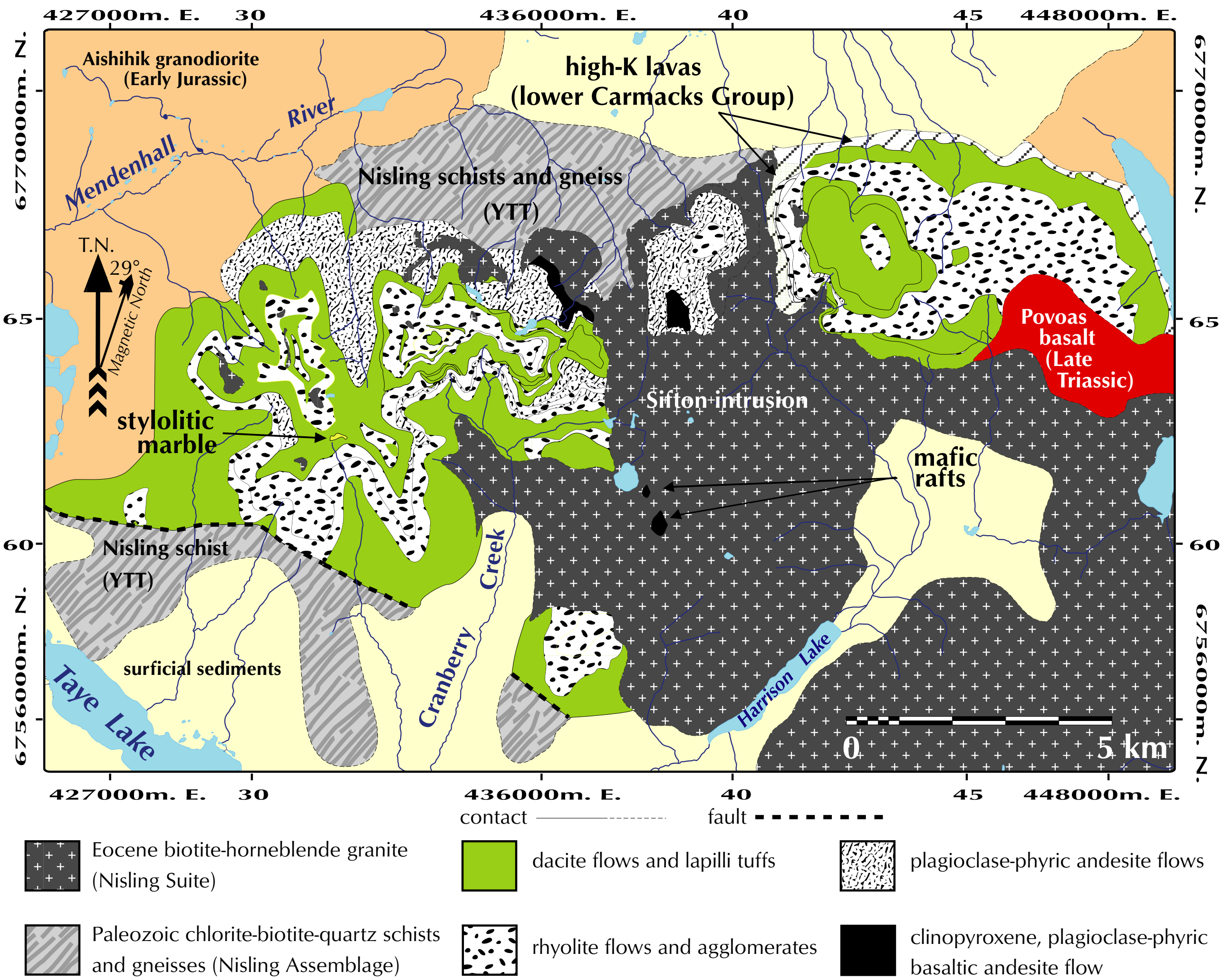


Figure 3. *Geological map of the Sifton Range volcanic complex, Yukon. The previously unrecognized shoshonitic lava rocks (lower Carmacks Group) underlie the northeastern part of the complex. Marble bed and mafic rafts exaggerated 30 times.*

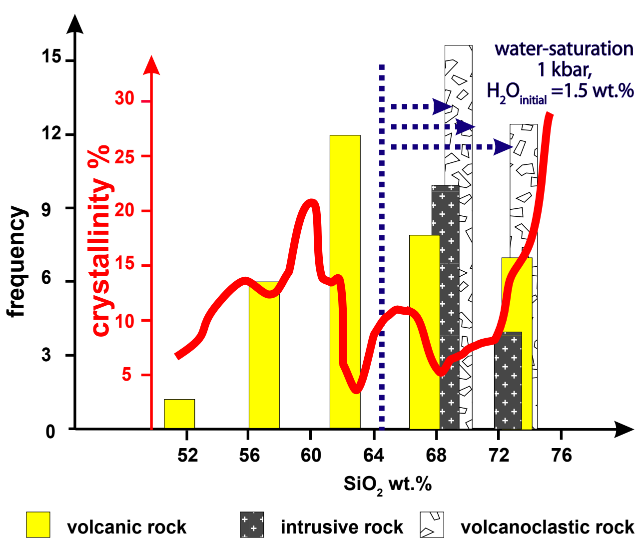


Figure 4. *Volumetric distribution of the Sifton volcanic rocks and measured lava phenocrysts as functions of the silica content. The distribution of erupted volcanic rock compositions varies as a function of magma viscosity (i.e., crystallinity), and roughly mirrors abundance of phenocrysts in the Sifton lava rocks. Fractional crystallization, modeled at the initial concentration of 1.5 wt. % and pressures of 1 kbar, predicts H_2O saturation at 65 wt. % SiO_2 – preceding the onset of rhyolitic pyroclastic rocks.*

VOLCANIC ROCKS

The Sifton lava and pyroclastic rocks comprise 40% of the Sifton complex by area (95 km^2), totaling 65 km^3 of preserved volcanic material. A central granitic plug separates the volcanic pile into larger, dominantly felsic segments to the east and west, while the relatively primitive lavas are exposed in the middle of the complex. The volcanic strata are gently inclined to the southwest (5-10°), however, the bedding attitudes change locally in the central part of the complex where the rocks dip to the northwest and northeast, away from the intruding granitoid stock. Overall, the Sifton volcanic rocks have experienced low-grade, post-depositional alteration characterized by zeolite and sub-greenschist mineralogies. Augite and hornblende phenocrysts have been replaced mostly by chlorite; plagioclase is saussuritized and partially replaced by secondary epidote, quartz and calcite. The phenocrysts and matrix mineralogies tend to be entirely obliterated along the margins of the pluton, and the rocks are locally hornfelsed.

The volcanic rocks were subdivided into lava flows, pyroclastic 'cooling units', and packages of polymictic breccias (agglomerates). Pyroclastic rocks of variable fragment size and crystallinity comprise 60% of the eruptive units. Three distinct volcanic sequences are recognized, from bottom to top: a) 1st Interbedded Unit, b) Middle Sequence, and c) 2nd Interbedded Unit (Fig. 5). The 1st Interbedded unit constitutes the lowermost 300 m of volcanic stratigraphy exposed on the southern and easternmost flanks of the complex. Due to restricted exposure, the true base of this unit is unknown. This sequence consists of thick (up to 20 m), massive, glassy, high-SiO_2 rhyolitic flows interstratified with dacitic and rhyolitic lapilli tuffs and breccias. Pyroclastic units are characterized by the following: homogeneous clast-size distributions (2 to 5 cm large lapilli fragments; volcanic bombs and breccia fragments, 10 to 20 cm in diameter), matrix-supported character, and monotonous chemical composition throughout the bed thickness. Coarser-grained volcanoclastic rocks near the base of the unit contain abundant fragments of the schist basement. A distinct sequence of high-potassium, shoshonitic lavas has been identified within the dataset in the lower part of the easterly volcanic succession (Fig. 3). These blue-weathering, exceptionally feldspar–phyric lavas may represent previously unrecognized outcrops of Lower Carmacks volcanics (Fig. 6), and as such, would contrast markedly with the less potassic character of the Carmacks-age volcanic rocks of the Miners Range just to the east.

The lavas of the Middle Sequence appear to represent a transition from explosive volcanism of the underlying 1st Interbedded cycle to more effusive volcanic activity. The sequence is 200 m thick and discontinuously exposed in the central, and the lowermost stratigraphy of the western part of the complex. It is composed of a succession of 5- to 10-m-thick, blue-weathering, sparsely plagioclase-phyric andesite flows overlain by dark grey augite- and plagioclase-phyric basaltic andesites, and the uppermost matrix-supported andesitic lapilli tuffs.

The 2nd Interbedded Unit consists of intermediate to felsic lava and pyroclastic rocks topping the volcanic column. It is the thickest stratigraphic subdivision, comprising over 550 m in stratigraphy in the western part of the complex. Overall, the unit is characterized by terraced outcrops formed by the presence of alternating resistant lava flows and recessive lapilli tuffs. The bottom 50 m of the sequence are dominated by 3- to 5-m-thick, high-SiO_2 rhyolite flows, with thin interbeds of green-weathering, epiclastic sandstone, and finely laminated ash tuffs (Fig. 7a). The overlying 150 m consists of columnar-jointed, porphyritic dacite and rhyolite flows that grade upward into dacitic volcanoclastic cooling units. The volcanoclastic rocks display lateral gradation from highly heterolithic volcanic breccias along the eastern and westernmost margins of the complex to thick lapilli tuffs, and variably welded ignimbrite sheets in the centre. Volcanic fragments spatially change from peripheral rhyolitic and andesitic volcanic bombs up to 50 cm in diameter (Fig. 7b, 7c) to central, 10-cm-long chloritized, eutaxitic fiammes, and angular lapilli fragments. In contrast to the compositionally homogeneous fragmental rocks of the 1st Interbedded Unit, the upper pyroclastic rocks exhibit zoning on a scale of individual cooling units, starting from coarse-grained, dominantly rhyolitic bottoms to matrix-dominated, dacitic tops. Thin rhyolite flows occur interstratified with breccias and lapilli tuffs within the uppermost 180 m of this sequence. A 4 m-thick, horizontal bed of white-weathering, coarsely crystalline dolomitic marble occurs 200 m below the top of the 2nd Interbedded Unit. This calc-silicate unit is characterized by prominent 1- to 3-mm-thick, sub-horizontal, wavy stylolites, anhedral dolomite crystals imbedded in calcite matrix, and the presence of sparse garnet and clinopyroxene.

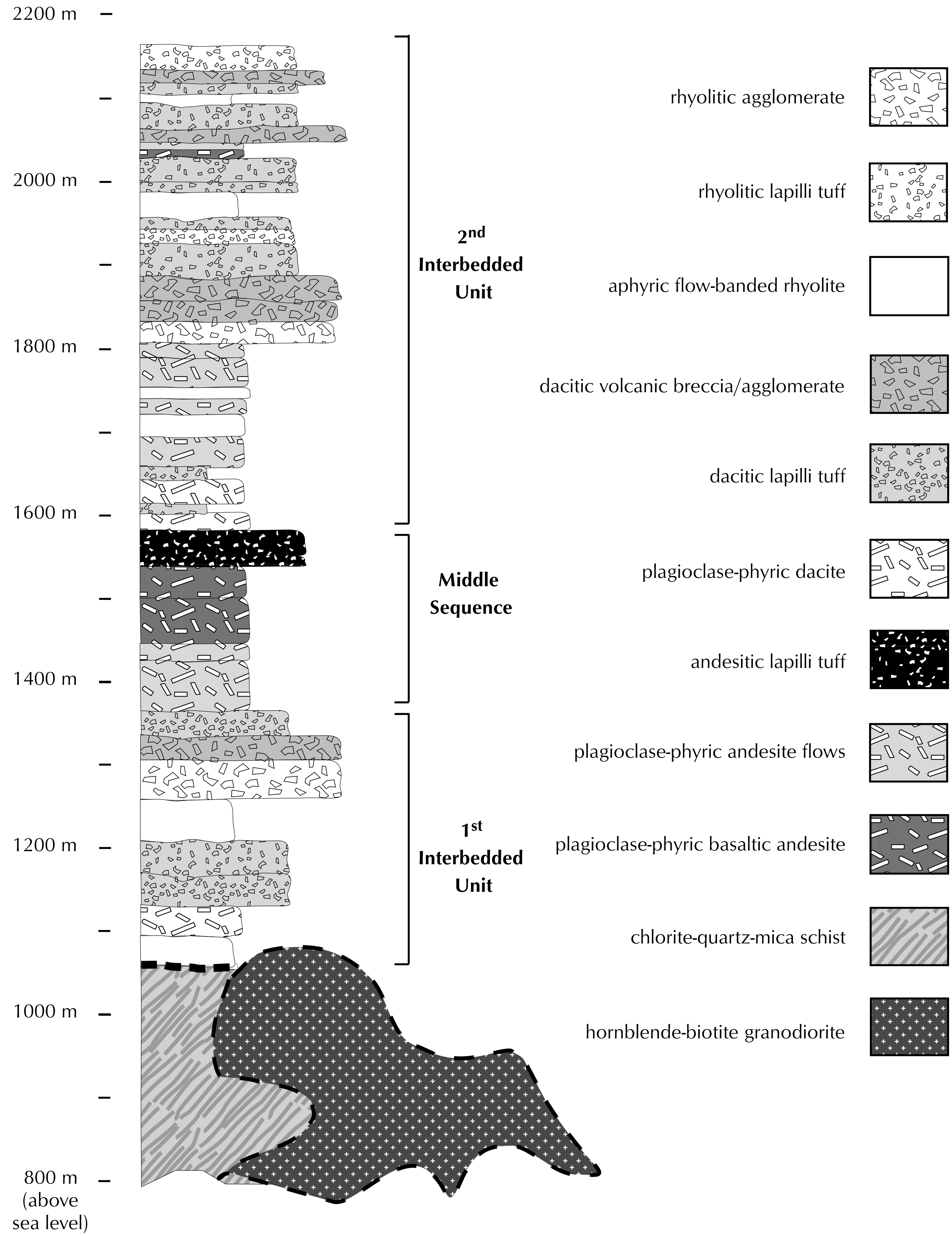
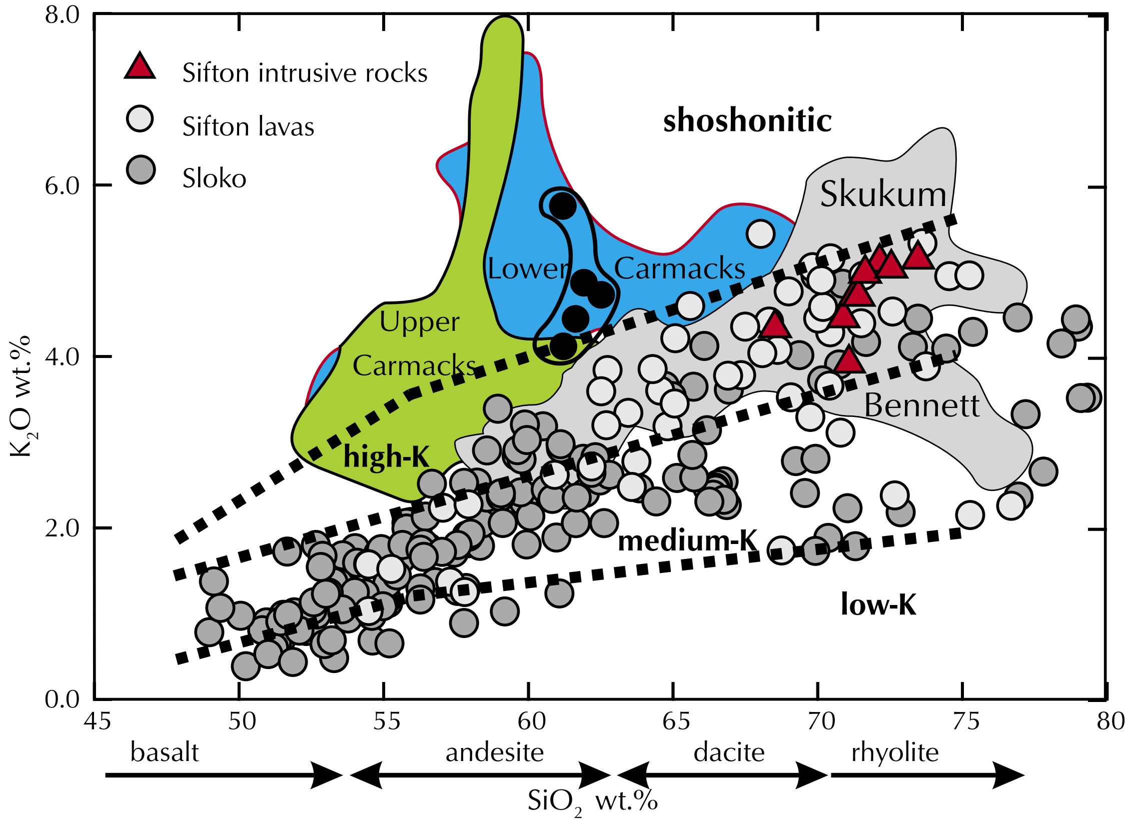


Figure 5. *Stratigraphy of the Sifton Range volcanic complex.*

__Figure 6.__ The Eocene magmatism of the northern Canadian Cordillera spans all four arc volcanic rock classification series of Tatsumi and Eggins, 1995 (modified after Gill, 1981). The Sifton shoshonites (black circles) are representative of the relatively more evolved Lower rather than Upper Carmacks Group.



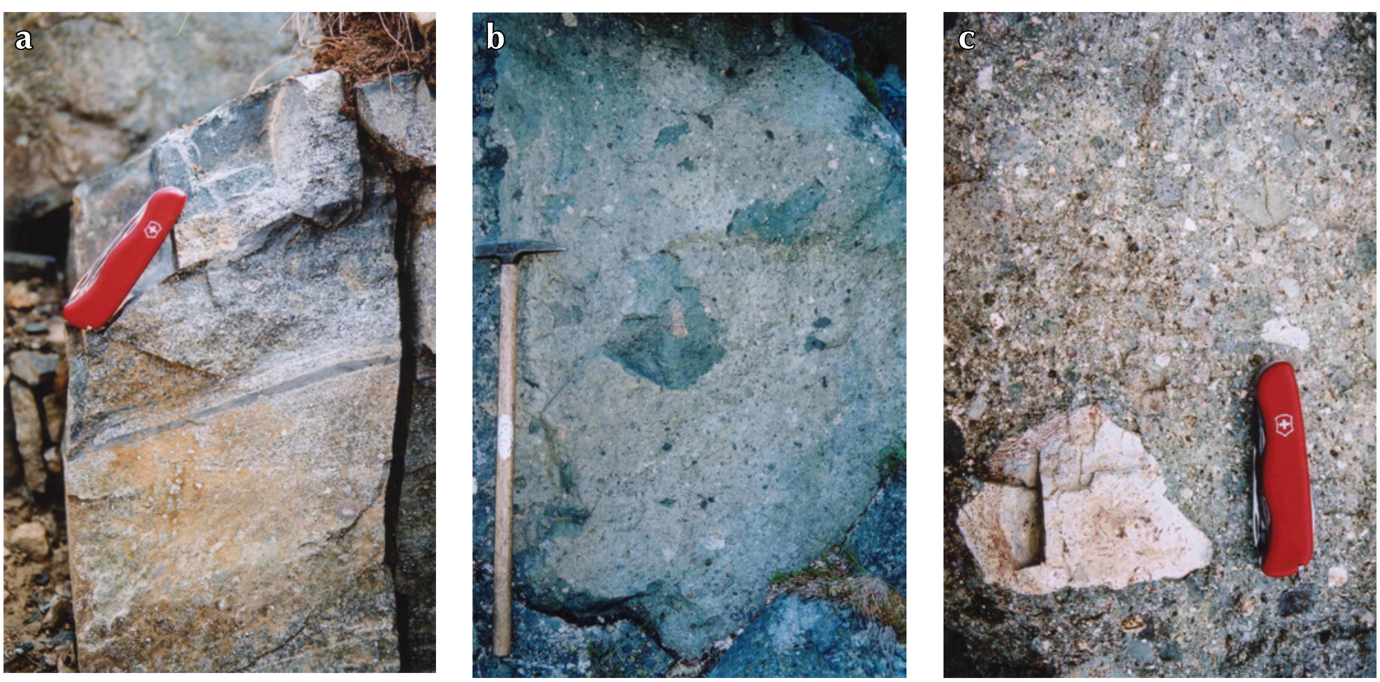


***Figure 7. (a)** A 0.5-m-thick layer of finely laminated ash tuff and epiclastic rocks (base of the 2nd Interbedded cycle); **(b)** a 30-cm-long angular andesitic volcanic bomb within a dacitic agglomerate; **(c)** a 10-cm-long fragment of flow-banded rhyolite incorporated into rhyodacitic lapilli tuff matrix.*

INTRUSIVE ROCKS

The Sifton Range volcanic complex (SRVC) is cored by the monotonous, medium-grained, granite stock containing sparse alkali feldspar megacrysts, and 5 to 10% biotite and hornblende by mode. The granite is characterized by two compositionally distinct feldspars (An_{36-50} and Or_{77-79}) exhibiting minor exsolution textures. The pluton is massive, lacking the structural fabric common in older (Mesozoic) intrusive rocks of the CPC (Rusmore, 1991). A sample collected from the centre of the complex, 300 m below the contact with the SRVC yielded a U-Pb (zircon) age of 57.5 ± 0.2 Ma (J.K. Mortensen, pers. comm., 2003). Two isolated, subangular mafic rafts, 3 and 8 m in diameter are found incorporated within the granitic stock (Fig. 3). These mafic enclaves are composed almost entirely of coarse-grained hornblende with traces of interstitial magnetite and pyrrhotite.

Dykes and sills are widespread throughout the SRVC, and exhibit a dominantly bimodal character. Clinopyroxene- and plagioclase-bearing mafic dykes, 1 to 3 m in thickness indiscriminately intersect the volcanic units, but are conspicuously absent in the underlying granite. Felsic dykes tend to be associated with epizonal granites, and a dense pattern of quartz- and feldspar-porphyritic rhyolite dykes radiates from the shallow intrusion in the western section of the complex.

The Sifton intrusive rocks locally mark the northernmost extent of the Early Tertiary Nisling Range Plutonic Suite — a northwest-trending Coast Plutonic Complex batholith that extends for 230 km from Whitehorse to the northern limit of Kluane Lake. In order to supplement the Sifton granite, and compare proximal, yet different plutonic phases, we conducted systematic sampling of the Nisling intrusive rocks along the Alaska Highway between Stony Creek (UTM: E447212, N6741594) and Mendenhall (UTM: E450592, N6744473, Zone: 8, NAD 27), 20 km south of the Sifton Range. This section of the Nisling Plutonic Suite is referred to as the Annie Ned pluton, and exhibits a composite, multiphase emplacement history (Hart, 1997). Early biotite quartz monzonites and diorites are intermingled with late leucocratic biotite granites and granodiorites. The plutonic rocks are commonly cut by north-trending basaltic and andesitic dykes up to 5 m in thickness. Numerous late-stage aplite dykes and localized clusters of coarsely crystalline gabbroic enclaves are also present.

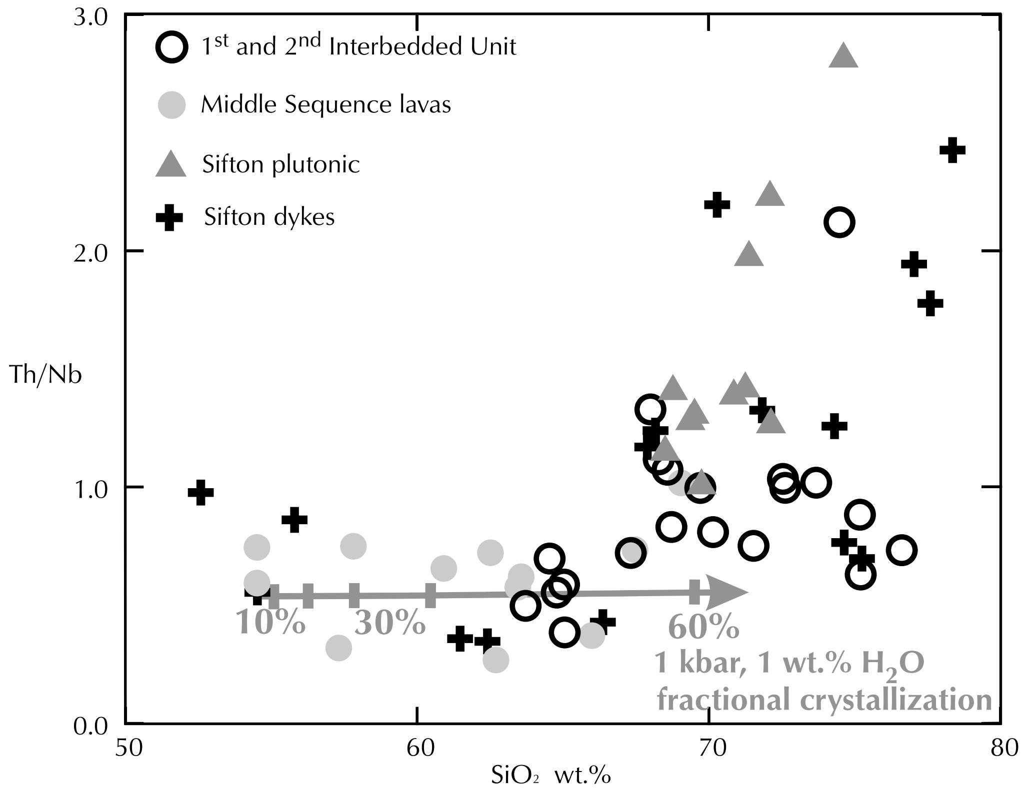
GEOCHEMISTRY

The Sifton volcanic suite exhibits a predominantly high-K, calc-alkaline fractionation trend (Fig. 6). The SRVC displays trace-element patterns characteristic of subduction-zone magmatism. The rocks are depleted in high field strength elements (HFSE: Ti, P and Nb), prominently enriched in thorium and uranium (Th, U) and the large ion lithophile elements potassium, rubidium and barium (LILE: K, Rb and Ba), with positive lead anomalies relative to the primitive mantle composition. The evolution of the relatively primitive Sifton lavas (< 66 wt. % SiO_2) can be modeled by a two-step fractional crystallization of plagioclase + clinopyroxene + orthopyroxene + iron-titanium (Fe-Ti) oxides at upper crustal (1 kbar), damp (1.5 wt. % H_2O) conditions. The more evolved volcanic rocks (SiO_2 >66 wt. %) and corresponding intrusive rocks are characterized by an anomalous rise in highly incompatible LILE (Ba, K), and HFSE (Th, Nb) that cannot be accounted for by up to 60 wt. % crystallization of a basaltic precursor (Fig. 8).

Although similar in terms of the major and trace-element chemistry (e.g., SiO_2 = 69-74 wt. %, LILE enrichment, moderate europium (Eu) anomalies), the Sifton rhyolites cluster near the low-pressure, water-saturated minimum of Tuttle and Bowen (1958), whereas the Sifton plutonic rocks are clearly two-feldspar (subsolvus) granites, requiring a minimum of 2.5 kbar of partial H_2O pressure. This pressure discrepancy may reflect different depths of crystal fractionation and/or different water contents.

Compared to the Annie Ned granitoids along the Alaska Highway, the Sifton Range granite is relatively enriched in the incompatible HFS elements (Th, Nb), and exhibits normative proportions of quartz, albite and orthoclase (Table 1) that reflect lower ambient pressures of ca. 3.0 kbars. The elevated rubidium-strontium (Rb-Sr) ratios with decreasing Ba concentrations of the Sifton plutonic rocks as compared to the Annie Ned granitoids can be explained by fractionation of potassium feldspar — a megacrystic phase readily observed in the Sifton Range. However, neither of the two plutonic localities exhibit trace-element (Ba, Sr, Rb) trends that are compatible with the extensive, late-stage fractional crystallization of the quartz-plagioclase-orthoclase assemblage — a trend clearly observed in the Early Tertiary alaskites of the Yukon Crystalline Terrane (Lynch et al., 1983).

Figure 8. *HFSE-SiO_2 plot displaying anomalous increase in Th relative to the equivalently incompatible high field strength element Nb for the SRVC rhyodacites, rhyolites and granites. Arrow indicates modeled HFSE ratios after 60 % fractionation by weight of a basaltic precursor (MgO = 6.62 wt. %) under closed-system conditions.*



INTERPRETATION

Extension by large-scale, normal (block) faulting appears to have imposed the primary structural control on deposition and preservation of the Sifton Range volcanic complex (SRVC). The linear juxtaposition of the southwest-dipping volcanic sequence with the Paleozoic basement rocks, and the dominant attitude of dykes (north-northwest) are complementary with the principal stress directions of a northwest-southeast transtensional regime. Local variability in dip attitudes, especially in the central part of the complex, is attributed to the post-depositional modification related to both, the Nisling Suite plutonism and prominent block faulting. The extent of erosion within the complex can be constrained by inspection of pressure-dissolution features found within the marble bed near the top of the 2nd Interbedded Unit (Fig. 3). If attributed solely to lithostatic pressure, the thickness of stylolites (1 to 3 mm) indicates a minimum of 600 m of overburden (Eric Mountjoy, pers. comm., 2003), and therefore at least 400 m of missing volcanic stratigraphy. Furthermore, if the marble unit was formed in a marine environment, its current position at 1830 m suggests a rate of apparent uplift along the northeastern margins of the Coast Plutonic Complex (CPC) of approximately 32 m/Ma since the Eocene.

Compared to the coeval evolved volcanism of the Mt. Skukum and Bennett Lake complexes on the one hand, and relatively primitive volcanic rocks of the Sloko Lake on the other, the SRVC constitutes a compositionally intermediate volcanic suite. The Sifton volcanic rocks cross boundaries between orogenic magma series defined on the basis of K_2O content (Fig. 6), and exhibit anomalous enrichment in the incompatible elements (Th, Rb, K), indicating an open-system petrogenesis. Compositional stratification and transition between effusive and explosive units of the SRVC are interpreted in terms of a dynamic interaction between a shallow (ca. 3 km) magma chamber undergoing fractional crystallization with increasing water content, and a granitoid crustal component. According to this scenario, the evolution of the Sifton volcanism commenced by initial eruption of crustally derived, LILE-enriched, high-SiO_2 rhyolites and pyroclastic rocks of the 1st Interbedded Unit, followed by effusive eruption of the Middle Sequence (basaltic) andesite and andesite lavas tapping deeper portions of the magma chamber. Continuing crystal fractionation and assimilation within the magma

Table 1a. *XRF, LA-ICP-MS[1] analyses and normative mineralogies for representative diorites, quartz monzonites and granites of the Annie Ned pluton (Nisling Plutonic Suite); major elements and normative phases shown in wt. % , trace elements in ppm.*

Locality: Alaska Highway transect (Annie Ned pluton - Nisling Plutonic Suite)							
Major elements (wt. %)							
Sample	SF-21	SF-29	SF-32	SF-33	SF-35	SF-44	SF-49
SiO_2	69.87	68.67	68.52	68.63	67.97	73.89	71.69
TiO_2	0.24	0.26	0.32	0.25	0.35	0.25	0.29
Al_2O_3	15.49	15.96	16.01	16.44	16.25	13.6	14.47
Fe_2O_3	3.08	3.15	2.81	2.31	3.1	1.86	2.28
MnO	0.06	0.09	0.1	0.07	0.09	0.04	0.04
MgO	0.05	0.04	0.77	0.19	0.77	0.34	0.41
CaO	1.54	1.78	2.69	2.47	2.67	1.49	1.79
Na_2O	5.06	5.39	4.57	4.53	4.48	3.44	3.53
K_2O	3.95	4.27	3.56	4.2	3.89	4.54	4.59
P_2O_5	0.05	0.05	0.12	0.1	0.14	0.06	0.08
LOI	0.2	0.26	0.37	0.52	0.37	0.27	0.25
Total	99.59	99.92	99.84	99.71	100.08	99.78	99.42
Trace elements (ppm)							
Rb	77	94	121	122	118	87	80
Zr	337	307	144	132	150	172	208
V	6	5	31	22	36	8	15
Co	3	7	13	9	6	6	7
Pb	16	18	15	15	13	17	17
Zn	27	60	27	3	12	3	0
Nb	0	6	10	9	10	4	1
Sr	216	222	316	335	339	344	487
Ba	3352	3590	1285	1711	1779	3471	5971
Ni	1	1	1	3	1	5	3
Cu	10	9	25	4	7	8	8
Cr	17	20	10	8	14	16	14
Ga	20	20	17	15	16	15	15
Y	20	28	21	19	21	12	10
Th	8	8	14	9	14	12	11
U	5	5	5	5	5	5	4
Normative mineralogy (phase wt. %)							
quartz	20.44	15.97	20.47	19.81	19.00	31.96	27.98
orthoclase	23.48	25.32	21.17	25.03	23.08	26.93	27.30
albite	43.09	45.78	38.92	38.68	38.08	29.23	30.08
anorthite	7.94	6.77	12.74	12.16	12.79	7.85	9.79
clinopyroxene	0.16	2.28	0.23	0.00	0.05	0.00	0.00
orthopyroxene	3.34	2.29	4.74	2.89	5.09	2.67	3.28
magnetite	0.90	0.92	0.82	0.68	0.91	0.54	0.67
ilmenite	0.46	0.50	0.61	0.48	0.67	0.48	0.56
apatite	0.11	0.11	0.26	0.22	0.31	0.13	0.18
zircon	0.07	0.06	0.03	0.03	0.03	0.03	0.04

[1]LA-ICP-MS: laser-ablation induced coupled plasma spectrometry

Table 1b. *XRF, LA-ICP-MS analyses and normative mineralogies for representative granites of the Sifton Range intrusion (Nisling Plutonic Suite); major elements and normative phases shown in wt. % , trace elements in ppm.*

Locality: Sifton Range Intrusion (Nisling Plutonic Suite)								
Major elements (wt. %)								
Sample	SF-60	SF-61	SF-62	SF-63	SF-64	SF-98	SF-116	SF-265
SiO_2	69.74	69.85	70.64	70.51	69.72	69.79	66.11	69.70
TiO_2	0.36	0.36	0.34	0.30	0.36	0.39	0.48	0.30
Al_2O_3	14.57	14.60	14.39	14.63	14.54	15.01	15.43	15.27
Fe_2O_3	2.60	2.64	2.37	2.30	2.53	2.66	3.21	2.69
MnO	0.12	0.08	0.06	0.11	0.07	0.11	0.09	0.09
MgO	0.71	0.71	0.64	0.08	0.64	0.66	0.93	0.72
CaO	1.74	1.68	1.41	1.00	1.57	1.96	2.21	2.42
Na_2O	4.03	3.93	3.71	4.42	3.63	4.13	4.48	4.04
K_2O	4.63	4.62	5.02	4.96	4.86	4.40	4.20	3.86
P_2O_5	0.10	0.10	0.09	0.08	0.10	0.13	0.17	0.11
LOI	1.38	1.13	1.17	1.19	1.57	0.60	2.60	0.47
Total	99.98	99.70	99.84	99.58	99.59	99.84	99.91	99.66
Trace elements (ppm)								
Rb	129	149	169	139	168	154	119	131
Zr	223	225	215	244	239	206	223	138
V	27	35	32	22	32	29	38	34
Co	4	8	3	2	10	3	5	5
Pb	16	16	16	10	16	16	14	16
Zn	37	27	13	29	10	17	28	0
Nb	11	9	9	10	7	9	9	8
Sr	213	230	242	175	271	299	337	297
Ba	2299	2370	2227	2722	2737	2183	2213	1356
Ni	13	3	4	2	3	1	0	7
Cu	44	5	9	9	10	7	27	0
Cr	15	21	19	9	21	11	19	23
Ga	17	17	17	16	16	16	17	16
Y	28	25	23	31	25	23	24	18
Th	15	17	20	13	23	12	11	13
U	5	5	5	5	5	5	5	5
Normative mineralogy (phase wt. %)								
quartz	23.10	23.87	25.22	22.82	25.09	22.87	17.36	24.30
orthoclase	27.76	27.70	30.06	29.79	29.30	26.21	25.53	23.01
albite	34.61	33.76	31.83	38.02	31.35	35.24	39.01	34.50
anorthite	8.11	8.36	7.03	5.13	7.94	9.49	9.86	11.77
clinopyroxene	0.45	0.00	0.00	0.00	0.00	0.00	0.70	0.00
orthopyroxene	4.24	4.44	3.94	2.61	4.14	4.32	5.19	4.62
magnetite	0.77	0.78	0.70	0.68	0.75	0.78	0.96	0.79
ilmenite	0.70	0.70	0.66	0.58	0.70	0.75	0.95	0.57
apatite	0.22	0.22	0.20	0.18	0.22	0.29	0.39	0.24
zircon	0.05	0.05	0.04	0.05	0.05	0.04	0.05	0.03

chamber resulted in appearance of siliceous, water-saturated melts that gave rise to the second cycle of explosive activity. Each eruptive episode began explosively with deposition of pyroclastic material (agglomerates and tuffs), and concluded with effusive outpouring of progressively more primitive lavas — a process that resulted in the localized 'inverse' zoning presumably reflecting the compsitional stratification of the magma reservoir.

The gradation from pyroclastic deposits through aphyric felsite into fine-grained, and finally medium-grained intrusive rocks described by Souther (1971) suggests a cogenetic relationship between the Early Tertiary volcanism and plutonism of the northern Canadian Cordillera. We interpret the Sifton Range plutonism as being linked to the increase in crystallinity of a magmatic 'mush' present in the shallow magma chamber, and ultimately related to rheological thresholds imposed by the build-up and subsequent release of magmatic water (i.e., degassing). Elevated water concentrations suppressed the rapid onset of plagioclase crystallization (Spulber et al., 1983), and postponed attainment of critical crystallinity until the magma reached the composition of dacite. At this point, the simultaneous saturation in water and appearance of exsolved gas bubbles resulted in elevated magma viscosities (Manga et al., 1998) ultimately leading to ponding of high-SiO_2 melt as granitic plutonism, or explosive eruption of pyroclastics rather than flows.

Similar to the overlying felsic volcanic rocks, the Sifton granites display enrichments of incompatible elements (Ba, Rb and Th) relative to HFSE (Nb, Zr, Ti) that cannot be entirely explained by closed-system crystal fractionation, and require a contribution of crustally derived magmas (Fig. 8). However, the low Sr-isotopic signature of the Eocene Nisling Plutonic Suite ($0.7045 < (^{87}Sr/^{86}Sr)i < 0.705$; Hart, 1995) suggests that the crustal components involved in the genesis of the Sifton granite were also isotopically juvenile. This excludes a possibility of any large-scale anatexis of the Precambrian schist basement, which by late Mesozoic time mostly exceeded $(^{87}Sr/^{86}Sr)i$ of 0.710 (Barker et al., 1986).

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Devonian-Mississippian metavolcanic stratigraphy, massive sulphide potential and structural re-interpretation of Yukon-Tanana Terrane south of the Finlayson Lake massive sulphide district, southeastern Yukon (105G/1, 105H/3,4,5)

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ABSTRACT

Upper Devonian and Lower Mississippian metavolcanic rocks of Yukon-Tanana Terrane in southern Finlayson Lake and Frances Lake map areas occur in three thrust sheets, locally modified by a Cretaceous normal fault. The lower thrust sheet, the Big Campbell sheet, comprises the Upper Devonian to Lower Mississippian metavolcanic stratigraphy that hosts the main volcanic-hosted massive sulphide (VHMS) deposits of the district. Metavolcanic rocks in the middle thrust sheet, the Money Creek sheet, include the Upper Devonian Waters Creek and Early Mississippian Tuchitua River formations. The former comprises primarily felsic metavolcanic rocks and carbonaceous phyllite and is extensively intruded by sheets of comagmatic porphyry. The latter comprises primarily intermediate metavolcanic, volcaniclastic and epiclastic rocks. The upper thrust sheet, the Cleaver Lake sheet, is in part made up of Late Devonian calc-alkaline basalt and rhyolite, the Cleaver Lake formation, and comagmatic felsic to ultramafic plutonic rocks. Of these, the Waters Creek formation and the formations in the Big Campbell sheet have the highest potential to host VHMS deposits.

RÉSUMÉ

Les roches métavolcaniques du Dévonien supérieur et du Mississippien inférieur du terrane de Yukon-Tanana dans le sud des régions cartographiques de Finlayson Lake et de Frances Lake forment trois nappes de charriage, localement modifiées par une faille normale du Crétacé. La nappe basale de Big Campbell comprend les formations métavolcaniques du Dévonien supérieur au Mississippien inférieur où l'on trouve les principaux gisements de sulfures massifs dans des roches volcaniques du district. Les roches métavolcaniques de la nappe intermédiaire, Money Creek, incluent les formations de Waters Creek du Dévonien supérieur et de Tuchitua River du Mississippien précoce. La première se compose principalement de roches métavolcaniques felsiques et de phyllades carbonées et elle est injectée de part en part de nappes de porphyre comagmatique. La dernière se compose principalement de roches métavolcaniques, volcanoclastiques et épiclastiques intermédiaires. La nappe de Cleaver Lake supérieure est, en partie, composée de basalte et de rhyolite calco-alcalins du Dévonien tardif, de la formation de Cleaver Lake et de roches plutoniques felsiques à ultramafiques comagmatiques. La formation de Waters Creek et les formations de la nappe de Big Campbell offrent le potentiel le plus élevé de receler des gîtes de sulfures massifs dans des roches volcaniques.

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INTRODUCTION

Recent work in the Finlayson Lake massive sulphide district of southeastern Yukon (FLD; Fig. 1) has established the geological settings of the volcanic-hosted massive sulphide (VHMS) deposits that define the district (Murphy et al., 2002, Fig. 2, 3). With the exception of the Ice deposit which is hosted by basalt of the Permian Campbell Range formation[1], the deposits of the FLD (Fyre Lake, Kudz Ze Kayah, GP4F and Wolverine) are hosted in Upper Devonian and Lower Mississippian metavolcanic rocks of the Grass Lakes and Wolverine Lake groups. These prospective stratigraphic units have geochemical signatures indicating deposition in an extensional setting in the back-arc region of a magmatic arc built primarily on sialic basement (Piercey, 2001; Piercey et al., 2000a,b, 2001, 2002, 2003). These units occur in the structurally deepest part of the imbricated Yukon-Tanana Terrane, in the footwall of the Money Creek thrust, an Early Permian thrust fault with greater than 35 km of northeast-directed displacement (Murphy and Piercey, 2000a,b; Murphy et al., 2003).

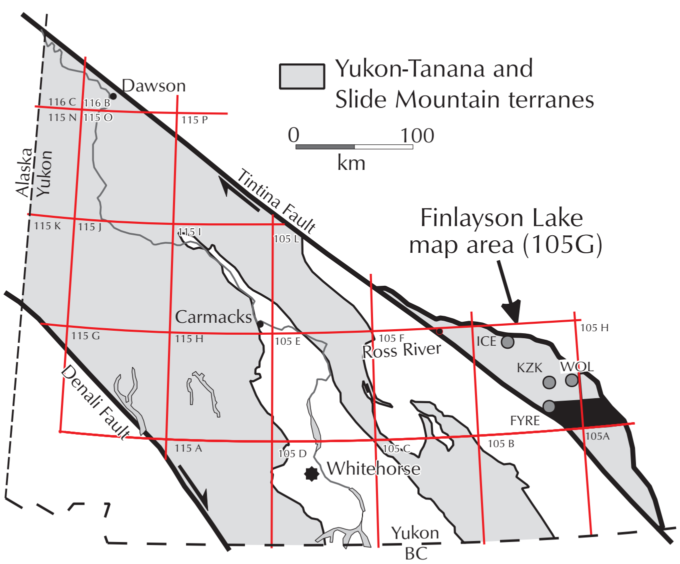


__Figure 1.__ Distribution of Yukon-Tanana and Slide Mountain terranes in Yukon. Area of interest south of the Finlayson Lake massive sulphide district is indicated in black. Locations of Ice (ICE), Kudz Ze Kayah (KZK), Fyre Lake (FYRE) and Woverine (WOL) volcanic-hosted massive sulphide deposits are shown with small circles.

[1]*Informal stratigraphic nomenclature used herein will be defined in upcoming bulletin.*

Devonian and Mississippian volcanic rocks also occur south of the FLD in both the hanging wall and footwall of the Money Creek thrust (Murphy and Piercey, 2000a,b), but their character and distribution have not yet been fully documented and their potential to host VHMS deposits has not been evaluated. Fieldwork in 2003 was focused on the southern part of Finlayson Lake (105G/1) and Frances Lake map areas (105H/4) in order to document the nature of these rocks and their relationships to other rocks in the area. In the process of mapping in this area, new insights into the age and geometry of faults within Yukon-Tanana Terrane were also gained. In this paper, the nature of the metavolcanic successions south of the FLD is described, a new interpretation of the age and geometry of the major intra-terrane faults of Yukon-Tanana Terrane is presented, and a preliminary evaluation of the geological setting and potential to host VHMS deposits of the metavolcanic rocks in this area is made.

YUKON-TANANA TERRANE, FINLAYSON LAKE MASSIVE SULPHIDE DISTRICT: AN UPDATE

The most recent interpretation of the extent of Yukon-Tanana Terrane (YTT) in the Finlayson Lake massive sulphide district (FLD) is shown in Figure 2. This interpretation differs from previous interpretations (Murphy et al., 2002, 2003) in three main ways. First of all, owing to their basinal character and lithological similarity to parts of the Sylvester Allochthon of Slide Mountain Terrane (Nelson, 1993), the rocks of the Fortin Creek group (Finlayson succession of Murphy et al., 2002) have been re-interpreted as belonging to Slide Mountain Terrane. Secondly, the Lower Permian Campbell Range formation and affiliated mafic and ultramafic plutonic rocks, deposited/intruded on/into both YTT and the Fortin Creek group, are interpreted as the magmatic products associated with 'leaky' transform displacement on the Jules Creek fault, the fault juxtaposing the two terranes. Hence, they represent an overlap assemblage on the two terranes, and an onlap of the ocean floor environment typical of Slide Mountain Terrane onto YTT. Therefore, they have been assigned to the Slide Mountain Assemblage, rather than the Slide Mountain Terrane. Thirdly, owing to their lithological similarity to the Campbell Range formation, and their uncertain pre-Triassic relationships to surrounding rocks of YTT, the pre-Triassic mafic volcanic rocks and ultramafic rocks in the structural window in Big Campbell Creek have been assigned to Slide Mountain Terrane.

In this new interpretation, rocks belonging to YTT in the FLD comprise all the rocks older than the Lower Permian Campbell Range formation south and west of the Jules Creek fault (Fig. 2). These rocks have been subdivided into several fault- and unconformity-bound metasedimentary and metavolcanic successions and affiliated metaplutonic suites (Fig. 3, Murphy et al., 2002, 2003). The structurally deepest rocks, and those that host the majority of the VHMS deposits of the district, are in the Big Campbell thrust sheet, bound below by the Big Campbell thrust, and above by the Money Creek thrust. These include the Upper Devonian and older Grass Lakes group and affiliated metaplutonic rocks, and the unconformably overlying Lower Mississippian Wolverine Lake group and affiliated metaplutonic rocks. The unconformably overlying Lower Permian Money Creek formation, previously considered to overlie and therefore post-date the Money Creek thrust (Murphy et al., 2002, 2003), is now inferred to have been offset by the thrust based on a re-interpretation of its geometry. Rocks in the hanging wall of the Money Creek thrust include metavolcanic and metaplutonic rocks coeval with those of the footwall but primarily of intermediate composition, Upper Mississippian to Lower Permian limestone, and

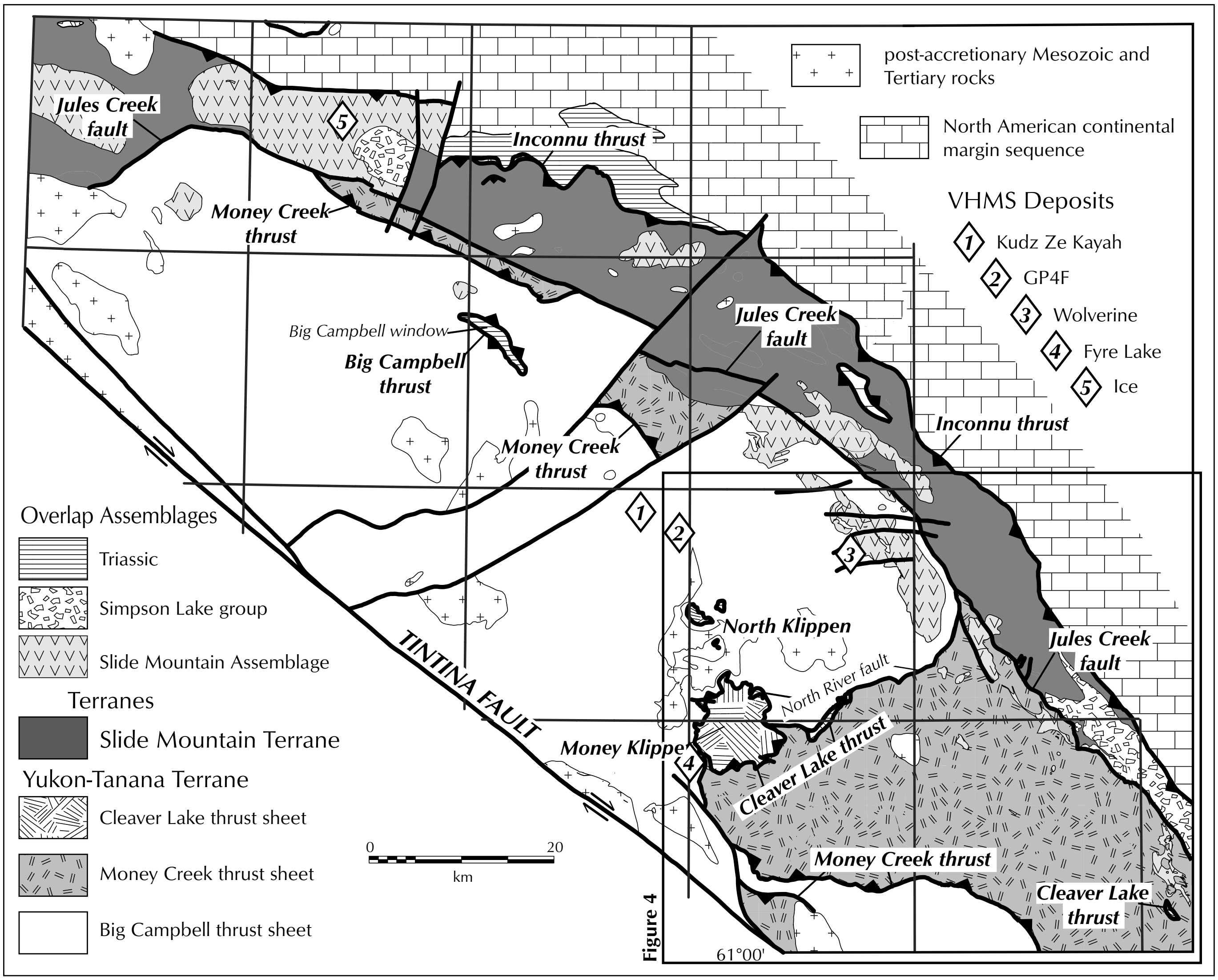


Figure 2. *Terranes and assemblages of the Finlayson Lake massive sulphide district. Yukon-Tanana Terrane is subdivided into its component thrust sheets, the lowest Big Campbell thrust sheet in the hanging wall of the post-Late Triassic Big Campbell thrust, the middle, Money Creek thrust sheet and the upper, Cleaver Lake thrust sheet, the latter two having formed in the Early Permian. Big Campbell window comprises both Triassic clastic rocks and mafic and ultramafic rocks of Slide Mountain Terrane; the area of these latter rocks is too small to portray at the scale of this map.*

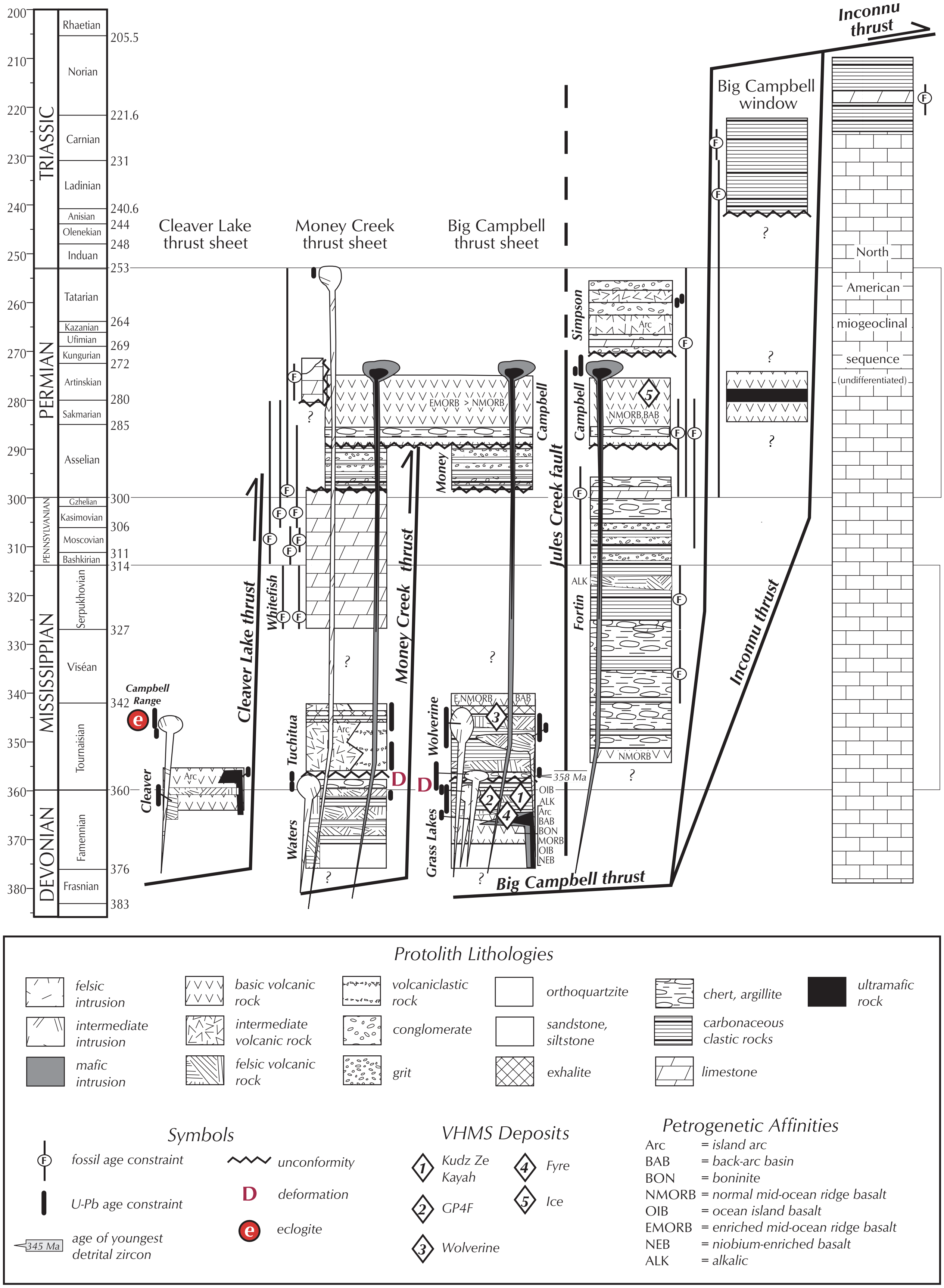


Figure 3. *Caption on facing page.*

Lower Permian carbonaceous clastic rocks and chert of the Money Creek formation. Murphy and Piercey (2000a,b) also included in the Money Creek thrust sheet undeformed Devonian basalt and rhyolite (Piercey and Murphy, 2000, part of Tuchitua succession of Murphy and Piercey, 2000a, b), comagmatic felsic to ultramafic plutonic rocks, and an early Mississippian pluton that lay above a fault inferred by them to be a minor backthrust within the Money Creek thrust sheet. However, as there are no rocks of equivalent composition in the Money Creek thrust sheet, their basal fault is now considered to be a structurally higher thrust fault, herein called the Cleaver Lake thrust.

GEOLOGY OF SOUTHEASTERN FINLAYSON LAKE AND SOUTH-WESTERN FRANCES LAKE MAP AREAS

The southern part of Finlayson Lake and Frances Lake areas is underlain primarily by pre-Upper Devonian to Lower Mississippian metavolcanic and metasedimentary rocks of the Big Campbell thrust sheet; and pre-Upper Devonian to Lower Permian metasedimentary and metavolcanic rocks, and Late Devonian and Early Mississippian metaplutonic rocks of the Money Creek thrust sheet (Figs. 2, 4). In addition a smaller part of the area is underlain by the Cleaver Lake thrust sheet comprising Upper Devonian volcanic and subvolcanic intrusive rocks, Early Mississippian plutonic rocks and two small bodies of coarse-grained metamorphic rocks interpreted as retrograded eclogite (Erdmer et al., 1998; see Devine et al., this volume). Cross-cutting plutons of Jurassic and Cretaceous age occur in the southern and central parts of the area.

BIG CAMPBELL THRUST SHEET

The same stratigraphic units that occur in the core of the FLD emerge to the south from beneath the Money Creek thrust sheet in Waters Creek map area (NTS 105G/1). The oldest rocks are quartz-rich psammite (meta-sandstone), meta-pelite and marble of the pre-Upper Devonian North River formation (unit 1 of Murphy, 1997; Murphy, 1998; unit Dq of Murphy and Piercey, 2000a; Murphy et al., 2001). The North River formation is overlain by the Fire Lake formation (unit 2 of Murphy, 1997; Murphy, 1998; unit DMF of Murphy and Piercey, 2000a; unit DF of Murphy et al., 2001), which consists primarily of chloritic phyllite or schist, and lesser carbonaceous phyllite or schist, and muscovite-quartz phyllite or schist of felsic volcanic protolith. The lower part of the Fire Lake formation in this area comprises a greater than 200-m-thick member of locally amygdaloidal felsic metavolcanic rock (muscovite-quartz schist). As in the FLD, mafic and variably serpentinized ultramafic metaplutonic rocks are spatially associated with the Fire Lake formation; in this area a several hundred-metre-thick sheet lies within the upper part of the formation. The Fire Lake formation is overlain by carbonaceous phyllite or schist, muscovite-quartz phyllite or schist (felsic metavolcanic rocks, locally amygdaloidal), rare light grey marble, and quartzofeldspathic metasandstone of the Kudz Ze Kayah formation (unit 3 of Murphy, 1997; Murphy, 1998; unit MK of Murphy and Piercey, 2000a; unit DK of Murphy et al., 2001). The youngest unit in the Big Campbell thrust sheet in this area is a several hundred-metre-thick succession of quartzofeldspathic grit and pebble conglomerate with lesser carbonaceous phyllite and locally amygdaloidal metarhyolite. This unit correlates with the lithologically similar basal clastic unit of the Wolverine Lake group which unconformably overlies the Grass Lakes group in the core of the FLD (unit 5l of Murphy and Piercey, 1999; unit CWcl of Murphy and Piercey, 2000a; unit MWcl of Murphy et al., 2001). The less highly strained nature of the basal clastic unit of the Wolverine Lake group in this area also suggests that the basal contact is an unconformity.

Figure 3. *(preceding page) Stratigraphic and structural summary diagram for Yukon-Tanana and Slide Mountain terranes, Finlayson Lake massive sulphide district. Time scale from Okulitch (2002). U-Pb geochronological data from Mortensen (1992), Breitsprecher et al. (2002), J.K. Mortensen, pers. comm., 1996-2003. Biochronological data from M.J. Orchard, pers. comm., 1997-2003 and Poulton et al. (2003).*

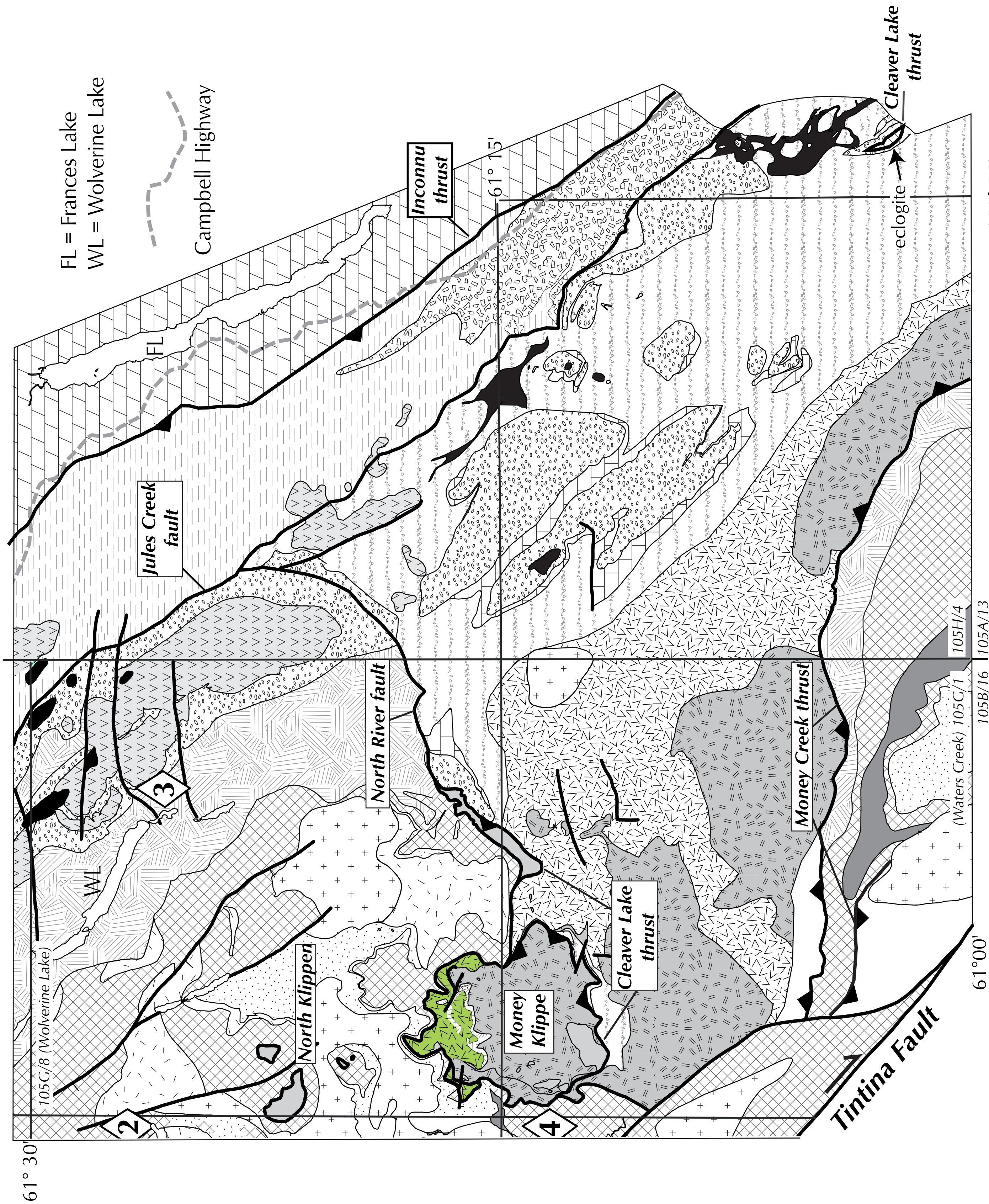


Figure 4. *Caption and legend on facing page.*

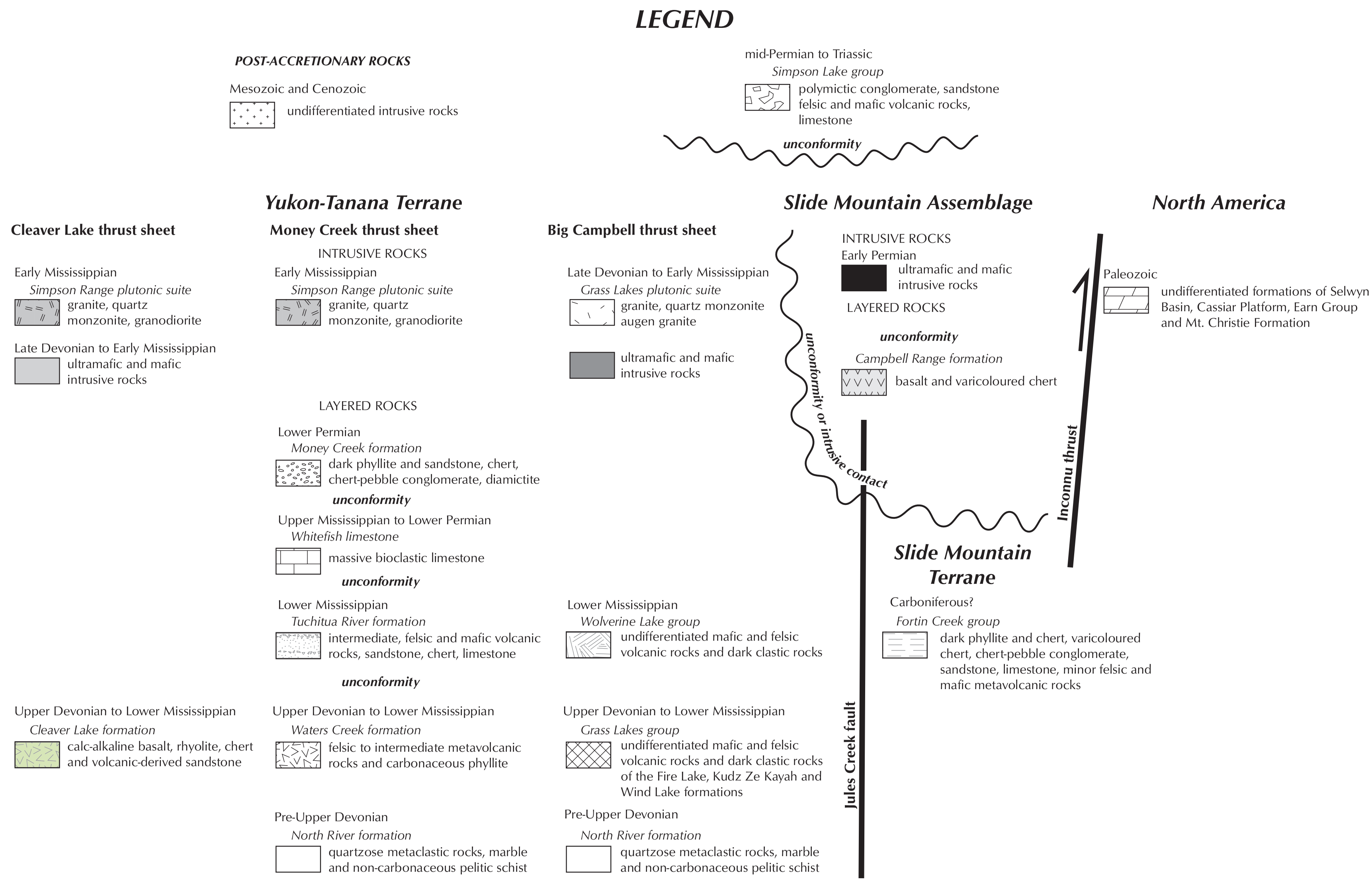


Figure 4. (a) *Geological map of southeastern Finlayson Lake map area and southwestern Frances Lake map area(on facing page);* ***(b)****Legend for 5a.*

MONEY CREEK THRUST SHEET

The oldest rock unit in the Money Creek thrust sheet, directly overlying the thrust in Waters Creek map area (105G/1), consists of quartz-rich psammite, metapelite and lesser marble, calcareous schist or calc-silicate rock (Fig. 5). This unit is lithologically identical to the North River formation in the footwall and is therefore correlated with it. As in the footwall, the stratigraphic base of the unit is not exposed in the area; its top is marked by the first appearance of rock of metavolcanic character or carbonaceous phyllite.

The North River formation is overlain sharply by the Upper Devonian Waters Creek formation, a succession of primarily felsic quartz-, feldspar- and locally hornblende-

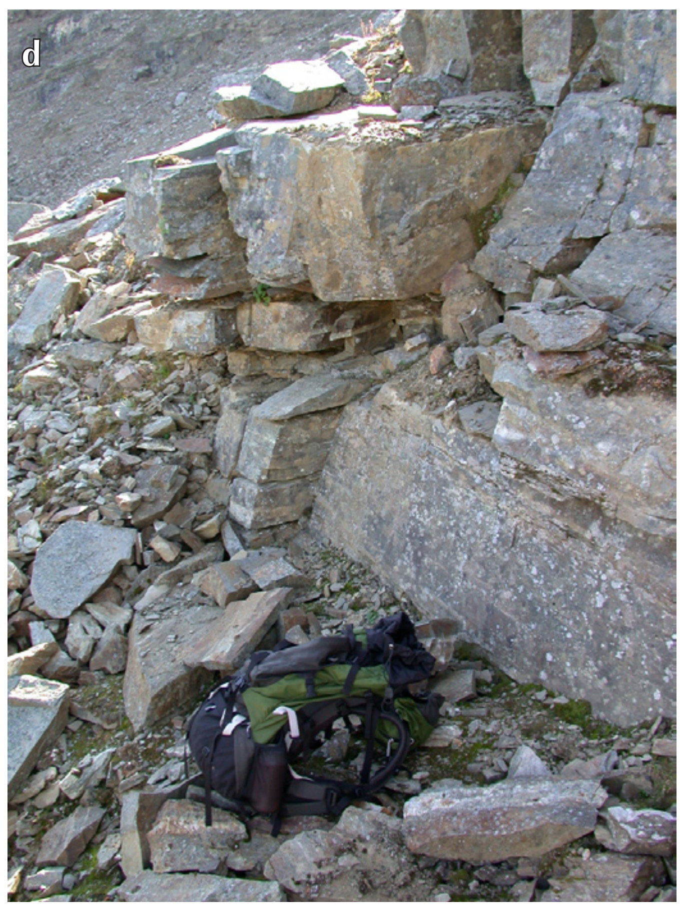
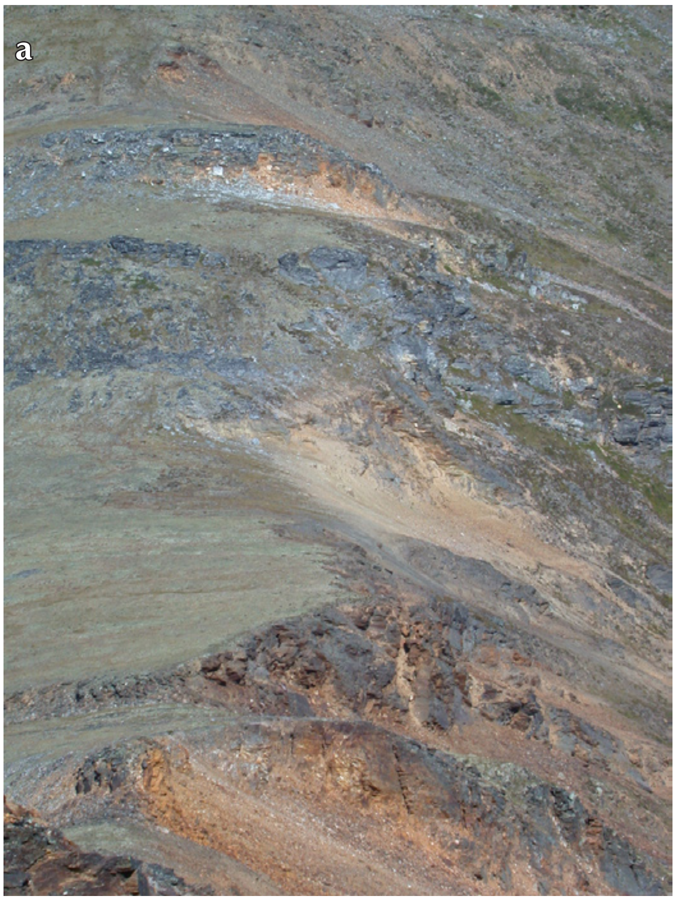


***Figure 5.** North River formation: **(a)** lineated and foliated calcareous and non-calcareous quartz psammite, light-coloured layer in centre is about 4 cm thick; **(b)** isoclinally folded grey marble layer, pen for scale at top of photo; **(c)** garnet-diopside skarn in marble near contact with intrusion of Simpson Range plutonic suite; **(d)** slabby quartz psammite, pack for scale.*

phyric metavolcanic rocks, carbonaceous phyllite and locally, bedded barite, quartzite and quartz-pebble metaconglomerate (Fig. 6). The top of the Waters Creek formation comprises thinly laminated dark grey, white, salmon and pale green chert. Massive greenstone occurs locally in the upper part of the formation. The age of the Waters Creek formation is constrained by a ca. 360 Ma U-Pb date on a felsic metavolcanic rock in the upper part of the unit (Mortensen, 1992; Breitsprecher et al., 2002).

The Waters Creek formation is overlain by the Early Mississippian Tuchitua River formation, a succession of metamorphosed, primarily intermediate volcanic, volcaniclastic and epiclastic rocks with lesser chert and limestone (Fig. 7). The Tuchitua River formation sits on



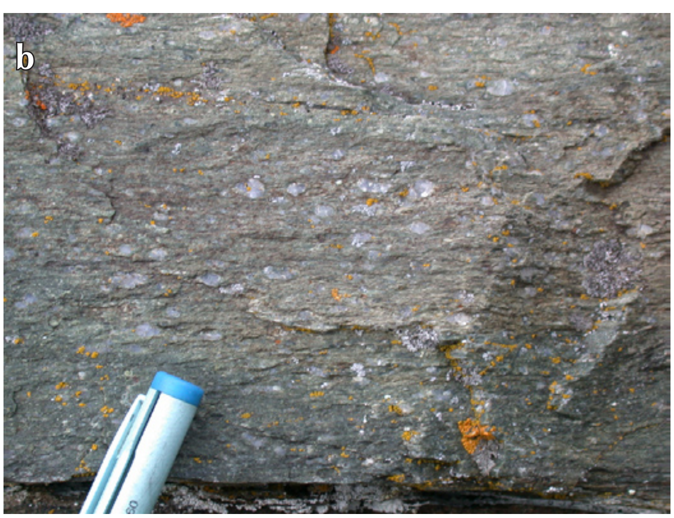


Figure 6. *Waters Creek formation:* ***(a)*** *intercalated carbonaceous phyllite, muscovite-quartz phyllite of felsic metavolcanic protolith and quartzite (light-coloured outcrops near far end of ridge);* ***(b)*** *quartz-feldspar meta-porphyry intercalated with rusty muscovite-quartz phyllite, Py occurrence (Yukon MINFILE 2003, 105G 083, Deklerk, 2003);* ***(c)*** *banded pale green, white and black chert near top of Waters Creek formation;* ***(d)*** *bedded barite, Akhurst occurrence (Yukon MINFILE 2003, 105G 083, Deklerk, 2003).*

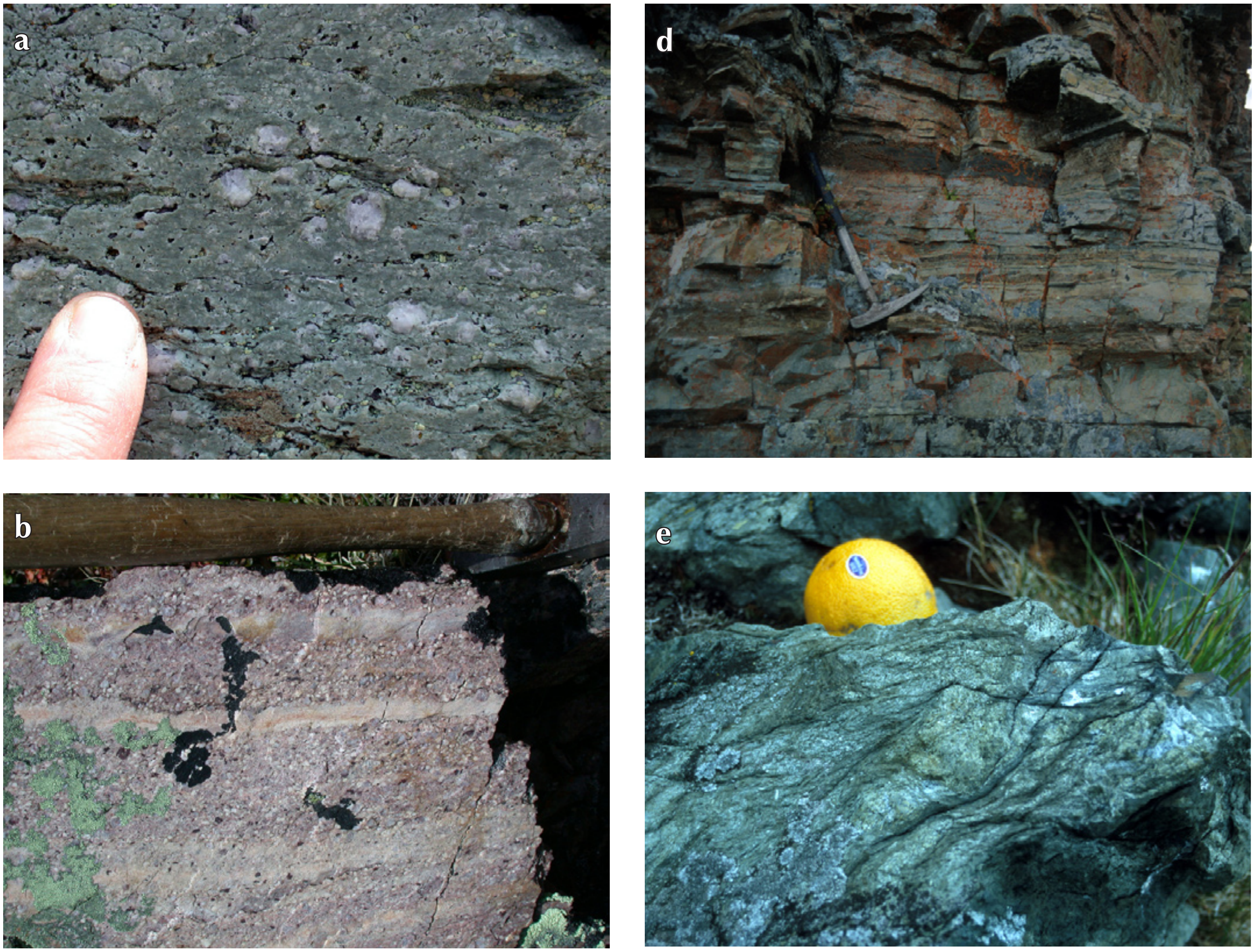


Figure 7. Tuchitua River formation: *(a)* quartz-feldspar porphyry flow; *(b)* bedded volcanogenic epiclastic rocks, light-coloured beds are about 3 cm thick; *(c)* rhyodacitic crystal-lithic tuff breccia; *(d)* banded pale green magnetite-bearing chert and grey (dark bands) limestone; *(e)* foliated intermediate to mafic metavolcanic rock (orange for scale).

top of different parts of the Waters Creek formation in different areas, suggesting that its basal contact is an unconformity, an interpretation further supported by the less highly strained nature of the overlying rocks. The age of the Tuchitua River formation is constrained by a ca. 354 Ma U-Pb date on rhyodacitic tuff breccia (Mortensen, 1992; Breitsprecher et al., 2002).

Two different episodes of hornblende-phyric plutonism are recorded in the Money Creek thrust sheet; owing to their similar metaluminous compositions, plutons of both episodes have been included in the Simpson Range plutonic suite (Mortensen and Jilson, 1985). Intercalated with both the North River and Waters Creek formations are metre-scale and thicker (to greater than a hundred-metre-thick) sheets of strongly foliated, locally potassium feldspar-megacrystic hornblende-quartz meta-porphyry (Fig. 8a,b). These sheets are lithologically similar to a pluton of foliated hornblende quartz monzonite to granodiorite that lies above the Money Creek thrust in west-central Waters Creek map area, and likely are sills and/or dykes that emanated from it. The porphyritic character of the intrusive rocks and their lithological similarity with the Waters Creek metavolcanic rocks suggests that the plutonic rocks are shallow subvolcanic intrusions. If so, then the age of the first plutonic episode is also ca. 360 Ma. The second plutonic episode is represented by discordant, weakly to unfoliated hornblende quartz monzonite plutons such as the Tuchitua River pluton (Fig. 8c,d,e), which are lithologically similar and possibly comagmatic with dacitic to rhyodacitic flows and tuffs of the Tuchitua River formation. The weakly to unstrained and discordant nature of the intrusions belonging to the second episode suggests that it, like the Tuchitua River formation, followed deformation of the Waters Creek formation and affiliated metaplutonic rocks. The age of the second plutonic episode is constrained by ca. 357 Ma U-Pb date on the Tuchitua River pluton (Mortensen, 1992; Breitsprecher et al., 2002).

The Late Devonian-Early Mississippian volcanic and plutonic rocks of the Money Creek thrust sheet are overlain by a thick and laterally persistent bioclastic limestone unit called the Whitefish limestone (unit Pc of Murphy, 2001). Conodont collections from the Whitefish limestone throughout the region indicate an Late Mississippian to Early Pennsylvanian/Early Permian age range for the unit (M.J. Orchard, pers. comm., 1997-2003; Poulton et al., 2003), implying a depositional hiatus between the youngest underlying rocks of the Tuchitua River formation and the base of the Whitefish limestone. The local occurrence of cobble conglomerate at its base and the observation that the Whitefish limestone is locally deposited on the Waters Creek formation implies that its basal contact is an unconformity.

The Whitefish limestone and underlying rocks are in turn unconformably overlain by the Money Creek formation (unit 7 of Murphy and Piercey, 1999; unit PPcs of Murphy and Piercey, 2000a; unit Pcl of Murphy et al., 2001), a poorly organized succession of carbonaceous phyllite, dark grey to black chert, chert-pebble conglomerate, quartzofeldspathic sandstone to pebble conglomerate and locally, matrix-supported diamictite. The age of the Money Creek formation is indirectly constrained by the Upper Pennsylvanian/Lower Permian age of the youngest conodont collection from the Whitefish limestone and the Lower Permian age of the Campbell Range formation which locally overlies it in the FLD.

CLEAVER LAKE THRUST SHEET

The Cleaver Lake thrust refers to the oft-photographed fault underlying what previous workers referred to as the Simpson Allochthon of the Money Klippe (Tempelman-Kluit, 1979; Erdmer, 1985). It exhibits older-over-younger relationships along its full map trace with Devonian and Mississippian rocks overlying Lower Permian rocks. The fault has been traced from its intersection with a younger low-angle normal fault east of Fire Lake, eastwardly to a second intersection with the normal fault in the Money Creek valley (Figs. 2, 4). Outliers of rocks of the thrust sheet are found to the north (North Klippen of Tempelman-Kluit, 1979), but their lower boundary is the younger low-angle normal fault, not the Cleaver Lake thrust.

In the Money Klippe, the Cleaver Lake thrust sheet comprises unstrained Devonian volcanic and volcaniclastic rocks of the Cleaver Lake formation, their subvolcanic intrusions, as well as a cross-cutting Early Mississippian intrusion of the Simpson Range plutonic suite. The Cleaver Lake formation comprises calc-alkalic pillow basalt, related volcaniclastic breccias and lesser vesicular rhyolite flows (Piercey and Murphy, 2000, Fig. 9). Minor graded epiclastic sandstone, shale and rare chert also occur in the formation. Quartz porphyritic rocks with a geochemical signature identical to the rhyolite locally intrude the basalt; these show magma-mingling textures with diabase dykes having a geochemical signature identical to the basalt (Piercey and Murphy, 2000). These observations suggest that basalt, rhyolite, quartz porphyry and diabase are broadly coeval. Their absolute ages are

Figure 8. *Simpson Range plutonic suite, older episode:* ***(a)*** *weakly foliated potassium feldspar-megacrystic hornblende-phyric augen granodiorite to quartz monzonite;* ***(b)*** *more strongly foliated version of 8a. Simpson Range plutonic suite, younger episode;* ***(c)*** *hornblende-quartz-feldspar porphyritic dyke near Tuchitua River pluton (end of marker for scale);* ***(d)*** *unfoliated potassium feldspar megacrystic granodiorite phase of the Tuchitua River pluton;* ***(e)*** *equigranular granodiorite to quartz monzonite of the Tuchitua River pluton.*

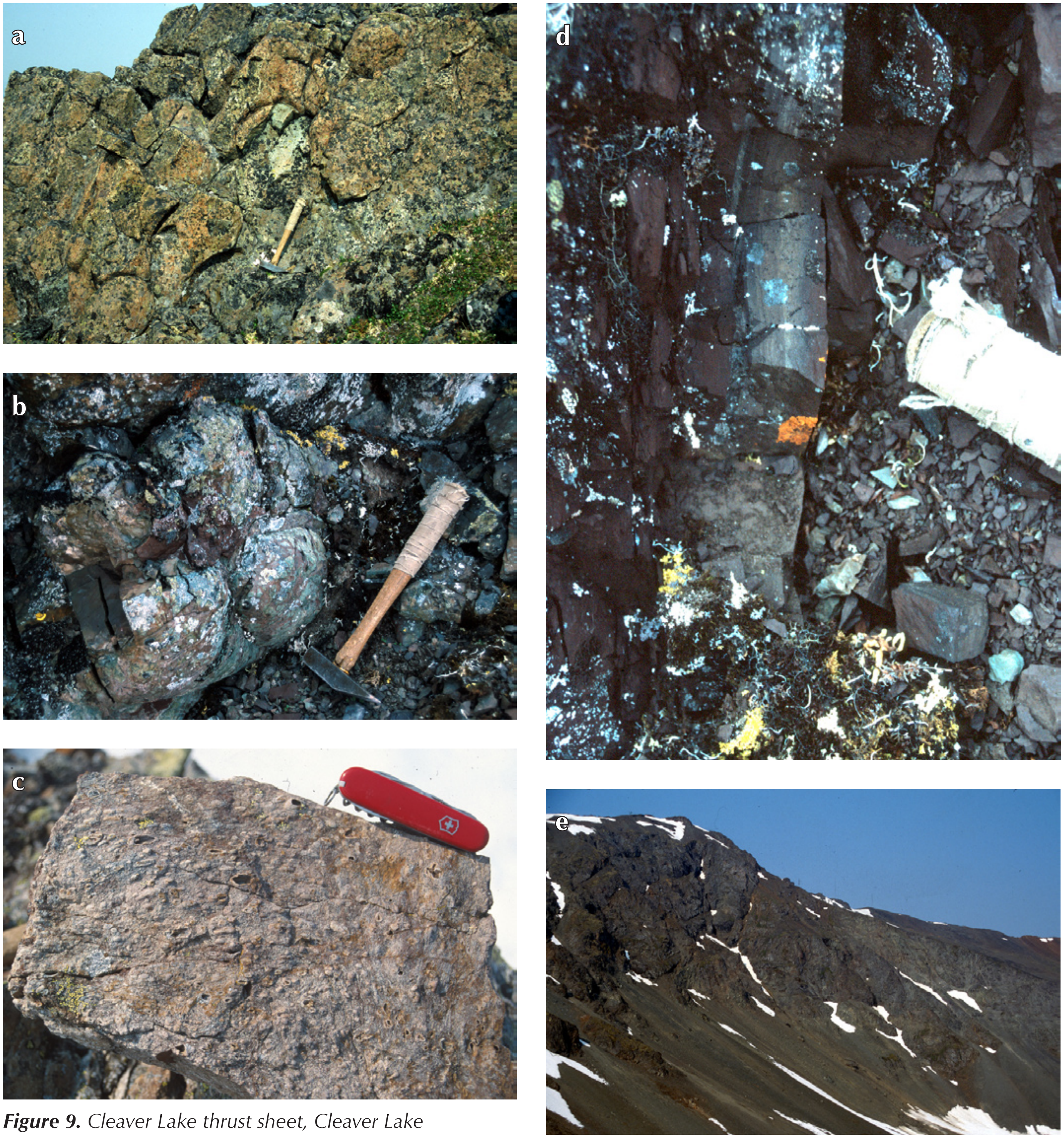


Figure 9. *Cleaver Lake thrust sheet, Cleaver Lake formation: **(a)** pillow basalt; **(b)** closeup of base of pillow basalt; **(c)** amygdaloidal rhyolite; **(d)** graded volcanogenic greywacke, top to right; **(e)** cliff of gabbro and serpentinized ultramafic rock underlying basalt and rhyolite on skyline to right*

constrained by a ca. 360 Ma U-Pb date on a quartz porphyry intrusion (Mortensen, 1992b). Gabbro and variably serpentinized ultramafic plutonic rocks (main rock type of North Klippen; Figs. 2, 4) that underlie the volcanic rocks are also interpreted as comagmatic products; a ca. 356 Ma U-Pb date was obtained from one gabbroic body (Mortensen, 1992a; Breitsprecher et al., 2002). All of these rocks are intruded by an extensive body of hornblende-biotite quartz monzonite and granite of the Simpson Range plutonic suite (Mortensen and Jilson, 1985). A ca. 348 Ma U-Pb age determination (Mortensen, 1992a; Breitsprecher et al., 2002) shows that it is one of the youngest bodies of the suite.

Two small isolated bodies of coarse-grained metamorphic rocks inferred to be retrogressed eclogite (Erdmer et al., 1998; see Devine et al., this volume; Figs. 3, 4) are also included in the Cleaver Lake thrust sheet. This interpretation is based on their structural position above the lower part of the Lower Permian Money Creek formation which is the same stratigraphic level followed by the Cleaver Lake thrust under the Money Klippe. The combined presence of volcanic and plutonic rocks with a volcanic arc geochemical signature, and rocks that formed in a coeval Devono-Mississippian subduction zone suggests that the Cleaver Lake thrust sheet, before erosional dissection, contained the Devono-Mississippian transition from arc to forearc environments.

GEOMETRY AND AGES OF FAULTING IN THE FLD

Throughout most of Waters Creek map area (105G/1) the Cleaver Lake and Money Creek thrusts are defined by the older-over-younger relationships described above and have a consistent stacking order above the rocks of the Big Campbell Creek thrust sheet. However, to the north in Wolverine Lake map area (105G/8), at the North Klippen and along the northern edge of the Money Klippe, rocks of the Cleaver Lake thrust sheet sit directly on the Kudz Ze Kayah formation of the Grass Lakes group that, to the south, lie in the footwall of the Money Creek thrust. In these places, younger rocks are faulted over older rocks and the intervening Money Creek thrust sheet is missing.

The younger-over-older relationship and unusual stacking order in Wolverine Lake map area are best explained by the presence of a low-angle normal fault along which the upper thrust sheet is down-dropped to rest above the rocks of the Big Campbell thrust sheet (Fig. 10). The trace of this normal fault, herein called the North River fault (Figs. 2, 4), extends eastwardly from the North River valley along what Murphy and Piercey (2000a,b) previously considered the trace of the Money Creek thrust. It continues down the valley of Money Creek where it likely intersects one of the poorly understood northwest-trending faults in the area. Along its trace it juxtaposes younger rocks of the Cleaver Lake and Money Creek thrust sheets against older rocks of the Big Campbell Creek thrust sheet. In Money Creek, it juxtaposes Lower Permian Money Creek formation of the Money Creek thrust sheet against the same formation, but in the Big Campbell Creek thrust sheet. Also, with the exception of the North Klippen, everywhere along its trace rocks in the hanging wall of the North River fault, the rocks dip moderately to the north, likely reflecting the original hanging wall cut-off angle.

The timing of displacement on the Money Creek and Cleaver Lake thrusts is constrained by the youngest age of footwall rocks and the oldest age of rocks or structures that cross-cut the faults. Lower Permian rocks of the Money Creek formation occur in the immediate footwall of both thrusts locally. Thrusting thus post-dates the Lower Permian Money Creek formation. The Lower Permian Campbell Range formation and spatially associated mafic and ultramafic plutonic rocks overlie or are intruded into both the hanging wall and footwall of the Money Creek thrust, suggesting that the Money Creek thrust pre-dated them. The Money Creek thrust is therefore an Early Permian fault. Although inferred to be part of the same Early Permian thrust system, the age of displacement on the Cleaver Lake thrust is less tightly constrained; its lower age limit is mid-Cretaceous, the inferred age of the North River normal fault cutting the thrust.

A Cretaceous age for the North River fault is suggested by the distribution of Cretaceous cooling ages with respect to the fault. Rocks in the footwall of the North River fault are characterized by mid-Cretaceous U-Pb ages on titanite (Breitsprecher et al., 2002) and $^{40}Ar/^{39}Ar$ cooling ages of biotite and hornblende (Villeneuve and Murphy, unpublished data). These rocks were ductily deformed prior to and during the emplacement of mid-Cretaceous granite. In contrast, rocks in the hanging wall lack Cretaceous granite, and are characterized by older (Mississippian) K/Ar and U-Pb titanite ages (Breitsprecher et al., 2002). The contrast in metamorphic and cooling ages across the fault suggests that the fault accommodated the uplift and cooling of the footwall, and hence is mid-Cretaceous in age.

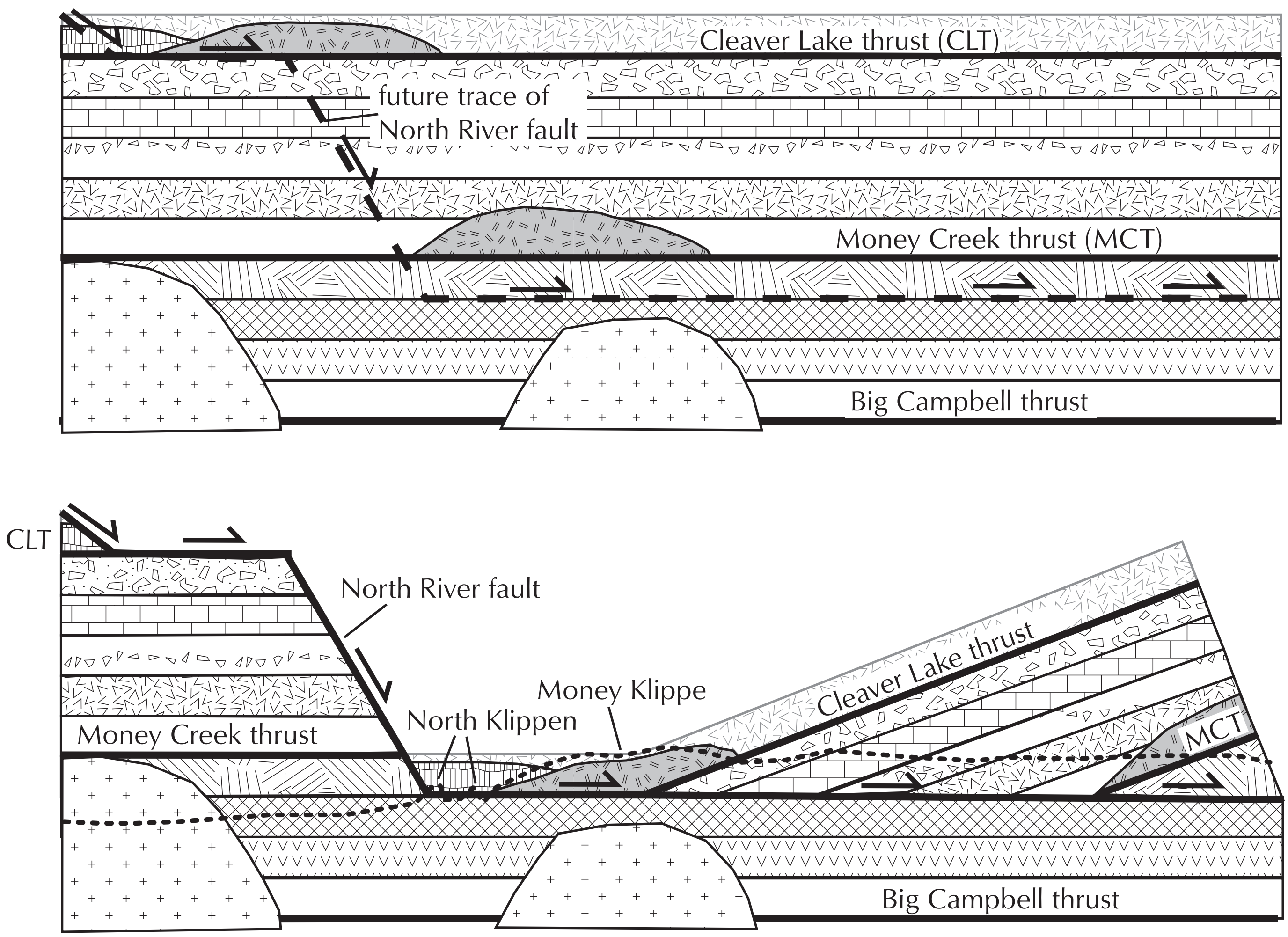


Figure 10. *Schematic cross-section illustrating how displacement on the stair-step trajectory North River normal fault down-drops the Cleaver Lake thrust sheet and juxtaposes it with the Big Campbell thrust sheet. Section broadly north-south and extending from north of the North Klippen to the southern part of 105G/1 (Fig. 4). Dotted line indicates schematic topographic profile. Patterns as in Figure 4.*

VOLCANIC-HOSTED MASSIVE SULPHIDE (VHMS) DEPOSIT POTENTIAL SOUTH OF THE FINLAYSON LAKE MASSIVE SULPHIDE DISTRICT (FLD)

The geological settings determined for the known deposits of the FLD provide models with which to evaluate the potential for VHMS deposits south of the FLD. Key features common to all the geological settings of the deposits include interbedded carbonaceous metasedimentary rocks in the metavolcanic-metasedimentary successions hosting the deposits, geological features indicating the presence of synvolcanic faults (Murphy and Piercey, 2000a,b), and voluminous comagmatic subvolcanic plutonic rocks near the deposits. The former indicates anoxic basinal bottom waters, key to the concentration of metal species and preservation of deposits (e.g., Bradshaw, 2003; Bradshaw et al., 2003a,b), and the latter provide conduits to focus hydrothermal fluids and the heat source to drive the hydrothermal cells, respectively. Coherent amygdaloidal felsic metavolcanic rocks as found at the Kudz Ze Kayah deposit are second-order indicators of proximity to volcanic vents/structures.

Two of the Devono-Mississippian volcanic successions south of the core area of the FLD have characteristics similar to those that host the deposits. First of all, the Grass Lakes group in the southern Waters Creek map area (105G/1) resembles the Grass Lakes group in the core of the FLD. Chloritic phyllite (mafic metavolcanic rock) of the Fire Lake formation is intercalated with carbonaceous phyllite and associated with voluminous amounts of comagmatic mafic and ultramafic metaplutonic rock (gabbro and variably serpentinized ultramafic rocks). Felsic metavolcanic rocks at the base of the Fire Lake formation are locally amygdaloidal and altered, suggesting proximity to a feeder zone. Amygdaloidal and altered felsic metavolcanic rocks also occur in overlying rocks of the Kudz Ze Kayah formation and Wolverine Lake group, but these units differ from their equivalents in the core of the FLD in the smaller amount of metavolcanic rock and subvolcanic intrusions. Secondly, with the exception of the hornblende-phyric composition of its felsic metavolcanic rocks, the Waters Creek formation in NTS 105G/1 and 105H/4 resembles the Kudz Ze Kayah formation near the Kudz Ze Kayah deposit in 105G/7. In this area, massive feature-less felsic (and lesser intermediate to mafic) metavolcanic rocks of the Waters Creek formation are intercalated with carbonaceous phyllite and porphyritic volcaniclastic rocks, and are intruded by sheets of locally megacrystic quartz-feldspar porphyry. A larger body of granodiorite of similar composition to the metavolcanic rocks is likely the subvolcanic feeder to both the metavolcanic rocks and sheets of porphyry. Signs of VHMS mineralization in the Waters Creek formation include disseminated to semi-massive pyrite, chalcopyrite and sphalerite in altered felsic flow rocks (e.g., Py and Ellen Creek, Yukon MINFILE 105G 083 and 135, respectively (Deklerk, 2003); Fig. 11). Bedded barite, barite veins, and local manganese staining attest to locally exhalative hydrothermal activity.

The other two Devonian to Mississippian metavolcanic successions in this area, the Cleaver Lake and the Tuchitua River formations, have little in common with the rocks that host the deposits in the FLD, and hence have little potential to host the associated types of VHMS deposits (Fyre, basalt-pelagic sediment-dominated, other felsic-siliciclastic sediment-dominated types of Franklin et al., 1999). However, as about 80% of the world's VHMS deposits occur in volcanic arc-related successions (Franklin et al., 1999), the mineral potential of these two arc and/or forearc successions can not be overlooked. Centres of magmatic activity associated with the Tuchitua River formation, identified by coherent flow rocks and

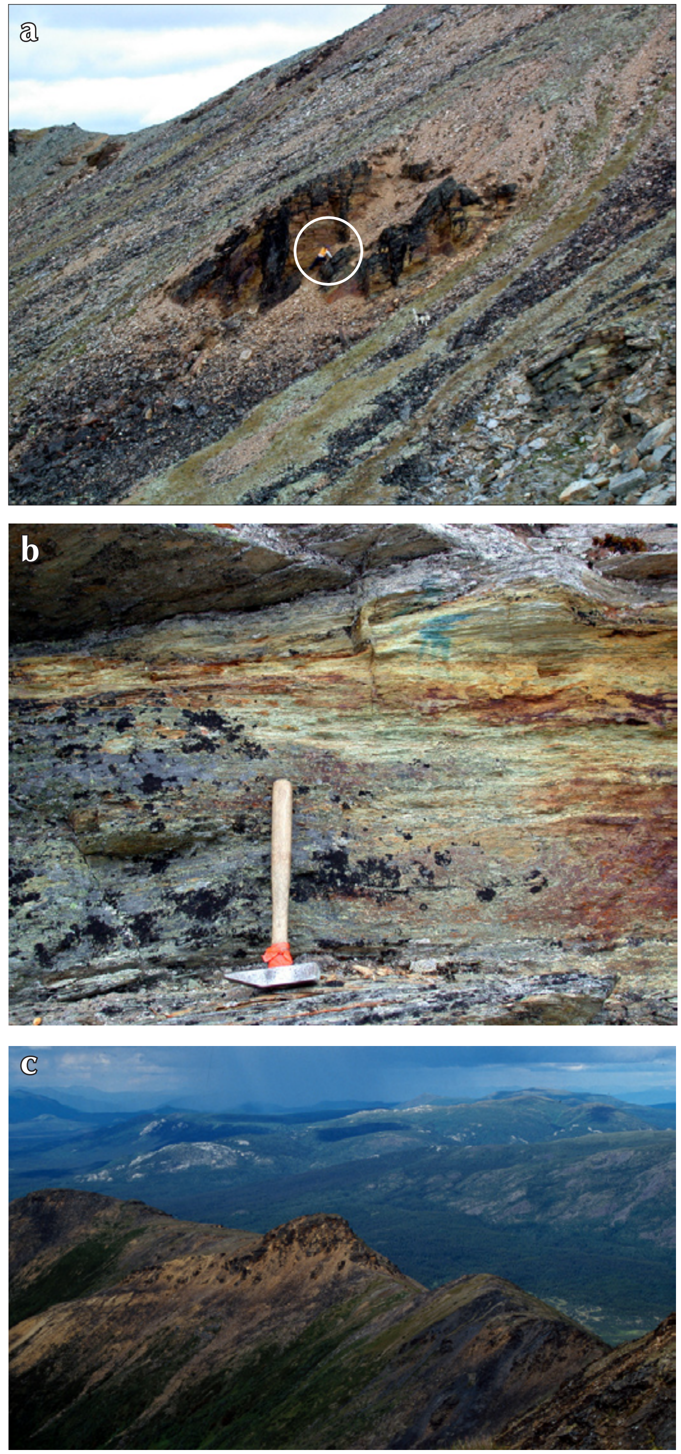


Figure 11. ***(a)*** *Rusty altered felsic metavolcanic rocks, Waters Creek formation near Ellen Creek occurrence (Yukon MINFILE 2003, 105G 135, Deklerk, 2003; person in centre for scale);* ***(b)*** *rusty, malachite-stained felsic metavolcanic rocks, Ellen Creek occurrence;* ***(c)*** *view of knob of rusty, altered felsic metavolcanic rocks with barite veins, Kneil occurrence (Yukon MINFILE 2003, 105H 080, Deklerk, 2003).*

large subvolcanic intrusions (Tuchitua River and Hasselberg Lake plutons), occur in southern Frances Lake map area and extend to the south into Watson Lake and Wolf Lake areas. Signs of hydrothermal activity in the Tuchitua River formation include laterally extensive magnetite-bearing pink, green and tan chert — which may be coeval (see Devine et al., this volume) with the siliceous barite-magnetite exhalite in the hanging wall of the Wolverine deposit (Bradshaw et al., 2003a) — and local members of altered felsic metavolcanic rock. The Cleaver Lake formation in the Money Klippe directly overlies coeval felsic to ultramafic mafic subvolcanic intrusions and therefore may be a preserved magmatic centre. However, the only mineral occurrences reported from the Money Klippe comprise jade formed near the faulted base of the klippe (Lady Lee, Yukon MINFILE 2003, 105G 114) and Reid (Yukon MINFILE 2003, 105G 039), a silver-copper-lead-zinc vein cutting basalt and underlying quartz porphyry (Deklerk, 2003). The volcanic character of these rocks has only been recently recognized (Piercey and Murphy, 2000), so the lack of mineral occurrences within this succession may have more to do with a lack of prospecting for VHMS targets in the area.

All of the Devonian and Mississippian volcanic successions described in this report track to the south and east out of the Finlayson and Frances Lake map areas into the less explored western part of Watson Lake map area and the northeastern corner of Wolf Lake map area. Although there has been little recent mapping in these areas, they contain rocks with significant potential to host VHMS mineralization.

CONCLUSIONS

1. The structure of Yukon-Tanana Terrane in and around the Finlayson Lake massive sulphide district has been re-interpreted to include a higher level thrust sheet, the Cleaver Lake thrust sheet. This thrust sheet includes outliers of both Devonian and Mississippian arc rocks, and rocks that formed in a Devono-Mississippian subduction complex; hence, it likely preserved the Devono-Mississippian arc to forearc transition before erosional dissection.
2. Much of what had previously been inferred to be the trace of the Money Creek thrust is now inferred to be a Cretaceous normal fault, the North River fault. This fault explains how rocks of the structurally high Cleaver Lake thrust sheet came to sit on top of the structurally low Big Campbell thrust sheet.
3. Devonian and Mississippian metavolcanic rocks south of the core area of the Finlayson Lake massive sulphide district have many characteristics in common with the rocks hosting the mineral deposits in the district. These similarities attest to the potential for more deposits to be found in this area and in western Watson Lake and northeastern Wolf Lake areas to the south.

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High-level terraces, Indian River valley, Yukon[1]

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Nelson, F.E.N. and Jackson, L.E., Jr., 2003. High-level terraces, Indian River valley, Yukon. *In:* Yukon Exploration and Geology 2004, D.S. Emond and L.L. Lewis (eds.), Yukon Geological Survey, p. 177-190.

ABSTRACT

High-level terraces in the Indian River valley, between the confluences of Ruby Creek and Dominion Creek with Indian River, are underlain by a sand-dominated fill. The fill formed when meltwater torrents from the margin of a Late Pliocene ice sheet drained into the Indian River valley from the divide with the Stewart River basin. A lake or lakes existed in the Indian River valley at that time. Mechanisms for ponding of the lake(s) include regional glacial damming of the ancestral Yukon drainage (Glacial Lake Yukon), or local damming by alluvial fans or landslides. Sufficient evidence does not exist to effectively eliminate any of these hypotheses. Placer gravel may exist below the sandy fill in a buried segment of the pre-glacial Indian River valley near the confluence of Montana Creek.

RÉSUMÉ

Les terrasses supérieures de la vallée de la rivière Indian, entre la confluence des ruisseaux Ruby et Dominion, résultent d'un remblaiement principalement sableux. Il a eu lieu lorsque les torrents de fusion en provenance de la marge de la nappe glaciaire du Pliocène tardif se sont jetés dans la vallée de la rivière Indian à partir de la ligne de partage avec le bassin de la rivière Stewart. Il existait à cette époque un ou plusieurs lacs dans la vallée de la rivière Indian. Les mécanismes de formation du ou des lacs incluent un embâcle glaciaire régional des eaux de drainage ancestrales du Yukon (Lac glaciaire Yukon) ou un embâcle local par des cônes alluviaux ou des glissements de terrain. Les indices sont insuffisants pour éliminer l'une ou l'autre de ces hypothèses. Il existe peut-être un gravier placérien sous le remblai de sable dans un segment enfoui de la vallée pré-glaciaire de la rivière Indian près de la confluence du ruisseau Montana.

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INTRODUCTION

The Indian River basin lies beyond the pre-Reid glaciation limit that marks the all-time limit of regional glaciation by a Cordilleran ice sheet (Fig. 1 and 2 (on adjacent page)). Lateral and vertical accretion of coarse gold-bearing alluvium (White Channel Gravel equivalent) filled the Indian River valley during the Pliocene (Westgate and Froese, 2001; Westgate et al., 2002). However, during an early regional (pre-Reid) glaciation, meltwater torrents from an ice sheet in the Stewart River valley entered the Indian River valley via a gap between Wounded Moose Dome and Australia Mountain (Figs. 2, 3). This incursion deposited a black chert-bearing valley train of extra-basinal gravel (Bostock 1942, 1966; Lowey, 1999; Froese et al., 2001).

To further understand the interrelationships of these sediments and the events that caused their deposition, high terraces along Indian River were mapped and their stratigraphy investigated as a part of the Late Cenozoic geology component of the Ancient Pacific Margin National Mapping Project (NATMAP). This included measurement, description, and sampling of the sediments underlying these terraces (Fig. 2). The high terraces are complicated in composition: alluvial fan gravel locally forms the tops of mesa-like terraces or overlies and intergrades with valley train gravel. Furthermore, thick successions of sand underlie the valley train gravel or appear to be lateral facies equivalent to it.

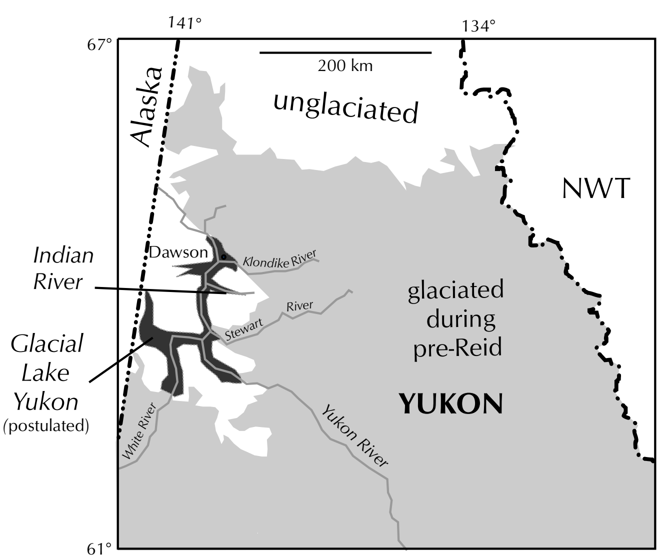

Figure 1. *Cordilleran glaciation limits and extent of Glacial Lake Yukon during the most extensive pre-Reid glaciation (modified from Duk-Rodkin, 1999 in the Stewart River valley after Jackson et al., 2001.*

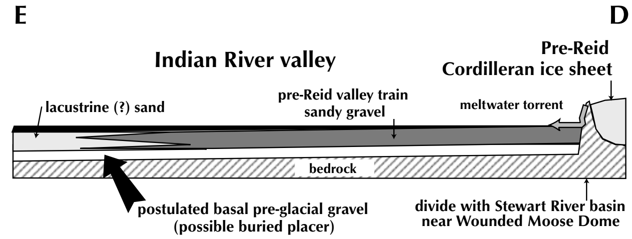

Figure 3. *Longitudinal profile (D-E) showing general facies relationships between pre-glacial gravel, pre-Reid valley train and lacustrine sand along a length of Indian River. A thick succession of valley train gravel and sand likely buries sediments equivalent to White Channel Gravel. Potential placers may exist within this buried unit.*

In this paper, we postulate that these sands are lacustrine in origin and we address the following questions:

1) What is the relationship between the valley train and the alluvial fan gravel?

2) What is the origin of the thick sand units and what relationships do they have with the valley train gravel?

3) Are there potential gold placers within this valley train gravel?

REGIONAL SETTING

Indian River, a gravel bed stream, is a tributary of Yukon River. The Indian River basin lies within the Klondike Plateau (McConnell, 1905; Mathews, 1986), a gently sloping upland south of Tintina Trench consisting of accordant summits (e.g., King Solomon Dome, Australia Mountain). The present flood plain descends about 53 m over a distance of 33 km with an overall gradient of about 1.6 m/km between the confluences of Dominion Creek and Ruby Creek, the reach of Indian River investigated in this paper.

Indian River forms the southern boundary of the Klondike placer district. Indian River and its tributaries are currently the largest placer gold producers in Yukon (LeBarge, 2002). In 2001, Indian River alone produced approximately 119 999 g (3840 ounces) of gold. Gold fineness is generally 780-843 (LeBarge, 2002). Placer diamonds have also been reported to have been recovered from gold mining operations (Casselman and Harris, 2002).

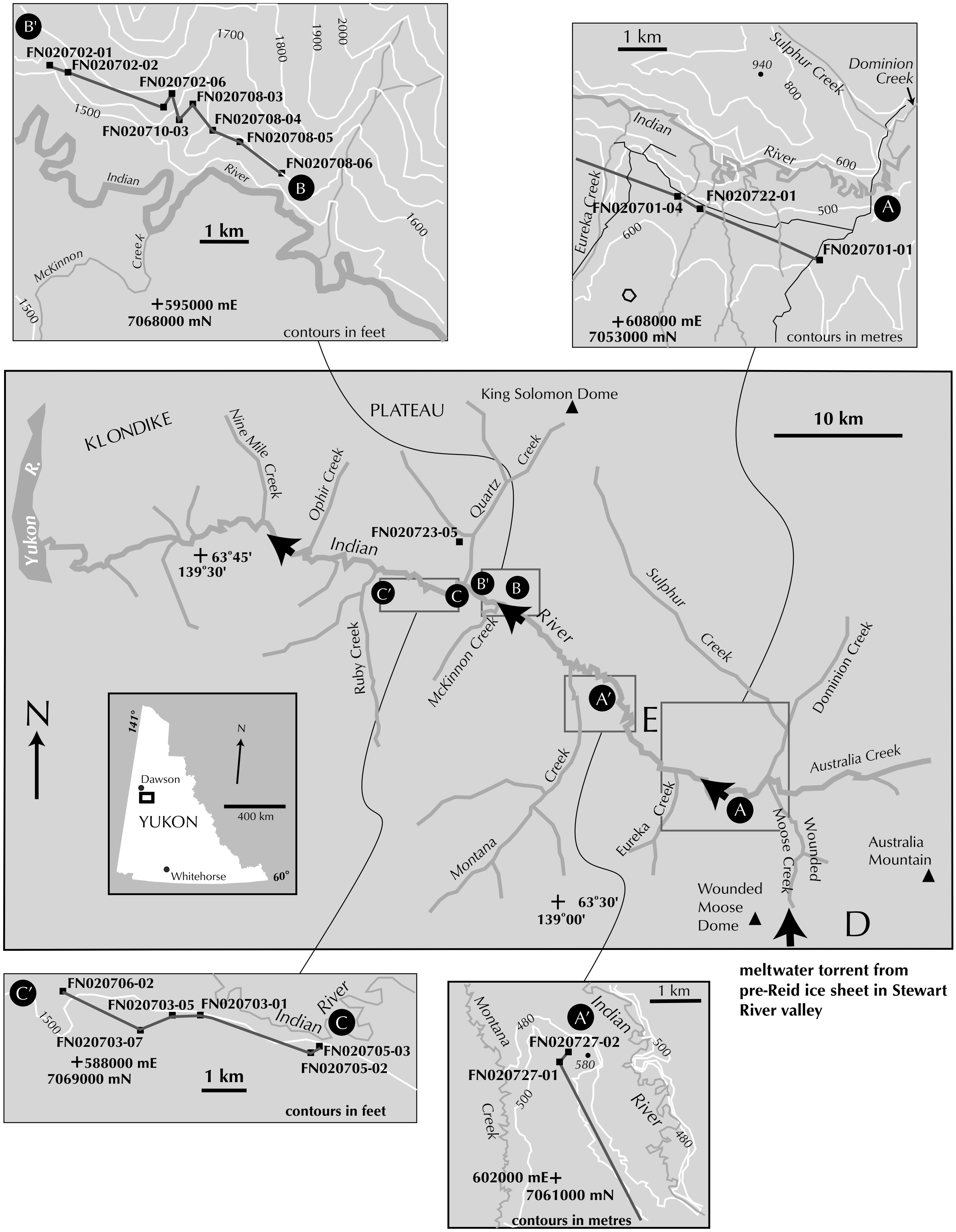

Figure 2. *Location map. Boxes indicate central parts of exploded views arrayed above and below. Profiles D-E, A-A', B-B' and C-C' are depicted in Figures 3, 6, 7 and 8, respectively. Base stations are shown by small solid squares and FN numbers.*

PREVIOUS WORK

Bostock (1942, 1966) noted black chert pebbles in outwash gravel of the Indian River valley and deduced that they were deposited by torrents draining the margin of an early Cordilleran ice sheet that reached the divide between Indian River and Stewart River basins near Wounded Moose Dome. Milner (1984) presented a comprehensive report on the geomorphology of the Indian River valley in the vicinity of Quartz Creek, as well as the metallurgy, grade and potential volume of gold, for the purpose of encouraging placer development in this area. Morison et al. (1998) described four sections in the high-level terrace in the Indian River valley upstream of the mouth of Quartz Creek. Lowey (1999) described Indian River drainage basin placers and used a system composed of five classes to group the placer deposits. He assigned the high-level terraces along Quartz Creek and Indian River to Bench Placer 1 and 2, respectively. These are characterized by approximately 16 m of slightly muddy, sandy gravel dominated by quartz clasts. Lowey (1999) interpreted this gravel as representing paleofloodplain deposits of a braided stream. Duk-Rodkin (1999) mapped glacial limits in the divide areas of Indian River basin and identified minor channels that carried meltwater from an early Cordilleran ice sheet into upper Australia Creek, as well as the major channel near Wounded Moose Dome previously noted by Bostock (1966). Froese et al. (2001) have dated placer deposits along Dominion Creek, a major tributary of Indian River, relative to the geopolarity time scale.

THIS STUDY

Accurate terrace elevation determinations were vital for the success of this study. Elevations determined from 1:50 000-scale topographic maps or single frequency handheld global position system devices were not adequate. A dual frequency global position system (DFGPS) survey was conducted along the Indian River valley to determine terrace elevations. This methodology has a decimetre-scale accuracy.

DFGPS METHODOLOGY

A summary of the theory of DFGPS can be found in Shimamura et al. (2000). As part of this survey, a base station was set up in the Dawson City area over a week-long period in early July, 2002 (Fig. 4a). Nine roving GPS stations were set up for observational periods of an hour or more in the Indian River valley during this period (Fig. 4b). Base and roving stations consisted of an Ashtech choke ring antenna, mounted on a surveying tripod. Transportation to roving stations was by truck, helicopter and foot. Stations were marked by 22-cm iron stakes, and tripods were centred over them using a tribrach. Stakes were left in the ground under a small rock cairn in the event of resurveying. An Ashtech Zxtreme GPS receiver was connected to an antenna by coaxial cable at each site. The base station (FN01) was situated at the GSC field camp at Callison Industrial Park, Dawson City, in the Klondike River Valley (Fig. 4a). An elevation mask was set to 5° at all GPS stations in order to reduce multipath error. At each station, the specific antenna height was calculated and entered into the receiver prior to starting the session. Sessions ran for at least one hour, with the base station session running concurrently. The data was periodically downloaded from the PCMCIA cards within the two receivers to a notebook computer. While at the field camp, the quality of the receiver data was checked using the DOS-based program TEQC (Transformation, Editing, Quality Check). The data was digitally transmitted to the Pacific Geoscience Centre/GSC in Sidney, BC for further post-processing.

LOCATION, ELEVATION AND DESCRIPTION OF SECTIONS

A laser range finder, Suunto PM-5 clinometer and pocket transit were used for trigonometric leveling in open traverses, tying section stations to the GPS benchmark stations. The data was logged in the field notebook and the trigonometry was later calculated using an Excel spreadsheet. Plan and cross-sectional plots of the traverses were plotted using AutoCAD version 13.

Detailed sedimentologic descriptions were completed at over 25 sites. Samples were collected from representative units for grain size, pebble lithology, paleoecology and heavy mineral analysis. Units were correlated based upon lithology, degree of weathering, grain size and stratigraphic position.

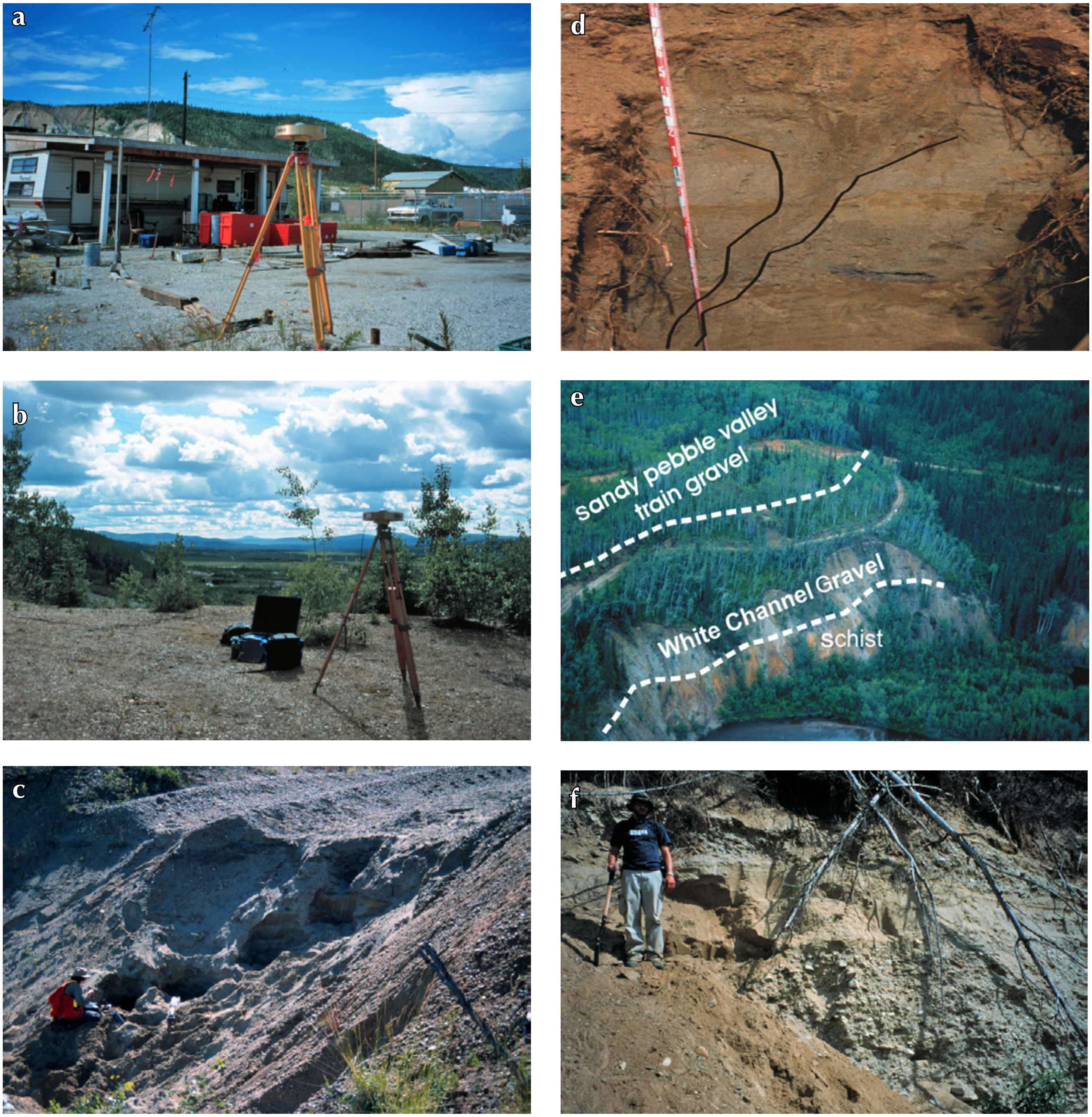

Figure 4. (a) *GPS base station (FN01) at Dawson City. Gravel exposure in background is Klondike Gravel at Jackson Hill (540 m).* ***(b)*** *GPS rover station in the Indian River valley (view upstream).* ***(c)*** *Thick sand bed 2 km upstream from the mouth of Eureka Creek. Sand abruptly overlies planar stratified coarse gravel immediately below seated person (Station FN020701-04).* ***(d)*** *Ice-wedge pseudomorph (indicated by line) buried within bedded fine sand and silty sand near the confluence of Montana Creek (Station FN020727-01).* ***(e)*** *A complete section through the fill underlying a high terrace on north side of Indian River valley (in the area of FN020702-02). Sandy pebble gravel and pebbly sand (top of section) contain chert pebbles. Underlying White Channel Gravel is derived from the Indian River basin upstream (right) or uplands to the north (top of photo).* ***(f)*** *White Channel equivalent gravel shown in B-B', section FN020708-06 (stratigraphically below sand unit).*

RESULTS

GRAVEL TYPES

Three categories of gravel lithologies are found within the high terraces along Indian River. These are called types 1, 2 and 3 for convenience (Fig. 5). Type 1 gravels are derived predominantly from the northern tributaries of Indian River. Pebble and coarser clasts consist of milky quartz, metaquartzite, mica schist, and lesser amounts of gneiss. Type 2 gravel reflects contribution of southern tributaries that are underlain by the Carmacks Group (Lowey and Hills, 1986; Lowey et al., 1986) to Indian River. The dominant lithologies in type 2 gravels include light- and dark-coloured quartzite with green and black mica schist. Type 3 contains lithologies that are exotic to the Indian River basin, most notably black chert and black chert-pebble conglomerate most likely derived from the Devono-Mississippian Earn Group in central Yukon. Type 3 was deposited as a valley train (outwash), by torrents from a Cordilleran ice sheet that crossed the divides between the Stewart River basin and Indian River (Bostock, 1942, 1966; Duk-Rodkin, 1999).

HIGH-LEVEL TERRACE STRATIGRAPHY

Three stratigraphic lines (A-A', B-B', C-C') present the stratigraphy of the high-level terraces, moving in a downstream direction (Figs. 2, 6, 7, 8). All elevations (right-hand scale) denote the upper surface of terrace gravel. The left-hand scale indicates section thickness.

Dominion Creek to Montana Creek

Figure 6 (section A-A') depicts the succession of sediments found in exposures along the south side of the Indian River valley between Dominion and Montana creeks. The surface of the highest terraces descends approximately 60 m over about 12 km or at an average gradient of 5 m/km. The gravel directly underlying the surface fines downstream from a pebble gravel at station FN020701-01 to a pebbly coarse sand at station FN020727-01. A borrow pit exposes 25 m of gravel at Station FN020701-04. The gravel contains black chert and chert-pebble conglomerate indicating that it is outwash (type 3). The lowest 2.5 m of the section is horizontally stratified sandy pebble gravel. This is abruptly overlain by about 5 m of massive to cross-laminated sand and slightly pebbly sand (Fig. 4c). The section progressively coarsens upward into interbedded pebbly coarse sand and sandy pebble gravel. A Wounded Moose paleosol (Smith et al., 1986) has developed within the upper 2 m of the section.

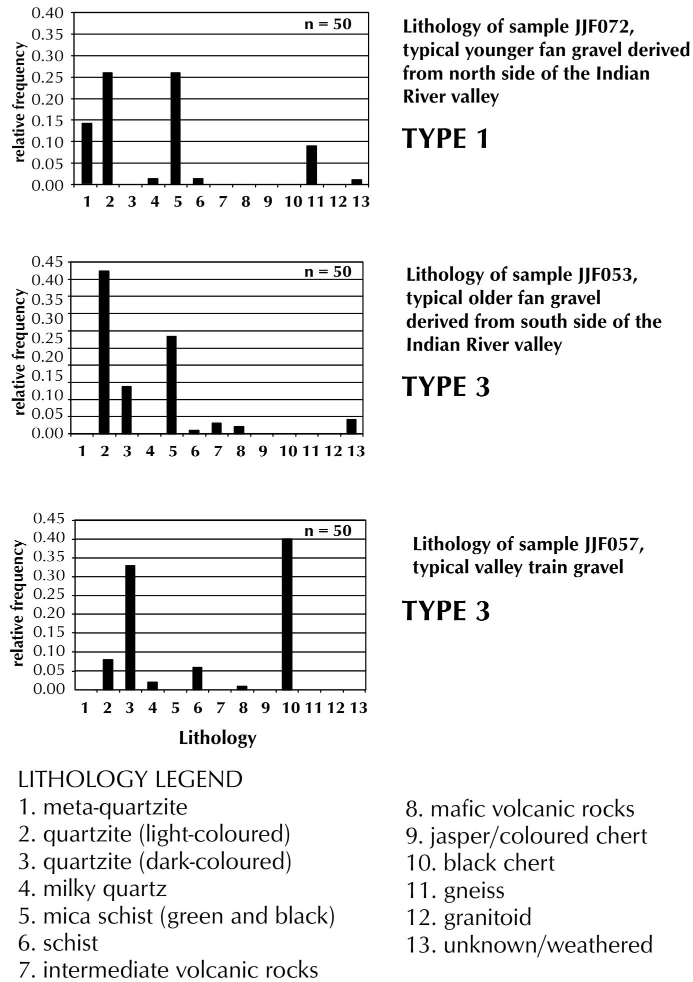

Figure 5. *Pebble lithologies of selected gravel samples illustrating differences of gravels derived from the north and south sides of the Indian River valley and valley train gravel.*

A thick sequence of fine sand also occurs in a smaller exposure at station FN020722-01 (Fig. 6) located about 480 m to the east. Approximately 9 km further downstream, stations FN020727-01 and FN020727-02 lie in exploration trenches cut into the upper part of a sedimentary fill within an entirely buried reach of the Indian River valley immediately upstream of the present confluence of Montana Creek (Fig. 2). The present anomalous course of Indian River is between bedrock cliffs immediately to the north of the buried preglacial valley. Sections at FN020727-01 and FN020727-02 are predominantly fine sand interbedded with sandy pebble gravel (Fig. 6). They contain several disconformities marked by ice-wedge pseudomorphs. These indicate

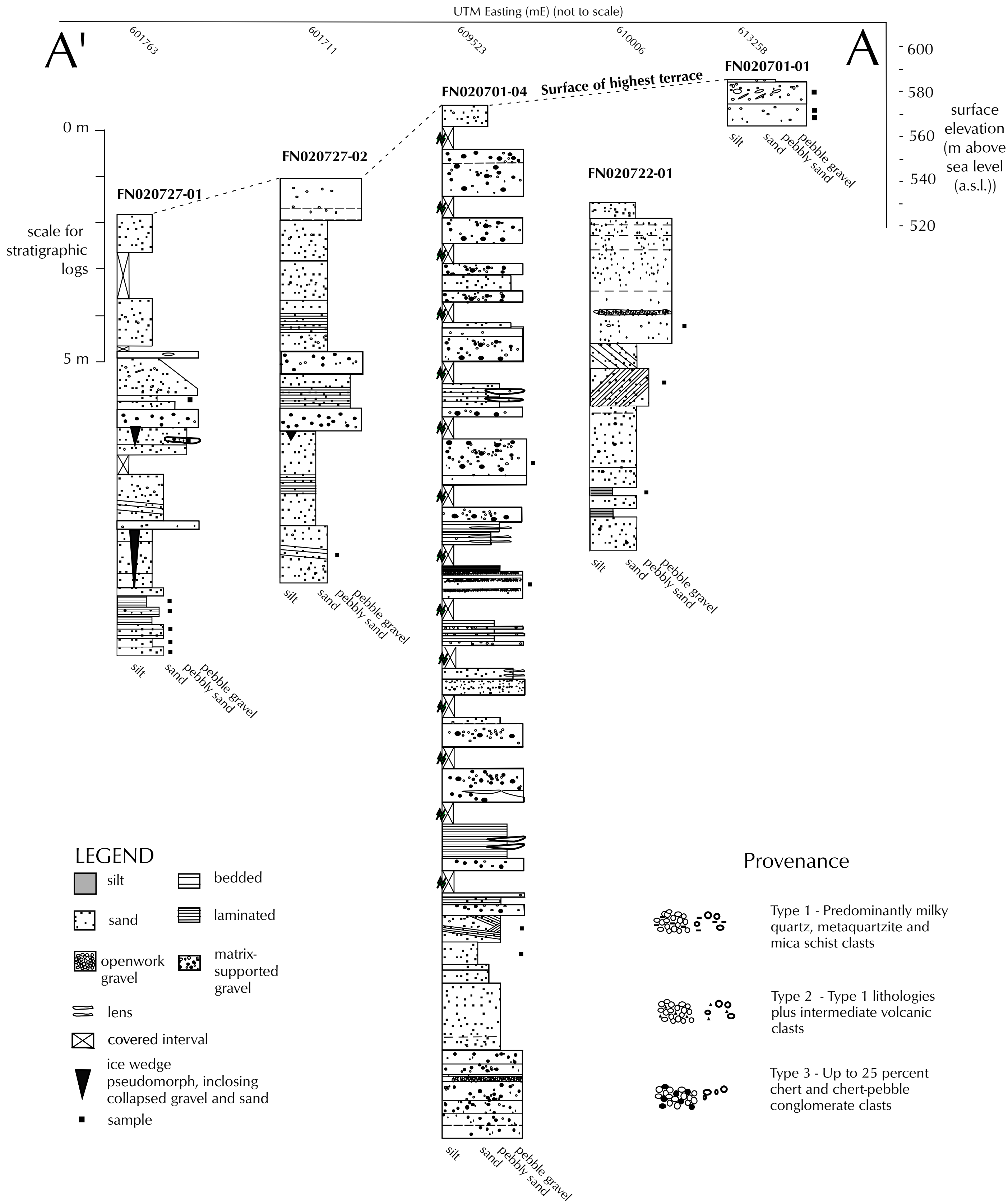

Figure 6. *Stratigraphic line A-A' on high-level terrace between Wounded Moose and Montana creeks. Profile location depicted on Figure 2.*

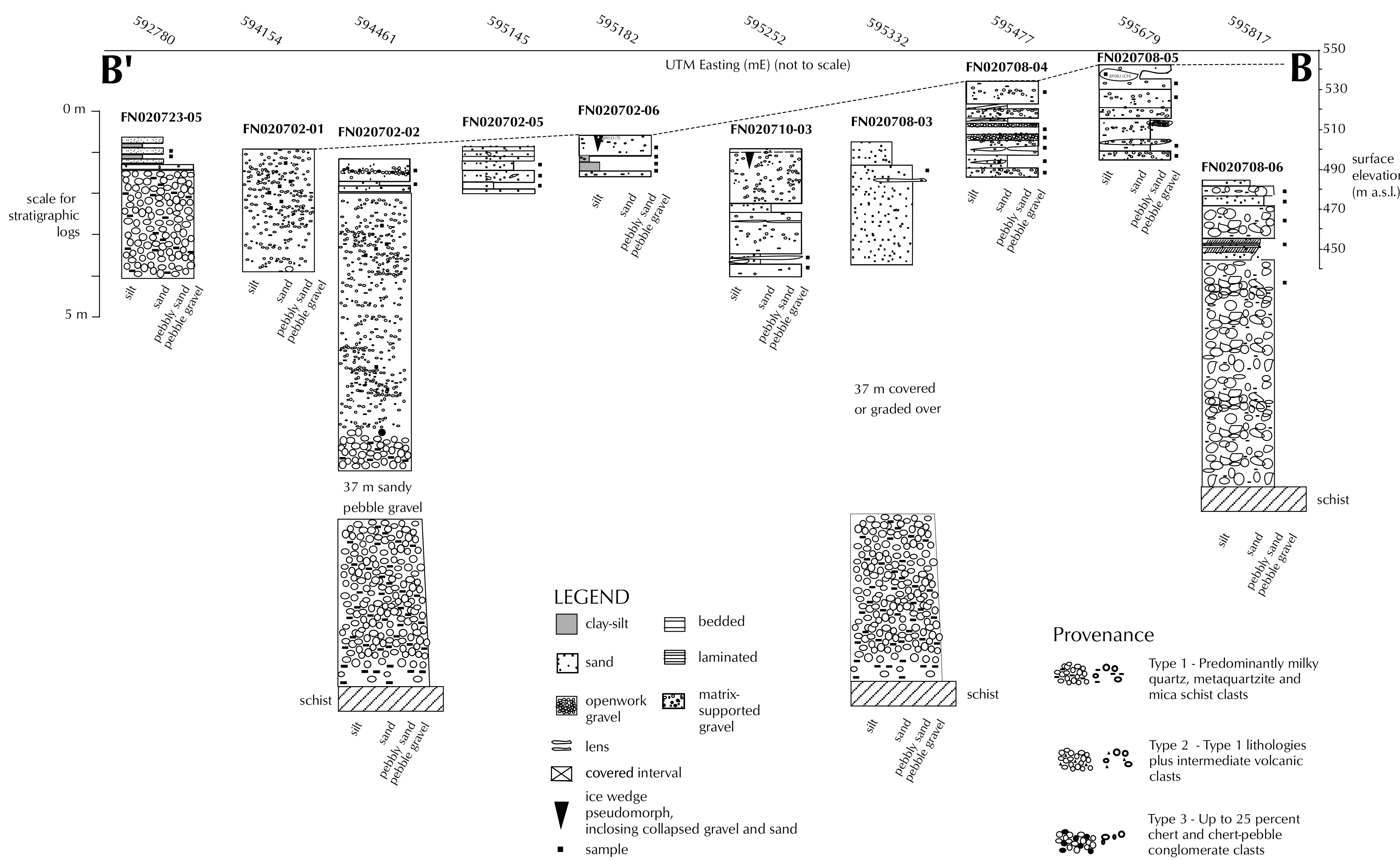

Figure 7. *Stratigraphic line B-B' on high-level terrace upstream of the mouth of Quartz Creek. Gaps in sections are not to scale. Profile location depicted on Figure 2.*

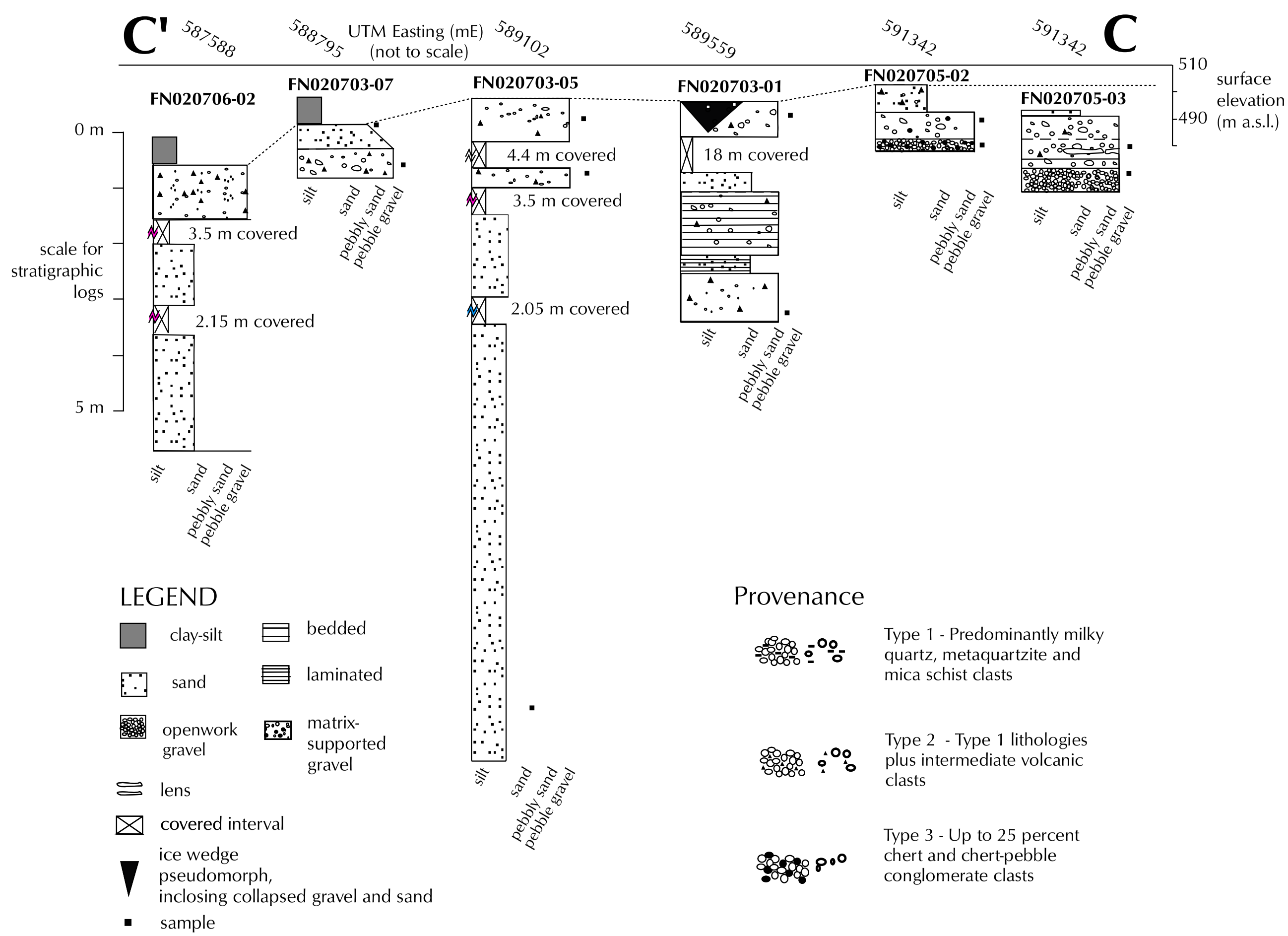

Figure 8. *Stratigraphic line C-C' on high-level terrace between McKinnon and Ruby creeks. Gaps in sections are not to scale. Profile location depicted on Figure 2.*

periods of nondeposition under periglacial conditions during which the sandy fill was exposed and then buried when deposition of the valley fill resumed. The fill is part of the Indian River valley train because black chert sand and pebble clasts occur throughout the exposure.

High-level terrace stratigraphy immediately upstream from the mouth of Quartz Creek

Section B-B' (Fig. 7) depicts the succession of sediments underlying the terraces upstream of Quartz Creek. These sediments are exposed in roadcuts, exploration trenches and natural cliffs discontinuously extending 3 km upstream from the mouth of Quartz Creek along the north side of the Indian River valley. At sections FN020702-02, FN020710-03 and FN020708-06, type 1 sandy cobble-pebble gravel (Fig. 4c) overlies bedrock and fines upwards. At section FN020702-02, the most complete section, gravel grades upward into a type 3 chert-bearing gravel approximately 6 m below the top of the exposure. The succession at FN020702-02 is identical to the well known upward succession of White Channel Gravel and Klondike Gravel in the area of the confluence of Bonanza Creek and Klondike River (e.g., Froese et al., 2000, their Fig. 7) and is apparently the same age. The gravels at both locations reflect the incursion of the most extensive pre-Reid Cordilleran ice sheet into the region (Fig. 1). Type 3 gravel is commonly cut by ice-wedge pseudomorphs. The gravel grades laterally into sand and pebbly sand in and around section FN020702-02 (Fig. 4e), indicating a change from gravelly flood plain or alluvial fan to low- energy conditions during the culmination of the sedimentary fill. Section FN020723-05 is situated along lower Quartz Creek at the top of the White Channel Gravel that fills the bottom of this valley. It lies upstream from the influence of the valley train gravel. A cut created by an exploration cat trail indicates that the White Channel Gravel grades upward into interbedded fine laminated sand and silt. It lies at about the same altitude as FN020708-03 and may represent the same low-energy environment that influenced sedimentation along the lower part of Quartz Creek valley.

High-level terrace stratigraphy immediately between Quartz Creek and Ruby Creek

Cross section C-C' (Fig. 8) depicts the succession of sediments underlying terraces between Quartz and Ruby creeks. These sediments are exposed in roadcuts, exploration trenches along terraces and the sides of intervening valleys along the north side of the Indian River valley between Quartz and Ruby creeks. Chert-bearing type 3 gravel is present along the surfaces of all terraces. Where undisturbed, the upper 2 m of sediment underlying the terraces commonly contain Wounded Moose paleosols, which are cut by ice-wedge pseudomorphs up to several metres in width and over 2 m in depth. Plentiful volcanic clasts also occur in this gravel, reflecting stream transport of sediment from the uplands to the south. No sections provide a complete exposure of stratigraphy from bedrock to terrace surface along this reach of the Indian River valley. However, discontinuous exposures and hand-auger probing of deposits indicate that two distinct successions of sediments underlie the terrace. The first succession type is represented by section FN020703-01. It is a composite of trench and road-cut exposures along an exploration road that descends northward to the Indian River from a high terrace. It is capped by type 3 gravel but is underlain at depth by bedded type 2 sandy pebble gravel and pebbly sand. The second succession type consists of thinly bedded or laminated to featureless silty fine sand. Sections FN020706-02 and FN020703-05 typify this succession. They are constructed from exploration trenches and hand augering of intervening slopes, which best represent this sand that can be traced along the 2 km separating these sections. This sand coarsens upward into the overlying type 3 gravel or type 2 gravel derived from uplands to the south. The sand contains scattered chert clasts. The chert-free gravelly sediments of FN020703-01 (lower interval) apparently grade laterally into or underlie the sands of FN020706-02 and FN020703-05. The lower FN020703-01 chert-free gravel is thought to be fan sediments that were built into the Indian River valley prior to, or during, the deposition of the chert-bearing sand in FN020706-02 and FN020703-05. The lower FN020703-01 chert-free gravel lies at the same elevation as similar gravel across the Indian River valley (cross section C-C') and is correlated to the White Channel Gravel.

POTENTIAL BURIED PLACERS AND DEPOSITIONAL RECONSTRUCTION

Schematic reconstructions of stratigraphy and depositional events are presented in Figs. 3 and 9. Placer gold environments, both known and potential, are noted on the reconstructions. The general scenario follows that of previous workers (Bostock, 1942, 1966; Lowey, 1999) whereby valley train gravel from the Stewart River basin covered gold-bearing braided stream floodplain gravel.

The chronology assumes equivalence of type 1 and type 2 gravels to White Channel Gravels where they overlie bedrock (e.g., base of sections FN020702-02 and FN020708-06, Fig. 7). The White Channel Gravel has been constrained in age in the Quartz Creek basin by dating of the overlying Quartz Creek tephra at about 3 Ma (Westgate and Froese, 2001; Westgate et al., 2003). The age of the deposition of the outwash gravel is assumed to be the same age as Klondike Gravel in the Dawson City area, which was deposited during the most extensive, and apparently, first regional (pre-Reid) glaciation, which has been assigned to the Late Pliocene (Westgate et al., 2001). The Wounded Moose paleosols in the upper part of the terraces indicate a minimum Early Pleistocene age.

Valley train gravel and sand units buried the White Channel Gravel in many locations. It also raised the local base level in Dominion, Eureka and Quartz creeks (Milner, 1977). There is a high potential for buried gold placers at the base of the extensive fill within the pre-glacial Indian River valley, between the present course of Indian River and Montana Creek (Fig. 9). Here, the fill of White Channel Gravel and overlying outwash diverted Indian River to the north side of a bedrock knob, where a new valley was cut by subsequent river incision. Although the placer gold content of the fill remains to be evaluated, it is thought to be of high potential for placer gold considering its location immediately downstream from known producing tributaries, Eureka and Dominion creeks. A younger analogue is the buried auriferous Middle Pleistocene Ross gravel along lower Dominion Creek (Froese et al., 2001).

MECHANISMS OF LAKE FORMATION

As noted above, sand makes up much of the fill underlying terraces along the Indian River valley. The overall gradient of the surface of the terrace fill between Dominion and Eureka creeks is approximately 3.5 m/km. This is about twice the gradient of the floodplain of the contemporary Indian River. In order to deposit the extensive sand fills, the valley gradient had to have been much gentler. We suggest, on the basis of the thinly bedded sand and silty sand that makes up much of the fill, that sedimentation occurred, at least partly, in a lake. We present two hypotheses for the origin of a lake or lakes in the Indian River valley. Neither of these can be fully tested or rejected based upon the evidence at hand due to the paucity of continuous exposures.

HYPOTHESIS A: SAND AGGRADED TO STANDS OF GLACIAL LAKE YUKON

Glacial Lake Yukon (GLY) is the name given to a lake inferred to have formed when a pre-Reid ice sheet blocked the paleo Yukon River drainage (Duk-Rodkin, 1999; Fig. 1). Spillage of ancestral Yukon drainage into Alaska resulted in the creation of the contemporary Yukon River drainage (Duk-Rodkin et al., 2001). We propose that the extensive sand units in the Indian River valley may have been deposited in an arm of GLY that extended up the valley to near the mouth of Dominion Creek. The sedimentary sequences seen within the sections described above are consistent with predictable attributes of sediments deposited into the arm of a large, rapidly formed and distantly glacially dammed lake (e.g., Smith and Ashley, 1985):

1. Where fluvial and glaciofluvial streams entered this lake, rapid facies changes from gravel to sand would be expected (e.g., FN020701-04, Fig. 6).
2. Such facies changes would be expected where a valley train suddenly becomes inundated by a rising lake. This would be succeeded by a coarsening-up sequence as coarser sediments prograded into the lake (FN020701-04, Fig. 6).
3. As glacially dammed lakes are unstable and prone to outburst floods and rapid drainage, marginal sedimentary sequences would provide evidence of fluctuations of lake elevation with subaerial exposure occurring between sedimentation intervals (e.g., FN020727-01 and FN020727-02, Fig. 6).
4. Locations distant from the ice dam would be dominated by thick accumulations of very fine sand and silt (e.g., FN020706-02 and FN020703-05, Fig. 8).

The elevation of the GLY spillway is not known. However, if the Indian River fill does prove to have been deposited in GLY, the highest elevations at which thick sand suddenly succeeds gravel, about 530 m, would be a minimum value for the initial elevation of this spillway.

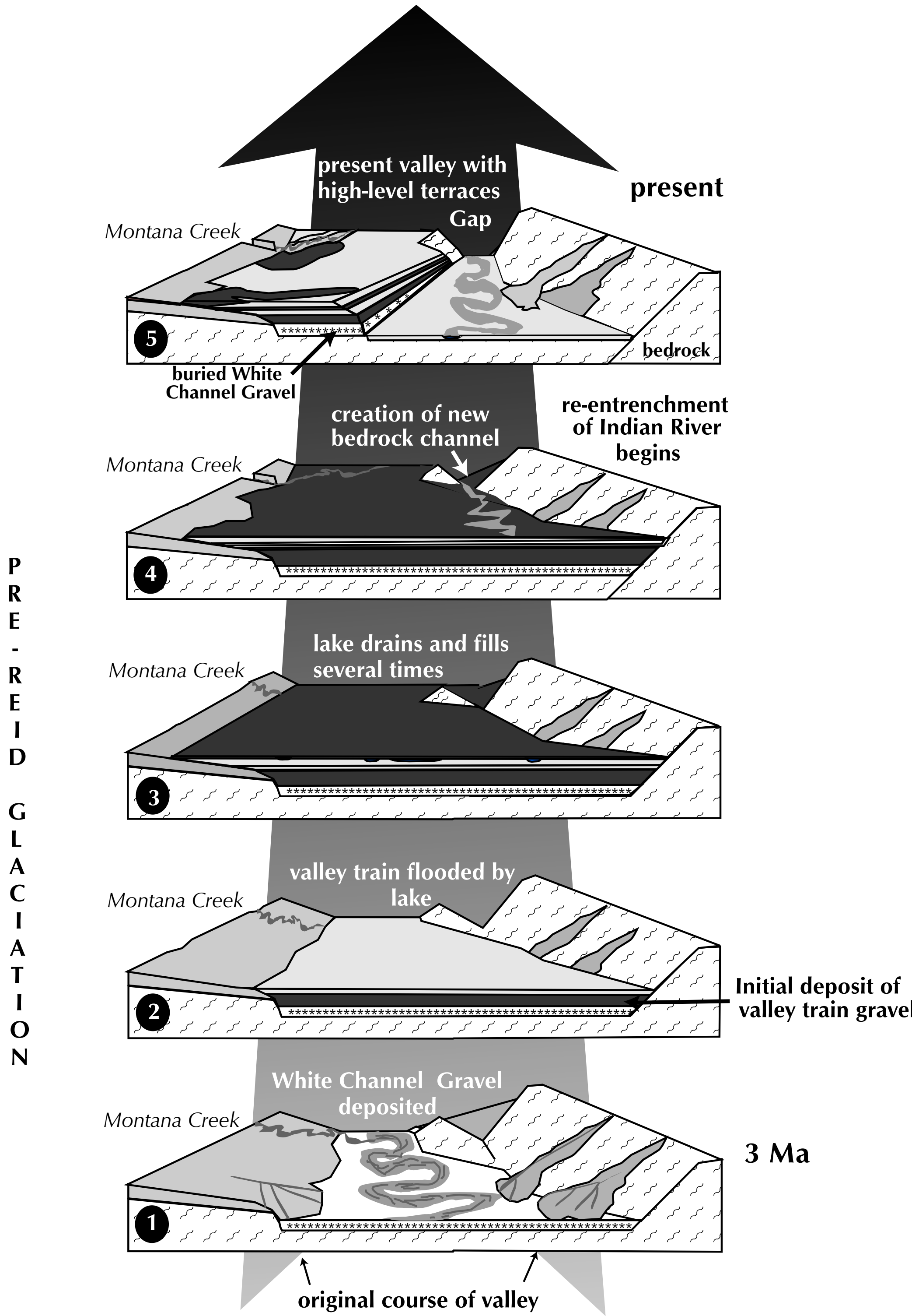

Figure 9. *Conceptual reconstruction of depositional and erosional events in the Indian River valley from about 3 Ma until present (large arrow indicates the direction of time). View downstream from vicinity of mouth of Eureka Creek. Sequence explains the diversion of Indian River through the narrow bedrock gap opposite the mouth of Montana Creek and the likely burial of White Channel Gravel (indicated by small stars) within a buried segment of the preglacial Indian River valley between lower Montana Creek valley and the present course of Indian River. The present Indian River valley represents 2 Ma of incision.*

HYPOTHESIS B: SAND AGGRADED TO TEMPORARY LAKES FORMED BY THE DAMMING OF INDIAN RIVER BY ALLUVIAL FAN GRAVEL OR LANDSLIDE

Alternatively, the intervals of low energy sedimentation could represent a temporarily dammed lake or string of lakes created by the impoundment of ancestral Indian River by alluvial fans or landslides. For example, in the narrow section of the Indian River valley below Ophir Creek (Fig. 2), rapid building of a fan, from one or more tributaries in this area or a landslide, could have lowered the stream gradient in the Quartz Creek area, which explains the deposition of extensive fine sand along the reach spanned by C-C'. Similarly, sands seen in the A-A' and B-B' reaches may have been deposited in lakes impounded by fans built out into the Indian River valley. Although no evidence of such landslides or an alluvial fan has been noted in the Indian River valley, upward of 3 Ma of incision and lateral erosion by Indian River could have erased evidence of such events.

There is no way to presently exclude either the glacially dammed lake or the fan/landslide hypotheses due to the relative paucity, and fragmented nature, of terrace sediment exposures.

CONCLUSIONS

The gravel fill underlying the high terraces along Indian River reflects three sources: schistose terrain to the north of the river (type 1), terrain underlain by extensive volcanic rocks to the south of the river (type 2), and valley train deposits (type 3) containing extensive amounts of black chert and chert-pebble conglomerate external to the basin. The type 1 and 2 gravels, where they overlie buried bedrock straths that mark the floor of ancestral (pre-glacial) Indian River valley, are equivalent in age to White Channel Gravel. The emplacement of the valley train fill likely has preserved these potentially auriferous gravels in a buried portion of the pre-glacial Indian River valley in the area of the confluence of Montana Creek and Indian River. This segment of the pre-glacial course was preserved due to the cutting of a new course to the north by the Indian River following valley train sedimentation.

Extensive bodies of sand occurring within the Indian River valley fill were deposited in one or more lakes. Two hypotheses are proposed to explain the development of the lake or lakes. The first is that an arm of Glacial Lake Yukon, impounded during the most extensive pre-Reid glaciation, extended up the Indian River valley. The second is that one or more alluvial fans or landslides affected the gradient of the valley, forming local lakes or reaches of reduced gradients. Insufficient exposures are present to effectively test these hypotheses.

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Distal micro-tephra deposits in southeast Alaskan peatlands

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ABSTRACT

Volcanic ash (tephra) provides a valuable tool in palaeoenvironmental research. Traditionally, the main emphasis in tephra studies has been on layers which are visible to the naked eye. Recently a large body of work in Europe has been established investigating microscopic tephra layers. Microscopic methods have allowed a massive expansion of the known limits of tephra deposition; however, they have rarely been used elsewhere in the world. This report summarizes the first use of these methods in northwestern North America. Five peatland sites in southeastern Alaska were cored and analysed for tephra. A total of 14 significant layers were recovered, representing a minimum of 4 different tephras. While it is not yet possible to identify the source of these layers, these results are significant as they show that microscopic methods may prove a valuable tool enabling an expanded tephrochronology and a better understanding of volcanic impacts in the region.

RÉSUMÉ

Les cendres volcaniques (téphra) constituent un outil très utile pour la recherche paléo-environnementale. Jusqu'à ce jour, les études portant sur le téphra étaient surtout axées sur les couches visibles à l'œil nu. De nombreux travaux récents ont toutefois été réalisés en Europe sur les couches microscopiques de téphra. Ils ont permis de repousser les limites connues du dépôt des téphras, mais ces méthodes microscopiques ont été peu utilisées ailleurs dans le monde. Le présent rapport résume la première utilisation de ces méthodes dans le nord-ouest de l'Amérique du Nord. On a prélevé des carottes dans cinq tourbières du sud-est de l'Alaska que l'on a analysées pour leur teneur en téphra. On a ainsi récupéré 14 couches significatives, représentant 4 téphras différents. Même s'il n'est pas encore possible d'identifier la source de ces couches, les résultats sont importants dans la mesure où ils montrent que les méthodes microscopiques peuvent s'avérer un outil valable pour perfectionner la téphrochronologie et mieux comprendre les impacts volcaniques sur la région.

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INTRODUCTION

Volcanic eruptions produce large amounts of pyroclastic material; the finest fraction of this tephra may remain airborne for some time and be deposited over a large area. Tephra has been widely used in palaeo-environmental studies as it provides a time-specific marker horizon (isochrone). This allows age comparison between sites and, where the age of the tephra is known, a means of dating sediments. Tephrochronology has been used for over a century, particularly in areas close to volcanic source regions such as Iceland and New Zealand. In these areas, tephra layers are significant and readily identifiable by eye. More recently, methods have been developed which allow the use of tephrochronology in areas considerably more distant from the source regions. A large amount of recent research in this field has been devoted to investigating the distal deposition of tephra from Iceland in northern Europe. Since microscopic tephra layers were first found in Scotland by Dugmore (1989), similar methods have been employed to find Icelandic tephra in locations as distant as northern England, Ireland, Germany and western Scandinavia (Pilcher and Hall, 1992, 1996; Van den Bogaard et al., 1994, Wastegård et al., 2000, 2001). The methods employed here allow for the potential to expand tephra study in other areas of the world where only visible layers have been recognized. This could increase both the geographic range of known tephra deposition and the temporal extent, increasing the number of isochrones at any one site. This would allow an expanded potential for tephrochronology, as well as a better understanding of the spatial impacts of these eruptions.

Alaska contains over 100 volcanoes which have been active within the Quaternary, perhaps 8% of all active above-water volcanoes on earth (www.avo.alaska.edu, Alaska Volcano Observatory, October, 2003). The majority of these volcanoes are located in the Aleutian arc although other volcanic systems occur in the Wrangell Mountains, southeastern and interior Alaska. The visible tephra deposits of these eruptions have been studied throughout much of Alaska and Western Canada (e.g., Riehle, 1985; Begét et al.; 1992; Robinson, 2001). To date, no studies have investigated micro-tephra deposits from these volcanoes. There is therefore great potential to expand the study of tephrochronology in the region.

TEPHROCHRONOLOGY OF PEATLANDS

Peatlands make particularly good media for studying tephrochronology at a high resolution. The wet and well vegetated surfaces of bogs are efficient at trapping atmospheric particles, and tephra particles undergo minimal alteration in the low energy and acidic environment of peat (Zoltai, 1988; Dugmore et al., 1992). In addition, the continuous accumulation of peat in bogs allows long-term tephra histories to be established, the high organic content of peat makes extraction straightforward, and peat provides a good medium for radiocarbon dating.

The aim of this study is to use microscopic methods to establish the presence of micro-tephra deposits in an area which does not have a well-established tephrochronological record. The area chosen is southeastern Alaska; this region has the dual advantages of numerous suitable peatlands and a sufficient proximity to volcanic systems to make the presence of micro-tephras probable.

SITES

Five suitable peatland sites were identified in the Juneau and Haines areas (Fig. 1). All sites are Sphagnum-dominated and largely ombrotrophic (all nutrients

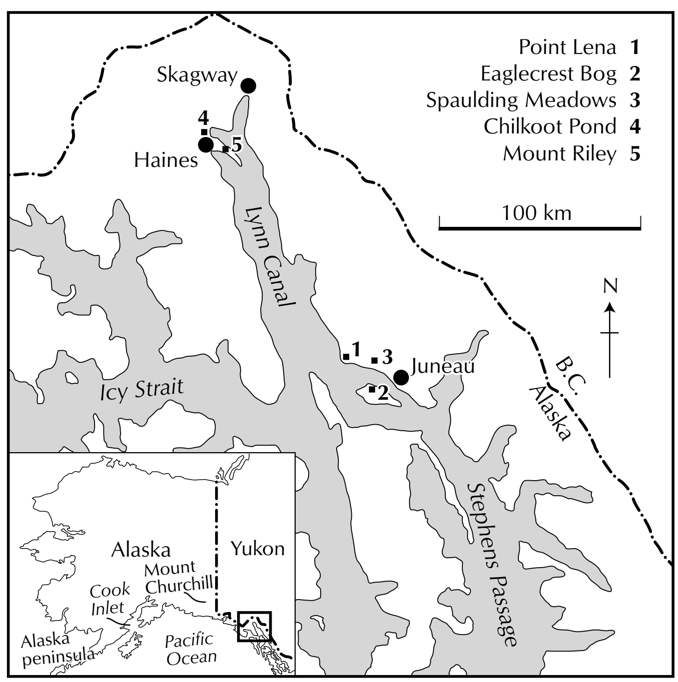

Figure 1. *Tephra sample sites (small, solid squares) in southeastern Alaska, and possible source regions (inset).*

supplied by precipitation). The sites include a range of peatland types including raised bog (Point Lena), upland blanket bog (Mount Riley, Spaulding Meadows), an intermediate site (Eaglecrest Bog), and a lake infill peatland (Chilkoot Pond). Further details of the structure and vegetation of the sites can be found in Payne (2003) and the references therein.

TEPHRA METHODS

The sites were repeatedly sampled (over five times) with a 4-cm-diameter auger to find the maximum depth of peat. A core was extracted from this deepest location using a Russian corer with a 5-cm-diameter, 50-cm-long chamber (Barber, 1984; Aaby and Digerfeldt, 1986). Extracted cores were placed in plastic gutter tubing and wrapped in plastic, the corer was cleaned after every core taken. Twin adjacent cores were taken and cores were overlapped by 5 cm using two separate boreholes for each core. A monolith was extracted from the surface where the peat was not solid enough to allow coring. The cores were packaged and returned to the United Kingdom for analysis in the laboratory.

A slightly modified version of the ashing method of Pilcher and Hall (1992) was used for tephra extraction. This method is quick and effective, however it is known to change the geochemical composition of tephra shards and is not suitable for sample preparation for geochemical analyses. Initially, contiguous 5-cm-diameter samples were sampled, oven dried and weighed. The dried peat was burned at 550°C and reweighed; the difference between these weights was used to calculate loss-on-ignition, used as an aid to rapidly locate the largest tephra layers. The residue remaining after burning was centrifuged for 5 minutes in 5 cm^3 of HCl at 3000 RPM. Following Caseldine et al. (1998), a Lycopodium inoculum was added in this stage to allow a quantitative count of tephra shards. The supernatant was then decanted off, 5 cm^3 of distilled water was added and the sample was centrifuged again. Finally, the supernatant was again decanted, 5 cm^3 of methanol added and centrifuged. The sample was transferred to a glass vial and the methanol left to evaporate. Slides were made up by mixing a drop of the final solution with glycerol. Tephra shards could then be located, described and counted under a microscope at 400x magnification. Where tephra was found to be present, the 5-cm sample was subdivided at 1-cm intervals to locate the zone of peak tephra concentration. The maximum tephra concentration in this 1-cm sample is shown in Table 1. This 1-cm sub-sampling stage was not carried out for one layer from the Spaulding Meadows site due to damage to the core in the intervening period.

RESULTS

A total of 14 significant tephra layers have been found in the 5 sites (Table 1, Fig. 2). All the tephra layers consist of small shards of volcanic glass, reaching a maximum of about 100 μm in length. Varying proportions of vesicular, columnar and platy shards are present; however this variation is insufficient to allow correlations to be made on the basis of appearance. For the rest of this paper the individual tephra layers are referred to by a code for their site followed by the depth of peak concentration. For instance, LNA39 refers to the layer at 39-cm depth in the Point Lena site.

DATING THE SEQUENCES

Preliminary radiocarbon dating has been performed on the cores. Bulk samples of approximately 1 cm^3 were submitted to the Natural Environment Research Council Radiocarbon Laboratory, East Kilbride, for AMS (accelerator mass spectrometry) radiocarbon dating. Dates were obtained from near the base of all the cores, with additional dates from near the middle of the longer Eaglecrest Bog and Point Lena cores. The raw radiocarbon dates were calibrated using the OXCAL program (Ramsey, 2002). The most probable 2σ calibrated age ranges and their mid-points are presented in Table 2.

The ages of the tephras have been inferred (Table 1) using the calibrated ages in Table 2. A constant, linear accumulation rate has been assumed and ages estimated based on the nearest available radiocarbon date. Studies have shown that while over a long period, peat bog accumulation rate may approximate to linear, there is considerable variation (Aaby and Tauber, 1975). It therefore seems likely that the real ages of these layers may differ from those estimated here by a substantial degree, and these estimates should be treated with considerable caution. It is likely that the errors will be greatest for the youngest tephra deposits, nearer to the top. This may be particularly the case for the tephras in the uppermost 50 cm due to accumulation rate differences between the acrotelm and catotelm (surface peat and relict peat). Age estimates for those tephras which are located adjacent to the dating points are likely to be more accurate, such as tephras MTR190 and

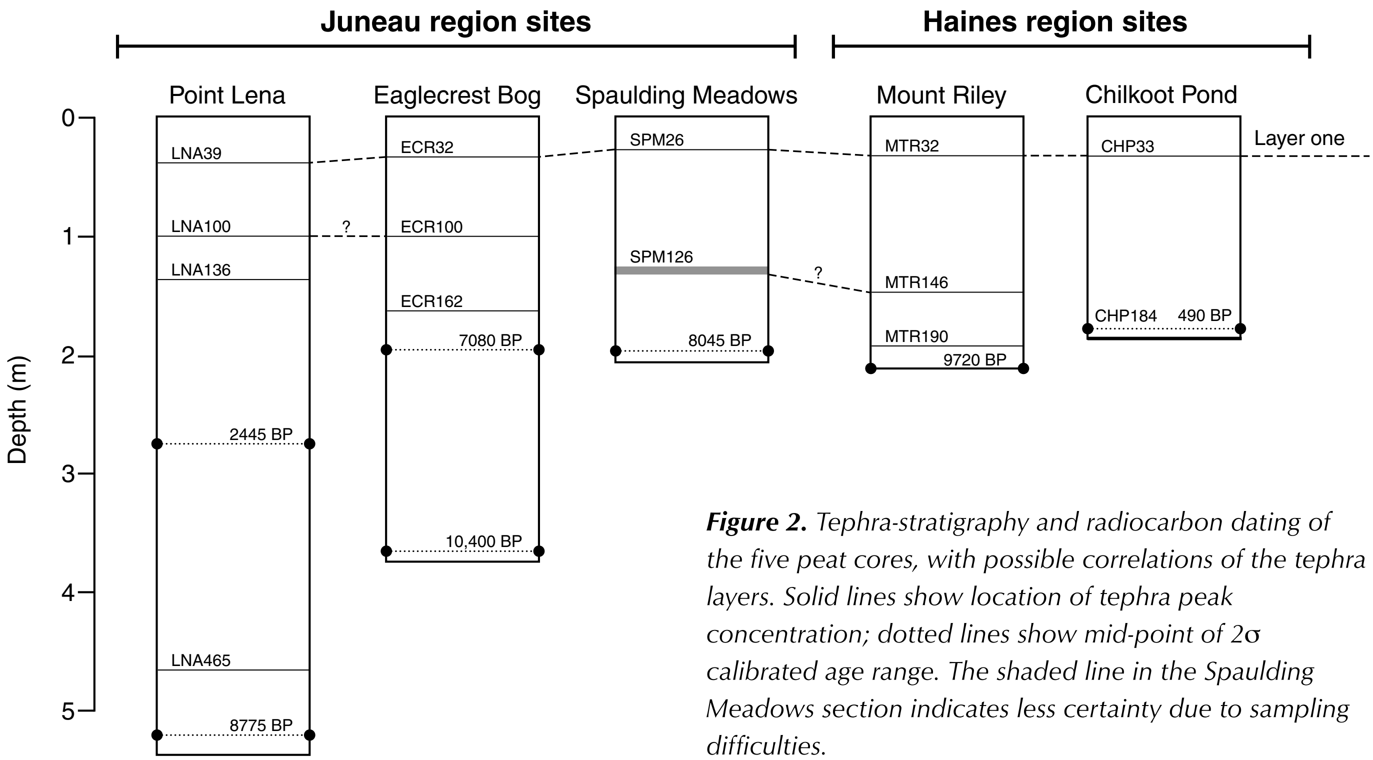

Figure 2. *Tephra-stratigraphy and radiocarbon dating of the five peat cores, with possible correlations of the tephra layers. Solid lines show location of tephra peak concentration; dotted lines show mid-point of 2σ calibrated age range. The shaded line in the Spaulding Meadows section indicates less certainty due to sampling difficulties.*

Table 1. *Tephra layer characteristics and inferred age estimate (see notes in text).*

Site name	Depth (cm)	Approximate maximum concentration (shards/gram)	Description	Age estimate (BP)
Mount Riley	32-33	2.7×10^4	Sparse layer. Small vesicular + columnar shards, 80% between 25-50 µm	1504
	146-147	1.6×10^4	Sparse layer. Shards vesicular mostly 50-75 µm	6780
	190-191	2.8×10^4	Sparse layer. Small highly vesicular shards, 80% below 50 µm	8816
Spaulding Meadows	26-27	1.7×10^6	Vesicular + columnar shards, mostly (60%) 50-75 µm	1067
	126-131	Unknown	A minor layer. More detailed description and accurate location not possible due to damage to core	5216-5376
Point Lena	39-40	2.9×10^6	Vesicular shards, 70% between 25-50 µm	351
	100-101	6.7×10^6	Shards mostly vesicular, 60% between 25-50 µm	893
	136-137	2.7×10^4	Small vesicular shards, most under 50 µm	1213
	465-466	8.9×10^3	Very sparse layer, much non-tephra mineral material. Shards vesicular generally less than 50 µm	7855
Eaglecrest Bog	32-33	1.9×10^6	Mostly vesicular shards with some columnar. Many (40%) above 50 µm	1179
	100-101	5.2×10^4	Sparse layer, much non-tephra mineral material. Vesicular shards with some platy and columnar. 80% between 25-50 µm	3648
	162-163	2.3×10^4	Small platy/vesicular shards, mostly <50 µm. Much non-tephra	5900
Chilkoot Pond	33-34	6.7×10^5	Mostly vesicular shards, 50% between 25-50 µm	N/A
	184-185	2.2×10^6	Numerous large vesicular/columnar shards, over 70% above 50 µm	N/A

Table 2. *Radiocarbon dates and calibrations.*

Laboratory code	Site	Depth (cm)	^{14}C date BP	2σ calibrated age range (BP)	Mid-point of calibrated age range (BP)
SUERC-564	Mount Riley	210	8688 +/- 65	9910–9530	9720
SUERC-565	Chilkoot Pond	175	468 +/- 55	560–420	490
SUERC-566	Spaulding Meadows	196	7207 +/- 53	8160–7930	8045
SUERC-567	Eaglecrest Bog	195	6183 +/- 56	7250– 6910	7080
SUERC-568	Eaglecrest Bog	365	9244 +/- 49	10,560–10,240	10,400
SUERC-569	Point Lena	275	2423 +/- 51	2550–2340	2445
SUERC-570	Point Lena	520	7919 +/- 83	9010–8540	8775

ECR162 (Fig. 2). The basal radiocarbon date from the Chilkoot Pond site is considerably younger than expected. This may be because the site represents lake infill. If the peat deposit developed as a schwingmoor (floating mire), accumulation would not be expected to be linear. It is therefore not possible to use this date to estimate the age of the CHP33 and CHP184 tephras.

TEPHRA CORRELATION

The only reliable method to compare tephra records between sites and to determine their source eruption is through examination of tephra geochemical composition by electron microprobe analysis. This is not yet complete for these tephras. However, in the absence of this data it is still possible to make some inferences based on the stratigraphic position and radiocarbon-based age estimates presented here. The very similar depths of the LNA39, ECR32, SPM26, MTR32 and CHP33 tephra layers would seem to strongly indicate that these are the same tephra (Fig. 2). There are significant differences between the inferred age estimates for these layers, ranging between 351 and 1504 BP. However, as noted previously, the irregularity of peat bog accumulation rates, combined with differences in accumulation rate between acrotelm and catotelm, imply that there would inevitably be particularly high errors in these estimates. Given the highly probable correlation of these five tephra layers, they are collectively denoted as 'Layer one' on Figure 2. It is interesting to note that this layer has a significantly greater shard concentration in the Juneau sites than the Haines sites; this could indicate a southern source.

Other layers which show some degree of similarity in stratigraphic context are SPM126 and MTR146 (both around 6000 BP) and ECR100 and LNA100 which differ markedly in dating but occur at an identical depth in nearby sites. It seems probable that the majority of these tephras occur in several of the sites; however the data here are inadequate to determine the exact correlations.

POSSIBLE SOURCES OF THE TEPHRA

At this stage it is not possible to reach any definite conclusions about the origins of these tephras. Given the relatively large (albeit microscopic) size of some of the layers, it seems most probable that the majority of the layers originate from relatively nearby volcanoes, probably in the Wrangell volcanic field or possibly Mount Edgecumbe near Sitka. It would seem likely that the products of large proximal eruptions, such as those forming the White River Ash, could have traveled as far as these sites. However, it also seems feasible that tephra could be transported to the site from distant sources such as the volcanoes around the Cook Inlet and Alaska Peninsula, possibly even the Cascade Range, British Columbia, Washington and Oregon. The recent micro-tephrochronology research conducted in Europe shows that tephra can be transported long distances (1200 km and more), and the prevailing winds are in the correct direction for tephra from the Alaska peninsula to be transported to these sites.

The most significant tephra layer found is that designated 'Layer one', found in all of the sites. The youngest inferred age estimate for this tephra is 351 BP for the LNA39 layer; it is possible that the layer may actually be younger. Richter et al. (1995) discussed a 1784 AD eruption of Mount Wrangell; this eruption is from a source relatively near the sites and within the right age range. However, given both the uncertainties in dating the layer and the poorly known volcanic history of the region, it is impossible to have sufficient confidence to attribute any single source. If the LNA100 and ECR100 layers do correlate, they could be assumed to be in the order of 1000 years old. This might put them in the right age range to be from the ca. 1147 BP eruption of Mount Churchill, the source of the White River Ash (eastern lobe; Clague, et al. 1995). The size and proximity of this eruption would strongly suggest that it could be found in these sites. The uncertainty in dating other tephra layers means that it is futile even to speculate on their possible sources.

IMPLICATIONS

This work is not yet complete and these preliminary results can tell us little about the actual distribution of products from specific eruptions, in the absence of electron microprobe data. However, the results are highly relevant to the study of tephrochronology in Alaska and Western Canada. This study has shown that microscopic analysis can reveal the presence of tephra layers in areas where none were previously recorded. This, therefore, allows the potential to greatly expand the distribution of many Holocene tephra layers, increasing the spatial and temporal utility of tephra for dating and correlating sediments. It seems probable that the same methods applied in other areas of Alaska, the Yukon and British Columbia would similarly reveal the presence of previously unrecorded micro-tephra layers. This is additionally relevant as some palaeoecological work has suggested that even micro-tephra layers as small as these may be associated with ecological impacts (Blackford et al., 1992; Dwyer and Mitchell, 1997). Expanding the limits of tephra distribution, therefore contributes to a more complete understanding of the impacts of eruptions in the past and the potential impacts of those in the future.

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Reconnaissance geology of northern Toobally Lake (95D/8), southeast Yukon

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ABSTRACT

The Toobally fault is a north-trending structure occurring along the west shore of northern Toobally Lake (95D/8) that juxtaposes Neoproterozoic-Cambrian sedimentary and volcanic rocks (to the west) against Devonian-Carboniferous sedimentary rocks (to the east). Paleozoic units east of the fault are tentatively correlated with an unnamed Devonian limestone, Besa River Formation and Mattson Formation, and are interpreted to form an asymmetric, east-verging anticline-syncline fold couplet with a sub-vertical common limb. Older units west of the fault constitute a homoclinal west-dipping succession consisting of (from oldest to youngest) an unnamed quartz sandstone, a diamictite and a basalt. The diamictite is a previously unrecognized unit, estimated to be at least 1800 m thick, for which we propose the name Toobally Formation. It is tentatively correlated with Ice Brook and Vreeland formations and is considered to be a glaciomarine succession in uppermost Windermere Supergroup. Overlying the Toobally Formation is an 850-m-thick succession of Neoproterozoic-Cambrian(?) basalt. The geochemistry of these basalts is consistent with rift volcanism in a within-plate tectonic setting.

RÉSUMÉ

La faille de Toobally est une structure à direction nord longeant la rive ouest du lac Toobally nord (95D/8). Elle juxtapose des roches sédimentaires et volcaniques (ouest) du Néoprotérozoïque-Cambrien à des roches sédimentaires (est) du Dévonien-Carbonifère. Les unités paléozoïques à l'est de la faille sont mises en corrélation avec un calcaire non désigné du Dévonien, la Formation de Besa River et la Formation de Mattson et elles sont interprétées comme un couplet d'anticlinal-synclinal asymétrique à vergence est dont le flanc vertical est commun. Les unités plus anciennes à l'ouest de la faille constituent une succession homoclinale à pendage ouest composée (du plus ancien au plus jeune) de grès quartzeux non désigné, de diamictite et de basalte. La diamictite est une unité définie antérieurement dont l'épaisseur estimée est d'au moins 1800 m et pour laquelle nous proposons l'appellation Formation de Toobally. Elle pourrait être corrélée avec les formations d'Ice Brook et de Vreeland et serait une succession glaciomarine dans le sommet du Supergroupe de Windermere. Sur la Formation de Toobally repose une succession de basalte néoprotérozoïque-cambrien(?) de 850 m d'épaisseur. La géochimie de ces basaltes est conforme à un volcanisme de rift dans un milieu tectonique intra-plaque.

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INTRODUCTION

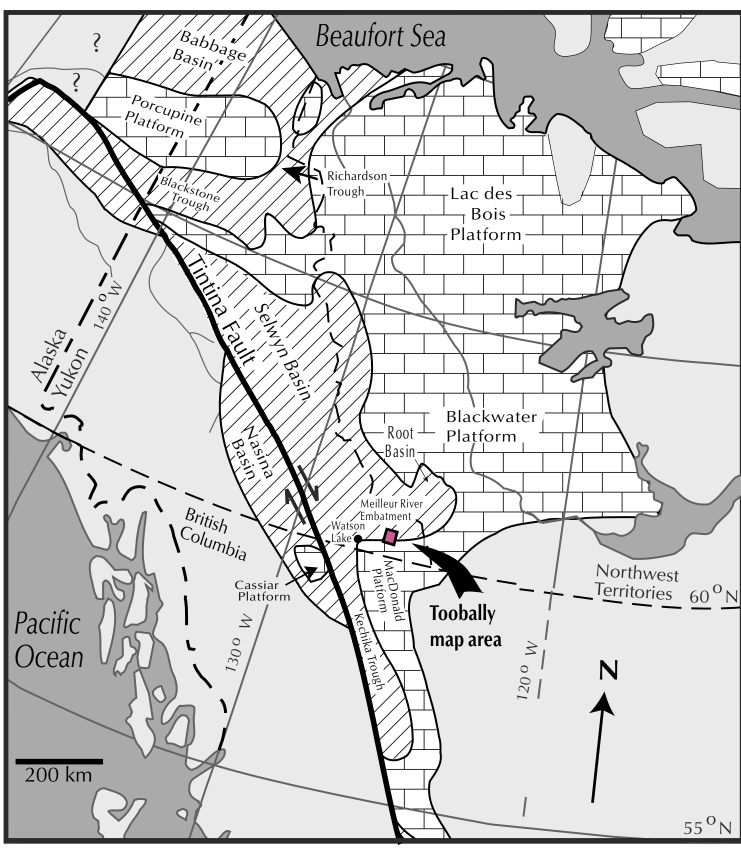
A short field season at the northern Toobally Lake (NTS 95D/8) in southeastern Yukon was completed in the last two weeks of July, 2003. The fieldwork was intended to clarify geologic relations implied from earlier regional geology mapping (Gabrielse and Blusson, 1969). The specific objectives included sampling the Cambrian (?) volcanic rocks west of northern Toobally Lake, characterizing them in terms of geochemistry and tectonic environment, and viewing stratigraphic relations between the volcanic rocks and the enclosing sedimentary rocks.

This brief report presents the results of the 2003 field season. Reconnaissance geologic mapping identified a previously unrecognized sedimentary succession underlying the Neoproterozoic-Cambrian (?) volcanic rocks. In this report we present a revised stratigraphy. In addition we comment on the existing structural interpretation in the immediate northern Toobally Lake area. The report is based on exposures along the lake and westward along one stream which drains east into northern Toobally Lake from headwaters about 1.5 km southeast of Gusty Lakes.

LOCATION AND ACCESS

Map sheets NTS 95D/1 and 95D/8 contain several large and small lakes in a north-south trend that are collectively called Toobally Lakes. Our fieldwork was completed around the northernmost of the larger lakes in the chain; we refer to it as the northern Toobally Lake (NTS 95D/8). It is located in southeast Yukon about 150 km northeast of Watson Lake (Fig. 1). It occurs within the Hyland Plateau (Bostock, 1948), an area of subdued, north-trending ridges separated by broad, forested, drift-filled valleys. Isolated ridge tops contain cliff exposures, but areas with extensive exposure are rare (Fig. 2). Old burn with resulting cross-piled blow-downs and dense young growth make walking difficult. Slopes away from the lake are steep but vegetated. Most outcrops occur along east-trending streams which have cut down through the ridges to form steep-sided gullies.

Roads into the area are nonexistent. We were mobilized into the lake by float plane from Watson Lake. Transportation on the lake was accomplished using an inflatable boat with an outboard motor. Traverses were completed by short hikes from lakeshore. A GPS unit was



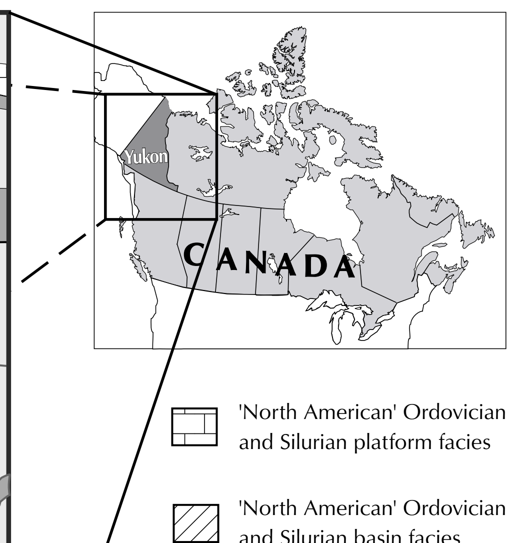


Figure 1. *Location of northern Toobally Lake map area (95D/8) in southeast Yukon. General distribution of Ordovician-Silurian platform carbonate and basinal shale facies for Canadian Cordillera and Alaska are indicated. Modified from Cecile et al. (1997).*

Figure 2. *View looking south of the northern Toobally Lake. Area is part of the Hyland Plateau with gentle mountains and broad drift-covered valleys.*

invaluable for reliable location fixes in the densely treed terrain.

PREVIOUS WORK

Gabrielse and Blusson (1969) completed 1:253 440-scale regional geology mapping in 1967 and published a preliminary map showing their results. The only Yukon MINFILE data record in NTS 95D/8 was reported as part of that regional mapping program (Deklerk, 2002). No active quartz claims are currently held within 95D/8. Allen et al. (2001), and Pigage and Allen (2001) reported on 1:50 000-scale geology mapping for the Pool Creek map area (NTS 95C/5) immediately east of this area.

REGIONAL GEOLOGY

The northern Toobally Lake occurs within the miogeocline of ancient North America, a prism of sedimentary rocks of Precambrian to Jurassic age deposited along the relatively stable margin of western ancient North America (Abbott et al., 1986). The area lies north of the northward facies transition (Fig. 1) from the Silurian-Devonian carbonates of the MacDonald carbonate platform to the basinal shales of the Meilleur River Embayment, a large embayment of the east margin of Selwyn Basin (Cecile et al., 1997).

Coal River map area (NTS 95D) contains stratified rocks ranging in age from late Proterozoic through Carboniferous (Gabrielse and Blusson, 1969). Gabrielse and Blusson (1969) reported Cambrian (?) volcanic rocks along the west side of northern Toobally Lake and Carboniferous sandstones of the Mattson Formation along the east side of the lake. Both units strike northerly and dip moderately to steeply to the west. They are separated by the Toobally fault, a steep fault with about 4000 m of stratigraphic throw (east-side down; Gabrielse and Blusson, 1969).

STRATIGRAPHY

We mapped six stratigraphic units during our reconnaissance work in the 2003 field season (Fig. 3). From west to east these are:

- Neoproterozoic-Cambrian (?) volcanic rocks (unnamed),
- Neoproterozoic diamictite of the Toobally Formation (new),
- Neoproterozoic sandstone (unnamed),
- black silty shale (Devonian-Carboniferous Besa River Formation ?),
- dark grey limestone (unnamed Devonian limestone ?), and
- sandstone of the Carboniferous Mattson Formation.

The black silty shale, dark grey limestone, and Mattson Formation are interpreted as occurring in the footwall (east) of the Toobally fault; and the Neoproterozoic-Cambrian (?) volcanic rocks, Toobally Formation, and Neoproterozoic sandstone are interpreted as occurring in the hanging wall (west) of the Toobally fault. Detailed descriptions of these units are presented in ascending stratigraphic order below.

NEOPROTEROZOIC SANDSTONE UNIT

The west ridge along the north part of northern Toobally Lake contains outcrop and talus of a pale pinkish grey, pale grey, or white, noncalcareous quartz sandstone with lesser granule and small-pebble conglomerate. Pebbly to granular sandstone is also common. Upper and lower contacts of the sandstone unit have not been observed. Bedding is not readily visible. Outcrops typically consist of resistant spires along streams and east-facing cliffs along the ridge.

Weathered surfaces are pale grey, orange, pink or white. Sand grains range from fine to very coarse, although they are dominantly medium to coarse. The grains are subangular to round, most commonly subround to round.

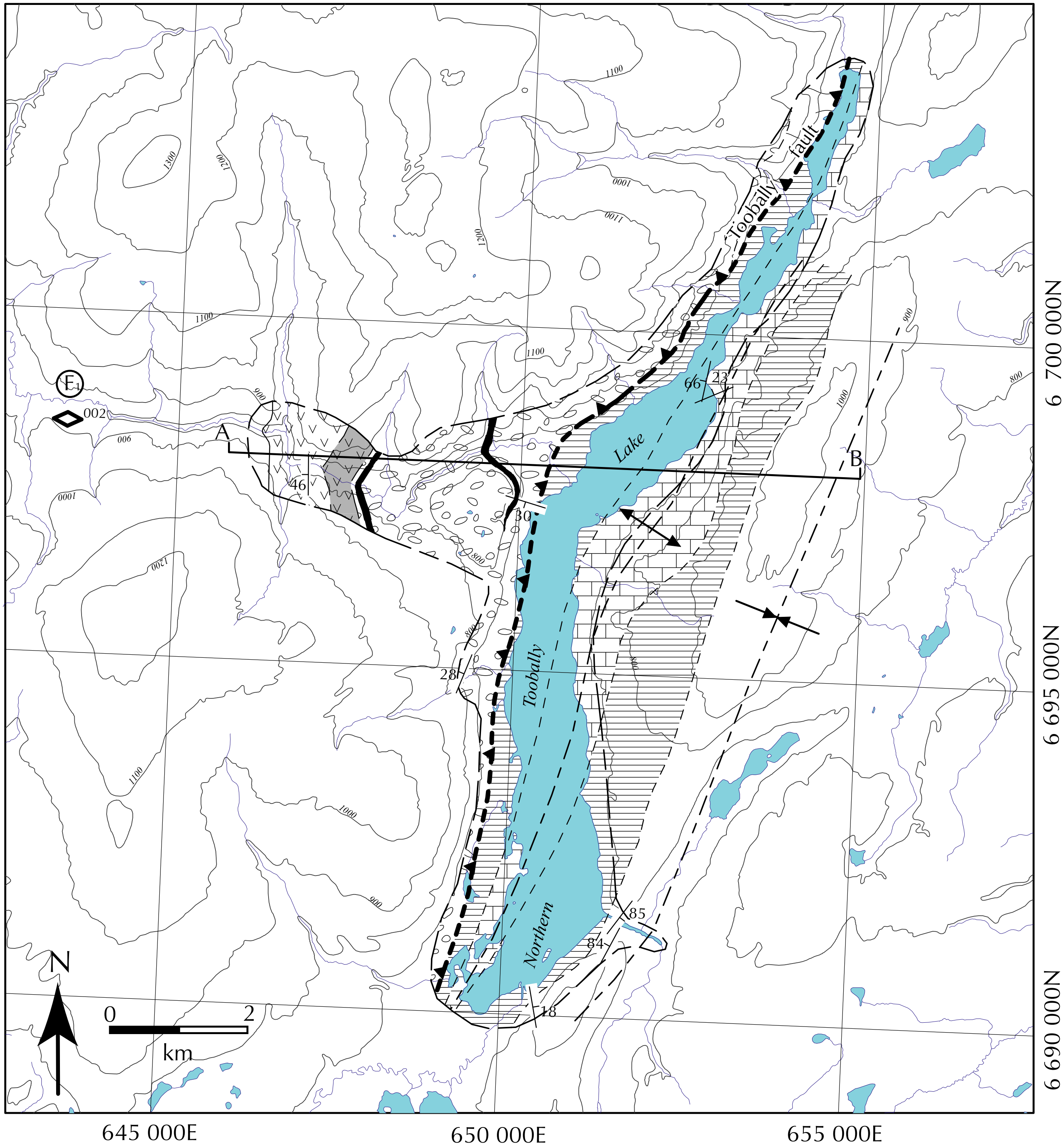
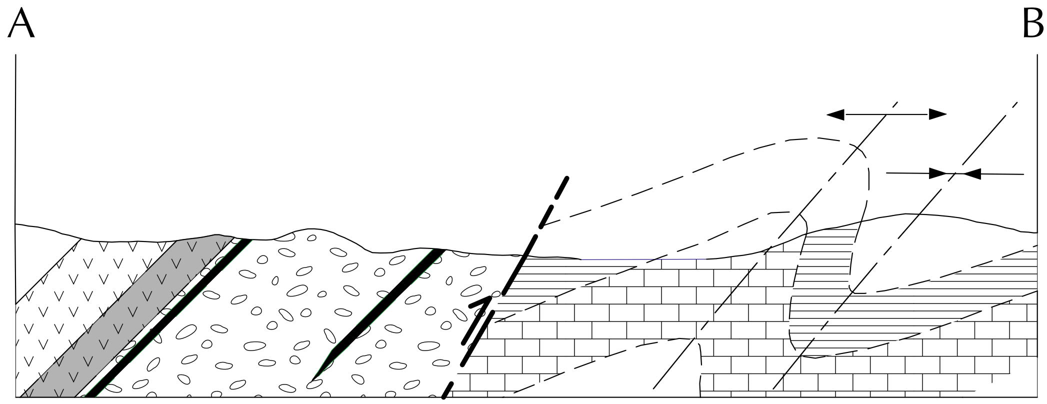
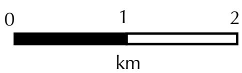


Figure 3. *Reconnaissance geology of northern Toobally Lake area. Coordinates are zone 9, UTM NAD83. Grid lines are spaced every 5 km. Legend on facing page. Diamond in west part of map indicates the Gusty Yukon MINFILE occurrence 95D 002 (Deklerk, 2002).*





INTRUSIVE ROCKS

Neoproterozoic-Cambrian(?)
gabbro / diabase
medium-grained, dark green, equigranular gabbro to diabase; subvolcanic feeder dykes and sills for Neoproterozoic-Cambrian(?) mafic volcanic rocks.

LAYERED ROCKS

Early Carboniferous
Mattson Formation
pale grey, strongly indurated, fine-grained quartz sandstone

Devonian to Early Carboniferous
Besa River Formation
black shale and argillite (from Gabrielse and Blusson, 1969)

Devonian
limestone
dark grey to black, finely crystalline, laminated to thin-bedded, locally bioturbated limestone

Early Cambrian
sandstone
varicoloured quartzitic sandstone; arkosic, pebbly sandstone (from Gabrielse and Blusson, 1969)

Neoproterozoic-Cambrian (?)
mafic volcanic rocks
grey-weathering, thick-bedded, basaltic volcaniclastic sandstones and breccias interbedded with amygdaloidal to vesicular flows

altered mafic volcanic rocks
pale grey, red to orange-brown weathering, fine-grained, slightly pyritic massive to brecciated, strongly carbonate-altered mafic volcanic rocks

Neoproterozoic
Toobally Formation
dark grey to black, orange-brown weathering, polymictic, matrix-supported, mudstone conglomerate

sandstone and pebbly sandstone
pale cream-weathering, pale grey to off-white, moderately indurated, quartz sandstone

SYMBOLS

geological contacts (defined, approximate, assumed)

reverse fault (assumed)

limit of mapping

bedding

fold axial surface trace (anticline: upright; syncline: upright)

line of cross-section A B

fossil locality (Lower Cambrian trilobites) F1

Yukon MINFILE (2002) record 002

Figure 3. *Legend for map on facing page.*

At one locality some samples contained less than 10% orange- to cream-coloured chalky grains intermixed with the quartz grains. In thin section these grains consist of fine-grained aggregates of sericite (former feldspar?). At another locality one sample contained minor dark pink clasts of reworked quartz sandstone. The sandstone unit is cut by thin (1-cm-thick) miarolitic quartz veins.

The absence of recognizable primary sedimentary structures precludes determining a detailed depositional setting for this unit. The dominance of quartz clasts and absence of interbedded shale or siltstone suggest a relatively high-energy, broadly nonmarine to shallow marine setting.

Fossils were not noted in the outcrops we visited. This unit occurs approximately 8750 m east of the closest fossil locality, a collection of Lower Cambrian trilobites and *Skolithos* trace fossils (Gabrielse and Blusson, 1969). Assuming structural continuity with the fossil locality and a homoclinal west-dipping succession with an average dip of 45 degrees, the quartz sandstone unit occurs approximately 6200 m structurally beneath the Lower Cambrian fossil locality. With these assumptions this unit cannot be younger than Lower Cambrian. We tentatively correlate the structurally overlying unit with upper Windermere Supergroup strata (see below). Consequently this unit would also be part of the Windermere and would therefore be Neoproterozoic in age.

The lithological description of this quartz sandstone is very similar to that of the Cambrian sandstone as presented by Gabrielse and Blusson (1969). A possible alternative structural interpretation is that this sandstone unit is a fold repeat of the Cambrian sandstone on the east limb of a large anticline, with its axial trace west of the lake and east of the Neoproterozoic-Cambrian (?) basalt (see Fig. 3). Due to time constraints we were not able to view the Cambrian sandstone immediately overlying (west of) the Neoproterozoic-Cambrian (?) basalt to ascertain the similarities and differences between these two sandstones. Further geology mapping is required to confidently select between these two structural interpretations. For now, we tentatively consider the rocks west of the northern Toobally Lake to be a homoclinal, west-dipping succession.

TOOBALLY FORMATION (NEW UNIT)

The most distinctive and areally extensive map unit examined during 2003 fieldwork is a thick succession of polymictic muddy conglomerate to pebbly mudstone (Fig. 3). This unit occupies much of the area previously considered to have been underlain by Neoproterozoic-Cambrian (?) volcanic rocks (Gabrielse and Blusson, 1969). It is exposed in numerous cliffs and hillside outcrops along the western edge of the northern Toobally Lake. It also outcrops extensively on the north- and south-facing walls of the valley cut by an unnamed stream that flows eastward into the lake roughly along grid reference line 6698000N (all coordinates are Zone 9, NAD83 UTM).

This unit is lithologically distinct and is demonstrably mappable at 1:50 000 scale. It has not previously been documented within Coal River map area (NTS 95D), nor has any similar lithology in a comparable stratigraphic position been reported in map areas adjacent along strike to the north (Flat River, NTS 95E; Gabrielse et al., 1973) or south (Rabbit River, NTS 94M; Gabrielse, 1962; Ferri et al., 1999). This unit thus merits establishment as a new formation, and in view of its exposure adjacent to the northern Toobally Lake, we propose the name “Toobally Formation”. No completely exposed section through this unit is currently known, and none is likely to be forthcoming in view of the extensive bush cover in this region. Therefore we propose the formation’s stratotype consist of exposures of this unit within the valley cut by the unnamed stream referred to above. These outcrops expose the formation’s characteristic lithologies, and air-photograph analysis shows the valley contains the most extensive, cross-strike exposures of the unit. We also propose a cliff exposure along another stream further south (UTM coordinates 649320E, 6694834N) as a reference section because this is one of the few localities where bedding can be recognized.

The easternmost (stratigraphically lowest) exposure of the Toobally Formation studied during our fieldwork is at coordinates 650123E, 6698395N. Additional exposures of this unit were observed from a distance in cliffs extending northeast along the lake from those coordinates. The Neoproterozoic quartz sandstone unit described above occurs east of these exposures and is tentatively considered to be the unit underlying the Toobally Formation. The basal contact of the Toobally Formation was not observed and is presently poorly constrained. We propose that the basal contact be placed at the base of the lowest bed of matrix-supported conglomerate or pebbly mudstone typical of the unit. The top of the unit is within a covered interval between the westernmost outcrop of pebbly mudstone (coordinates 647579E, 6697595N) and an overlying outcrop of the brecciated volcanic unit (coordinates 647452E, 6697600N) that occurs approximately 127 m upstream. No evidence was seen for interbedding of these lithologies, suggesting a relatively abrupt contact. We consider the upper limit of the Toobally Formation to be defined by the highest occurrence of pebbly mudstone.

The lack of continuous exposure, particularly at the upper and lower contacts of the unit, presents a less-than-ideal situation for establishing a new formation. However, we emphasize that the Toobally Formation can be both "distinguished and delimited on the basis of lithic characteristics and stratigraphic position" (North American Commission on Stratigraphic Nomenclature, 1983, p. 848), and we consider this to be the ultimate test of a formal lithostratigraphic unit.

Previous mapping by Gabrielse and Blusson (1969) indicated that surface exposures of their volcanic-dominated map unit 3, the lower part of which corresponds to the Toobally Formation, does not extend significantly south of the northern Toobally Lake. Likewise the upper contact of their map unit 3 is truncated against the Toobally fault approximately 5 km north of the northern Toobally Lake. Thus the Toobally Formation may extend for approximately 16 km along strike. We have mapped outcrops or observed exposures from a distance over most of the belt likely to contain outcrop. The minimum thickness of the Toobally Formation along the 'type' valley is 1800 m, assuming structural continuity and a uniform dip of 45 degrees to the west (cf., Gabrielse and Blusson, 1969). Unrecognized structural repetition by folding and/or faulting may cause this thickness estimate to be too large.

Internally the Toobally Formation consists almost entirely of a monotonous succession of polymictic, matrix-supported conglomerate to pebbly mudstone (Fig. 4). The matrix consists of dark brown to dark grey, brown-, buff-, or orange-weathering silty shale to siltstone and accounts for 50 to 80 % of total rock volume. Clasts are most commonly within the granule to pebble size range; cobbles are rarely present. One cliff face, inaccessible to us, exposed a probable olistolith (exotic block transported by submarine slumping) estimated to be 1 m by 2 m in size. Other blocks of olistolith scale may also be present (see discussion of the buff carbonate below). Clasts are angular to subrounded and show no preferred orientation (Fig. 5). Numerous clast compositions were observed, including quartzitic meta-sandstone, calcareous sandstone, lithic sandstone, mudstone, massive lime mudstone and dolomudstone, laminated lime mudstone, massive grainstone, and rare fragments of vesicular to amygdaloidal basalt (Fig. 6). A lithogeochemical analysis of the large basalt clast shown in Figure 6 is presented in Table 1 and will be discussed further in the following section on Geochemistry.

Bedding generally cannot be recognized within this unit at outcrop scale. The unit is generally well preserved, affected only by a moderately developed, pervasive slaty cleavage, which suggests that the unit is very thickly bedded. In rare cases, normally graded to massive beds

Figure 4. *Polymictic muddy conglomerate of the Toobally Formation. Hammer for scale. Marks on hammer handle are 10 cm apart. Slaty cleavage dips gently down from right to left (west-dipping). Photo taken looking north.*

Figure 5. *Randomly oriented, angular carbonate clasts (circled) in silty mudstone matrix, Toobally Formation. Scale divisions are in centimetres.*

Figure 6. *Amygdaloidal basalt clast in mudstone conglomerate, Toobally Formation. Scale divisions are in centimetres.*

Figure 7. *Rare bedding in Toobally Formation.*

that are less than 10 cm thick are preserved (Fig. 7). These beds consist of a lower, massive to graded horizon of granules to small pebbles in a silty/muddy matrix and an upper, massive, mudstone horizon. In another area, within an apparently unbedded succession of pebbly mudstone, we observed a gradational change upward from a silty mudstone matrix to a siltstone matrix.

In a streamcut outcrop along the 'type' valley (coordinates 649705E, 6698302N) the conglomeratic mudstone appears to be overlain by a succession of cream- to orange-weathering, microcrystalline to very finely crystalline dolostone at least 20 m thick. Fresh surfaces of the dolostone are buff coloured. This lithofacies is parallel-bedded, with beds from 10 to 40 cm thick. Internally, beds are massive or display parallel lamination, low-angle cross-lamination, or ripple cross-lamination (Fig. 8). Rare, bedding-parallel stylolites are also present. The contact between this unit and the conglomeratic mudstone is sharp and stained red (possibly by goethite or hematite). The dolostone

Figure 8. *Closeup of finely parallel-laminated dolostone forming large olistolith in Toobally Formation.*

immediately above the contact is highly fractured and generally harder than that further upsection, suggesting that it has been silicified. The upper contact of the dolostone has not been observed. This dolostone is also present at one other small outcrop (coordinates 649877E, 6698326N) slightly further downstream.

The dolostone presents something of a conundrum. Although it may be a stratigraphic unit lying comformably upon the Toobally Formation, this interpretation carries stratigraphic difficulties. Bedding within the dolostone dips to the northeast, whereas regional dip within the succession west of the northern Toobally Lake is to the west. Although folding might explain the variable dip, the dolostone is absent as one proceeds upstream to the west for some 2.2 km through massive pebbly mudstones of the Toobally Formation. For these reasons we suggest that the buff dolostone is a large olistolith within the Toobally Formation. The presence of at least one other recognizable olistolith within the Toobally Formation (see above) supports this interpretation.

The Toobally Formation is cut by scattered dark green, orange-weathering, fine-grained, diabase to gabbro dykes and sills from less than 10 cm to greater than 10 m thick. In many outcrops the dykes and sills are extensively altered to a pale grey, orange-weathering, pyritic carbonate-sericite assemblage. Lithogeochemical analyses of samples collected from several locations within the Toobally Formation are listed in Table 1 (Geochemistry section). The chemistry of the dykes and sills will be discussed further in the Geochemistry section. Similar dykes and sills have intruded Proterozoic and/or Cambrian strata to the south in Rabbit River map area (Gabrielse, 1962).

Further detailed work is needed to ascertain the Toobally Formation's precise depositional environment and paleophysiographic setting. Outcrops consist of a mud-rich, matrix-supported, polymictic conglomerate with no preferred orientation to the clasts; this lithotype can be deposited readily under glacial and/or non-glacial conditions (Eyles, 1990). In the 2003 fieldwork we found no definitive evidence for glacial deposition (e.g., dropstones and lonestones in associated sediments, till pellets, striated clasts). The great thickness and lack of associated high-energy outwash facies also implies the unit is not a terrestrial till (Flint, 1961), as does the lack of preferred orientation of clasts (Eyles and Eyles, 1992). Therefore, we interpret the Toobally diamictites as deposits produced by relatively viscous, sediment-gravity flows, probably debris flows. The rare, thin, normally graded to massive beds may be thin-bedded turbidites in which the grainy interval represents the A horizon and the mudstone interval the E horizon (i.e., Ta,e). Thick accumulations of debris flows associated with turbidites are typical of marine slope to toe-of-slope settings.

Nevertheless, the Toobally Formation resembles Neoproterozoic glacial diamictites that have been documented in western Canada: the Shezal Formation (Eisbacher, 1978, 1981), the Ice Brook Formation (Aitken, 1991), the Vreeland Formation (McMechan, 2000), and the Toby Formation (Aalto, 1971). The diamictites in these other formations are massive; however they are visibly interbedded with rhythmically bedded marine and nonmarine sediments. Maximum thickness of Shezal Formation diamictite is 200 m (Eisbacher, 1981), and that of the Ice Brook Formation diamictite is 300 m (Aitken, 1991). McMechan (2000) described diamictite sheets up to 40 m thick with a maximum of 1500 m of the Vreeland Formation consisting largely of massive diamictite. Aalto (1971) described diamictite beds in the Toby conglomerate as occurring in lenses up to 16 m thick and not laterally persistent beyond 100 m. Glacially striated clasts are common in the Shezal Formation (Eisbacher, 1981). By contrast, Aitken (1991) noted that glacially striated clasts are extremely rare in the Ice Brook Formation. The inferred thickness of at least 1800 m for the Toobally Formation is much greater than the measured thicknesses of either the Ice Brook Formation or the Shezal Formation but is similar to that indicated for the Vreeland Formation. It may be that associated bedded sedimentary rocks in the Toobally Formation are present but not observed because of outcrop gaps. McMechan (2000) suggested that the glacial diamictites of the Vreeland Formation formed as large, unconfined debris flows in a distal glaciomarine environment. A similar deposition mechanism could be envisioned here to allow for the extensive massive succession represented by the Toobally Formation.

Fossils have not been recognized within the Toobally Formation. In the valley containing its stratotype, its upper contact is structurally 2900 m beneath a Lower Cambrian fossil locality reported by Gabrielse and Blusson (1969). Therefore it has a minimum Early Cambrian age and is more likely to be Neoproterozoic. Of the Neoproterozoic diamictite units in western Canada, the Shezal and Toby formations occur in the lower part of the Windermere Supergroup, and the Ice Brook and Vreeland formations occur in its upper part. The stratigraphic position of the Toobally Formation beneath Lower Cambrian strata suggests that it is more likely to be correlative with the Ice Brook and Vreeland formations. Variable cutout beneath the sub-Cambrian unconformity in northwestern Canada (Aitken, 1989; MacNaughton et al., 2000) necessitates caution regarding this suggestion. The depositional age indicated by this tentative correlation is just after the appearance of Ediacaran fauna (Aitken, 1991), around 570 Ma (Okulitch, 2002).

With this correlation the Toobally Formation may represent another example of Neoproterozoic glacial deposits (Kennedy et al., 1998). The Ice Brook and Vreeland formations are both locally overlain by a ‘cap carbonate’ (Aitken, 1991; McMechan, 2000). A similar carbonate is not observed at the top of the Toobally Formation, although a finely parallel-laminated dolostone does occur as a large, probable olistolith low in the succession. The absence of a cap carbonate does not necessarily preclude the correlation of the Toobally Formation with these other units; rather it might indicate non-deposition or that the upper contact of the Toobally Formation is a disconformity.

NEOPROTEROZOIC-CAMBRIAN (?) VOLCANIC ROCK UNIT

Gabrielse and Blusson (1969) recognized an extensive succession of basic volcanic rocks consisting of amygdaloidal volcanic flows, tuffs and breccias immediately west of the northern Toobally Lake (their map unit 3). They estimated an aggregate thickness of volcanic rocks exceeding 2700 m in this immediate area. Our 2003 fieldwork shows that the Toobally Formation forms the lower part of this succession as previously mapped (approximately 70% of the unit). The revised thickness of the volcanic rock unit is approximately 850 m. Four stations within the lower part of the volcanic rock unit were examined during the 2003 mapping.

The lower contact of the unit is within a covered interval between the westernmost outcrop of pebbly mudstone (coordinates 647579E, 6697595N) and an overlying outcrop of the brecciated volcanic unit (coordinates 647452E, 6697600N). The upper contact was not observed during our fieldwork but was located as a defined contact by Gabrielse and Blusson (1969) at coordinates 646219E, 6698317N.

Outcrops visited in 2003 consist of volcaniclastic rocks: predominantly lapilli tuffs with lesser interbedded, thin maroon mudstones and volcanic breccias. No volcanic flows were observed in the few outcrops visited. Fresh exposures are dark green; weathered surfaces are greyish green with purple, maroon, and blue-green hues. Lapilli tuffs are poorly bedded on a scale of 50 cm to several metres (Fig. 9). Thin maroon mudstone intervals in the tuffs have normally graded beds and load casts, which indicate the unit is structurally upright with tops being to the west (Fig. 10). Volcanic breccias range from centimetres to metres in thickness. Breccias are clast-supported with a dark green, fine-grained, interstitial matrix; clasts are up to 5 cm across and consist entirely of varieties of basalt.

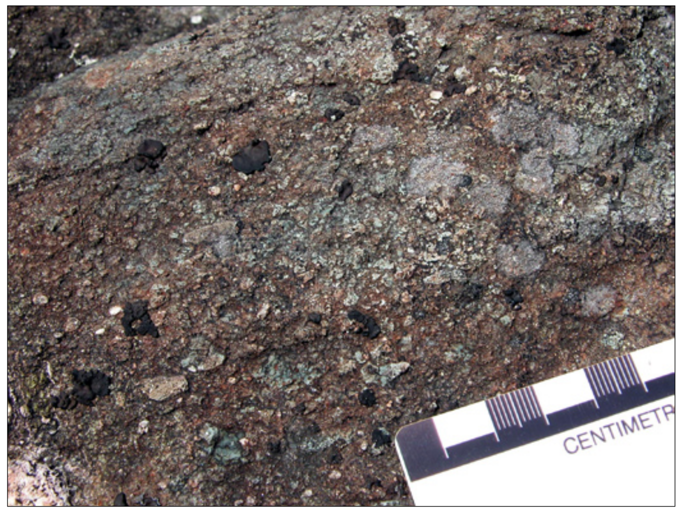


Figure 9. *Closeup of lapilli tuff in Neoproterozoic-Cambrian(?) volcanic rock unit.*

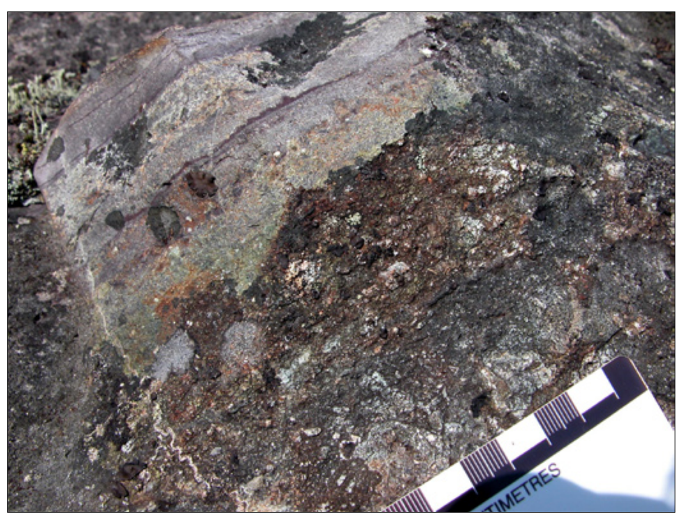


Figure 10. *Closeup of thin, maroon mudstone horizon in Neoproterozoic-Cambrian(?) volcanic rock unit. Load casts and graded bedding indicate beds are structurally upright. Photo taken looking west.*

Two basalt lithotypes predominate in the clasts of the lapilli tuffs and the volcanic breccias. In the first lithotype, plagioclase phenocrysts are contained within a fine-grained, brown matrix of felted feldspar microlites with lesser opaques. The other lithotype contains plagioclase phenocrysts in a matrix of devitrified glass. The latter clasts are typically amygdaloidal. Primary mineralogy is not preserved; metamorphic minerals include chlorite, epidote, sericite and carbonate.

The lowermost outcrops of this unit are highly carbonate- and sericite-altered. Fresh surfaces are pale grey, and weathered exposures are dark orange-brown. Rocks are fine-grained. Exposures are massive to thick-bedded. Breccia textures are locally visible on weathered surfaces, with clasts being up to 3 cm across (Fig. 11).

No fossils were found in the volcanic unit. The top of the unit is structurally 2080 m below a fossil site containing Lower Cambrian trilobites located 2940 m upstream. Volcanic rocks therefore have a minimum age of Lower Cambrian; a more appropriate age would probably be Neoproterozoic. The source area for the volcaniclastic material is uncertain. If flows are present (as described by Gabrielse and Blusson, 1969) exposures west of the northern Toobally Lake are proximal to source vents. The presence of devitrified glass clasts in the tuffs and breccias supports the inferred proximal nature of the volcanic rocks. Analyses of the Neoproterozoic-Cambrian volcanic rocks are listed in Table 1. These analyses will be further discussed in the section on Geochemistry.

Other occurrences of volcanic rocks in the same general area are limited. Gabrielse and Blusson (1969) documented the same volcanic unit in a few scattered outcrops 16 km southeast of the present occurrence. Approximately 18 km east of the present occurrence, in NTS 95C/5 (Pool Creek map sheet), Allen et al. (2001) described a green laminated argillaceous siltstone unit containing a significant volcaniclastic component. This siltstone is approximately 500 metres thick and contains interbeds of volcanic breccia. It is slightly hornfelsed by the Pool Creek syenite; isotopic dating of the Pool Creek syenite at about 650 Ma (J.K. Mortensen, pers. comm., 2003) places the siltstone as being older than 650 Ma and therefore significantly older than the Toobally volcanic rocks.

DARK GREY LIMESTONE MAP UNIT (DEVONIAN?)

This map unit is exposed in two lake-shore outcrops on the northeastern side of the lake at approximate coordinates 652710E, 6699208N. Its base and top have not been observed. It is dominated (>80%) by limestone and silty limestone, with lesser (<20%) silty shale interbeds. The limestone is medium to dark grey on fresh surfaces and weathers light to dark grey, buff or brown (Fig. 12). It is very finely crystalline or, locally, finely particulate. Bedding is irregular and ranges in thickness from 1 cm to 30 cm, most commonly 1 cm to 10 cm. Beds are massive to parallel-laminated. Locally the beds

Figure 11. *Carbonate-altered breccia at base of Neoproterozoic-Cambrian(?) volcanic rock unit.*

Figure 12. *Devonian (?) limestone outcrop on northeast lake shore of northern Toobally Lake. André Lebel for scale.*

are bioturbated. When treated with dilute (10%) HCl, the limestone gives off a strong smell of sulphur. The silty shale lithofacies is fissile and is dark grey on fresh and weathered surfaces.

The fine crystal and grain size of both the carbonate and shale lithofacies, together with the predominance of carbonate, suggest deposition in a low-energy, marine environment. Previous mapping in Coal River (Gabrielse and Blusson, 1969) and La Biche River (Pigage and Allen, 2001) outlines major carbonate successions as Sunblood Formation (Ordovician) or an unnamed Devonian limestone. Because of the proximity of these outcrops to Mattson Formation located on the ridge top to the east, it is suggested that these carbonates are correlative with the unnamed Devonian limestone as mapped in the Pool Creek area (Pigage and Allen, 2001; unit Dl), some 18 km to the east. A sample has been submitted for conodont analysis to test this correlation.

BESA RIVER FORMATION (?) – BLACK SILTY SHALE

A single hillside locality on the northwestern side of the lake (coordinates 651721E, 6699162N) exposes a shale-dominated map unit. The lithofacies at this locality include black, dark grey, and greenish-grey shale to silty shale that weathers black, dark grey, and medium greenish-grey (Fig. 13). Mica is locally visible as small flakes on the slaty cleavage surface of the shale. Also present are very thin beds of very fine-grained sandstone that are medium greenish-grey on fresh surfaces and weather greenish grey with rusty patches. The sandstone makes up 10% or less of the exposed strata and preserves small load casts and possible gutter casts. The shale and sandstone are both locally concretionary, with concretions in the black shale reaching diameters in excess of 10 cm.

Figure 13. *Outcrop of black silty shale of Devonian Besa River Formation (?) on northwest side of northern Toobally Lake. Outcrop is presumed to be in immediate footwall of Toobally fault.*

Rare trace fossils are preserved in the sandstone and consist of horizontal burrows with poorly preserved, external scratch ornamentation. No other fossils were observed. The base and top of this unit have not been observed. The presence within this unit of burrows displaying external scratch traces indicates that these strata are of Early Cambrian age or younger (Crimes, 1987). Major black shale successions in the immediate area include the Silurian-Devonian Road River Group and the Devonian-Carboniferous Besa River Formation. This succession has been tentatively interpreted as Besa River Formation (Kidd, 1963) on the west limb of an east-verging anticline. A palynology sample has been collected to test this tentative correlation.

The prevalence of shale and paucity of sandstone in this unit suggest deposition under low-energy conditions. Load casts and gutter casts are typical features of deposition in continental-shelf settings, although gutter casts are more typical of shallow-water environments on mud-dominated shelves (Myrow, 1992).

MATTSON FORMATION

The Mattson Formation (Patton, 1958) was mapped by Gabrielse and Blusson (1969) as occurring extensively on the ridges immediately to the east of the lake. Our observations are based on outcrops and talus trains along the lake's eastern shore. Exposures higher on the ridges are visible on aerial photographs but were not visited as part of this work.

Compact, very well cemented, very fine- to fine-grained quartz sandstone dominates outcrops of Mattson Formation in the study area (Fig. 14). Grains are highly rounded and spherical. The only accessory phase observed consists of sporadic, very fine to fine blebs of black material, probably pyrobitumen. Fresh surfaces are white or light, medium, or dark grey. Weathering tones are dominantly light to medium grey, with local orange-weathering zones. Orange, red and brown liesegang banding is present on some fracture surfaces.

Bedding is commonly difficult to recognize in exposures of Mattson Formation visited during this work. It is generally best recognized based on the presence of a distinctive bedding-plane texture of uncertain origin,

Figure 14. *Outcrop of Mattson Formation at southeast end of northern Toobally Lake. Bedding is vertical. André Lebel is standing on outcrop for scale.*

consisting of a network of pits and bumps that are of centimetre-scale diameter in plan view and show a few millimetres of relief. This texture is also common in exposures of Mattson Formation in Larsen Lake map area (NTS 95C/4; MacNaughton and Pigage, 2003), immediately southeast of the current study area. Poorly preserved cross-bedding was also recognized in one outcrop during the current study.

Further east, in La Biche River (NTS 95C) and Fort Liard (NTS 95B) map areas, the Mattson records a variety of shallow-marine and nonmarine depositional environments (Richards et al., 1993), and can be subdivided into up to three informal members (Douglas and Norris, 1959; Douglas, 1976; Currie et al., 1998; MacNaughton and Pigage, 2003). No such subdivision is currently possible in the Toobally Lakes region and poor exposure of primary sedimentary structures precludes any meaningful statement of depositional setting.

GEOCHEMISTRY

Table 1 lists analyses for four samples of the Neoproterozoic-Cambrian (?) volcanic unit, five samples of dykes/sills within the Toobally Formation, and one sample of an amygdaloidal basalt clast from the Toobally Formation. It also presents three analyses of Neoproterozoic basalt and volcaniclastic rocks from the Pool Creek map area (95C/5) immediately to the east. In spite of the excellent preservation of primary textures in hand sample, thin section studies indicate many of the primary minerals have been replaced during subsequent alteration and/or metamorphism. Locally extensive alteration and/or metamorphism are also reflected in the large loss on ignition (LOI) for several of the samples. The alteration and metamorphism implies that some of the elements have been mobilized to varying degrees (Rollinson, 1993). In contrast, several elements have been shown to be immobile during alteration and metamorphism (Pearce and Cann, 1973; Wood, 1980; Jenner, 1996). To test for immobility of elements commonly used in discriminant diagrams, we have plotted LOI against several key elements and element ratios for the Toobally dyke/sill and Neoproterozoic-Cambrian volcanic unit samples (Fig. 15). With these plots we are inferring that increasing LOI corresponds to an increasing extent of alteration and/or metamorphism. Figure 15a shows an inverse correlation between SiO_2 and LOI, indicating mobility and loss of SiO_2 with increasing LOI. Systematic increasing or decreasing linear patterns for elements niobium, zironium, titanium dioxide, yttrium and thorium (Nb, Zr, TiO_2, Y and Th) when plotted vs LOI are not obvious (Figs. 15b,c,d,e,g). Element ratios Nb/Y and Zr/TiO_2 (Figs. 15f,h) are even more robust and show no variation when plotted against LOI. From these plots we conclude that alteration and metamorphism have not significantly affected the validity of discriminant diagrams utilizing immobile elements from all of the analyses presented in Table 1.

The Neoproterozoic-Cambrian (?) volcanic rock unit samples plot in the alkali basalt field in a Zr/TiO_2-Nb/Y diagram (Fig. 16a; Winchester and Floyd, 1977; modified by Pearce, 1996). The altered and unaltered dykes/sills in the Toobally Formation plot within the same tight alkali basalt cluster as the overlying Neoproterozoic-Cambrian (?) volcanic rock unit (Fig. 16a). In contrast, the Pool Creek basalt clast plots in the basalt field and the Pool Creek volcaniclastic siltstone unit plots in the andesite/basalt field. Displacement of the Pool Creek volcaniclastic siltstone samples to higher Zr/TiO_2 values

Table 1. *Lithogeochemical analyses 95D/8 and 95C/5.*

Sample rock	03LP007v basalt clast	03LP003 dyke/sill altered	03LP004 dyke/sill	03LP010 dyke/sill altered	03LP017 dyke/sill altered	03LP021 dyke/sill	03LP023 breccia altered	03LP028 lapilli tuff	03LP028[4] lapilli tuff	03LP029 lapilli tuff	00LP033 siltstone	00LP034 siltstone	00LP009 basalt clast
Formation	Toobally	Toobally	Toobally	Toobally	Toobally	Toobally	Volcanic unit	Volcanic unit	Volcanic unit	Volcanic unit	Pool Creek	Pool Creek	Pool Creek
UTM E[1]	649 694	649 516	649 441	649 320	650 123	647 628	647 538	647 053	647 053	646 909	345 833	345 601	345 458
UTM N	6 696 296	6 698 177	6 698 146	6 694 834	6 698 395	6 697 581	6 697 584	6 697 555	6 697 555	6 697 722	6 695 449	6 695 823	6 694 401
UTM Zone	9	9	9	9	9	9	9	9	9	9	10	10	10
SiO_2 (%)	39.44	31.79	45.35	34.74	52.62	42.08	36.67	47.45		51.12	54.95	57.03	48.46
Al_2O_3 (%)	11.49	13.45	15.26	14.98	14.85	14.68	10.18	14.62		12.90	12.85	12.47	11.02
Fe_2O_3 (%)[2]	8.96	11.55	11.24	10.61	10.59	15.01	15.90	11.39		10.11	8.58	7.68	13.28
MnO (%)	0.123	0.183	0.184	0.125	0.045	0.176	0.230	0.162		0.209	0.097	0.114	0.130
MgO (%)	7.44	8.04	7.57	3.72	2.26	4.65	4.66	8.55		8.55	8.06	8.29	5.77
CaO (%)	11.40	8.57	8.72	12.15	1.95	8.23	7.99	6.21		6.54	6.30	5.13	6.01
Na_2O (%)	0.54	1.62	2.41	2.91	0.16	2.88	0.12	3.87		3.10	1.51	1.31	2.96
K_2O (%)	2.26	2.00	2.07	1.45	2.71	0.47	1.43	0.63		0.76	2.01	3.61	1.26
TiO_2 (%)	2.592	1.438	1.672	2.067	2.753	3.369	2.461	1.596		1.824	1.427	1.064	2.207
P_2O_5 (%)	0.63	0.31	0.32	0.20	0.34	0.37	0.43	0.18		0.25	0.23	0.15	0.30
LOI (%)[3]	13.84	19.68	4.31	15.64	10.88	6.92	18.56	4.35		3.34	2.81	2.02	7.52
Total	98.72	98.63	99.11	98.59	99.16	98.84	98.63	99.01		98.70	98.82	98.87	98.92
Ba (ppm)	750	389	814	268	260	337	92	326		295			
Sr (ppm)	221	198	257	526	52	698	76	380		732			
Y (ppm)	42	21	27	21	22	24	27	16		18			
Sc (ppm)	17	31	34	30	32	20	16	31		29			
Zr (ppm)	253	83	95	97	201	177	159	105		122			
Be (ppm)	2	2	1	1	2	2	1	1		1			
V (ppm)	172	226	258	249	272	270	178	193		156			
V (ppm)	159	211	247	237	249	257	162	178	181	143	180	153	292
Cr (ppm)	31	314	271	528	254	-20	-20	279	291	250	77	89	36
Co (ppm)	20	39	38	52	69	47	26	45	45	34	26	41	33
Ni (ppm)	112	100	80	198	103	52	25	130	136	69	26	43	-20
Cu (ppm)	390	-10	51	317	635	28	13	60	69	-10	48	14	13
Zn (ppm)	86	62	91	80	67	125	42	83	112	122	70	64	102
Ga (ppm)	14	14	16	18	17	20	14	15	15	15	19	18	19
Ge (ppm)	2	2	2	2	3	2	2	1	2	2	1.6	1.8	1.4
As (ppm)	23	-5	12	115	60	-5	21	-5	-5	-5	-5	-5	-5
Rb (ppm)	63	50	27	54	69	14	36	10	10	13	86	134	30
Sr (ppm)	216	196	249	503	51	735	75	378	387	746	104	97	114
Y (ppm)	40	20	23	18	23	26	24	17	17	20	43.2	37.4	52.4
Zr (ppm)	275	87	105	110	210	200	172	110	112	133	249	236	202
Nb (ppm)	28	35	38	23	48	38	29	27	27	28	16.3	14.7	15.9
Mo (ppm)	>100	3	>100	>100	2	2	>100	-2	-2	-2	-2	-2	-2
Ag (ppm)	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5
In (ppm)	-0.2	-0.2	-0.2	-0.2	-0.2	-0.2	-0.2	-0.2	-0.2	-0.2	-0.1	-0.1	-0.1
Sn (ppm)	2	-1	-1	1	2	2	1	1	2	1	2	2	2
Sb (ppm)	0.7	-0.5	-0.5	-0.5	1.5	0.7	1.9	-0.5	0.7	-0.5	0.7	2.1	1.3
Cs (ppm)	1.7	7.8	3.3	3.1	4.1	2.2	1.4	0.8	0.8	-0.5	5.9	9.2	2.2
Ba (ppm)	773	396	828	275	264	362	95	336	340	313	208	400	296
La (ppm)	17.0	29.9	31.4	15.7	23.6	34.1	21.6	14.9	15.6	25.3	33.5	34.2	22.3
Ce (ppm)	39	59.9	62.5	33.8	49.8	73.2	46.3	32.8	34.3	50.4	69.4	69.8	50.8
Pr (ppm)	4.98	6.53	6.86	4.12	5.58	8.19	5.45	3.92	4.02	5.64	7.69	7.48	6.18
Nd (ppm)	24.5	27.9	28.8	19.5	24.5	35.6	24.6	18.0	18.1	25.3	31.4	30.7	28.5
Sm (ppm)	6.8	5.0	5.6	4.4	4.9	6.8	6.0	3.9	3.9	5.0	6.73	6.36	6.96
Eu (ppm)	2.35	1.88	2.10	1.29	1.53	2.83	2.15	1.73	1.71	2.17	1.53	1.41	2.01
Gd (ppm)	8.4	5.0	5.8	4.6	5.4	6.8	6.5	4.3	4.2	5.3	6.26	5.46	7.24
Tb (ppm)	1.4	0.8	0.9	0.7	0.9	1.1	1.0	0.7	0.7	0.8	1.06	1.01	1.31
Dy (ppm)	7.8	4.1	4.7	3.8	5.0	5.5	5.0	3.6	3.6	4.3	6.34	5.93	8.07
Ho (pmm)	1.5	0.8	0.9	0.7	0.9	1.0	0.9	0.7	0.7	0.8	1.24	1.16	1.57
Er (ppm)	4.4	2.3	2.7	2.0	2.7	2.9	2.7	1.9	1.9	2.1	3.81	3.56	4.78
Tm (ppm)	0.66	0.32	0.36	0.27	0.39	0.38	0.36	0.26	0.26	0.28	0.569	0.526	0.671
Yb (ppm)	3.9	1.8	2.1	1.5	2.2	2.3	2.2	1.5	1.5	1.7	3.66	3.51	4.37
Lu (ppm)	0.62	0.3	0.32	0.23	0.33	0.34	0.33	0.23	0.23	0.25	0.546	0.511	0.637
Hf (ppm)	7.4	2.3	2.7	3.2	5.5	5.1	4.4	2.9	2.9	3.5	7.2	7.0	6.0
Ta (ppm)	1.5	1.9	2.2	1.3	3.2	2.3	1.8	1.7	1.5	1.6	1.37	1.32	1.2
W (ppm)	-1	1	-1	-1	2	-1	-1	-1	-1	-1	1.2	1.5	0.6
Tl (ppm)	0.2	0.2	0.2	0.2	0.3	-0.1	0.3	-0.1	-0.1	-0.1	0.27	0.52	0.13
Pb (ppm)	25	-5	10	18	-5	7	14	-5	10	9	6	9	14
Bi (ppm)	-0.4	-0.4	-0.4	-0.4	-0.4	-0.4	-0.4	-0.4	-0.4	-0.4	0.4	0.3	0.3
Th (ppm)	6.2	2.6	3.1	1.6	5.2	4.0	3.6	1.6	1.6	2.4	10.80	11.50	5.85
U (ppm)	2.5	0.7	0.8	0.4	1.4	0.9	0.8	0.4	0.4	0.6	2.44	2.45	1.42

[1]all coordinates NAD83 UTM [2]total iron as Fe_2O_3 [3]loss on ignition [4]replicate analysis

Samples were prepared using a ceramic mill and analysed for major, trace, and rare-earth elements at Activation Laboratories Ltd. in Ancaster, Ontario.
Major elements and first seven trace elements were determined with lithium metaborate/tetraborate fusion X-ray fluorescence (XRF).
Remaining trace and rare-earth elements were determined with lithium metaborate/tetraborate fusion inductively coupled plasma mass spectrometry (ICP-MS).
Analysis below detection limit shown with detection limit as negative number.

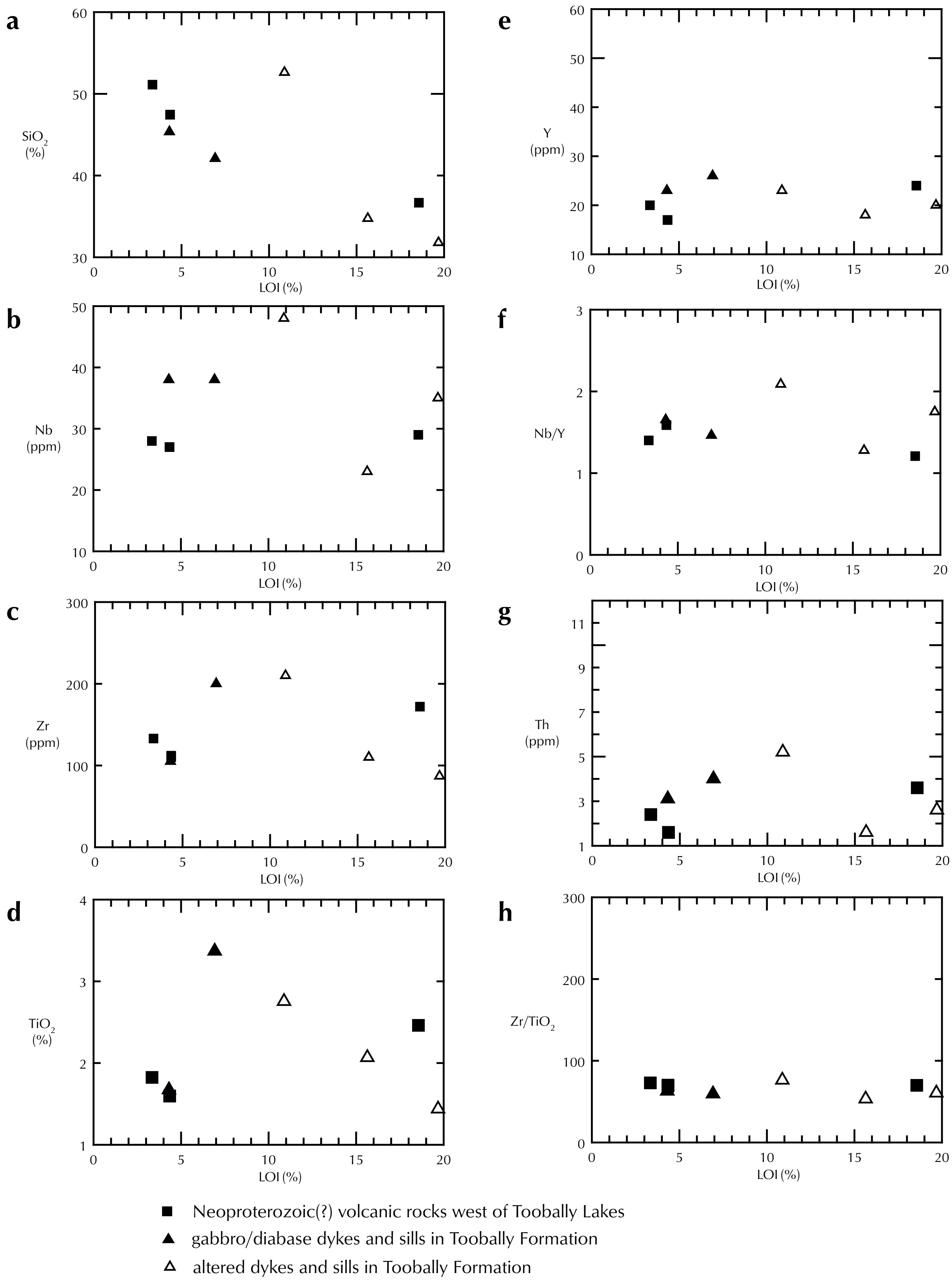
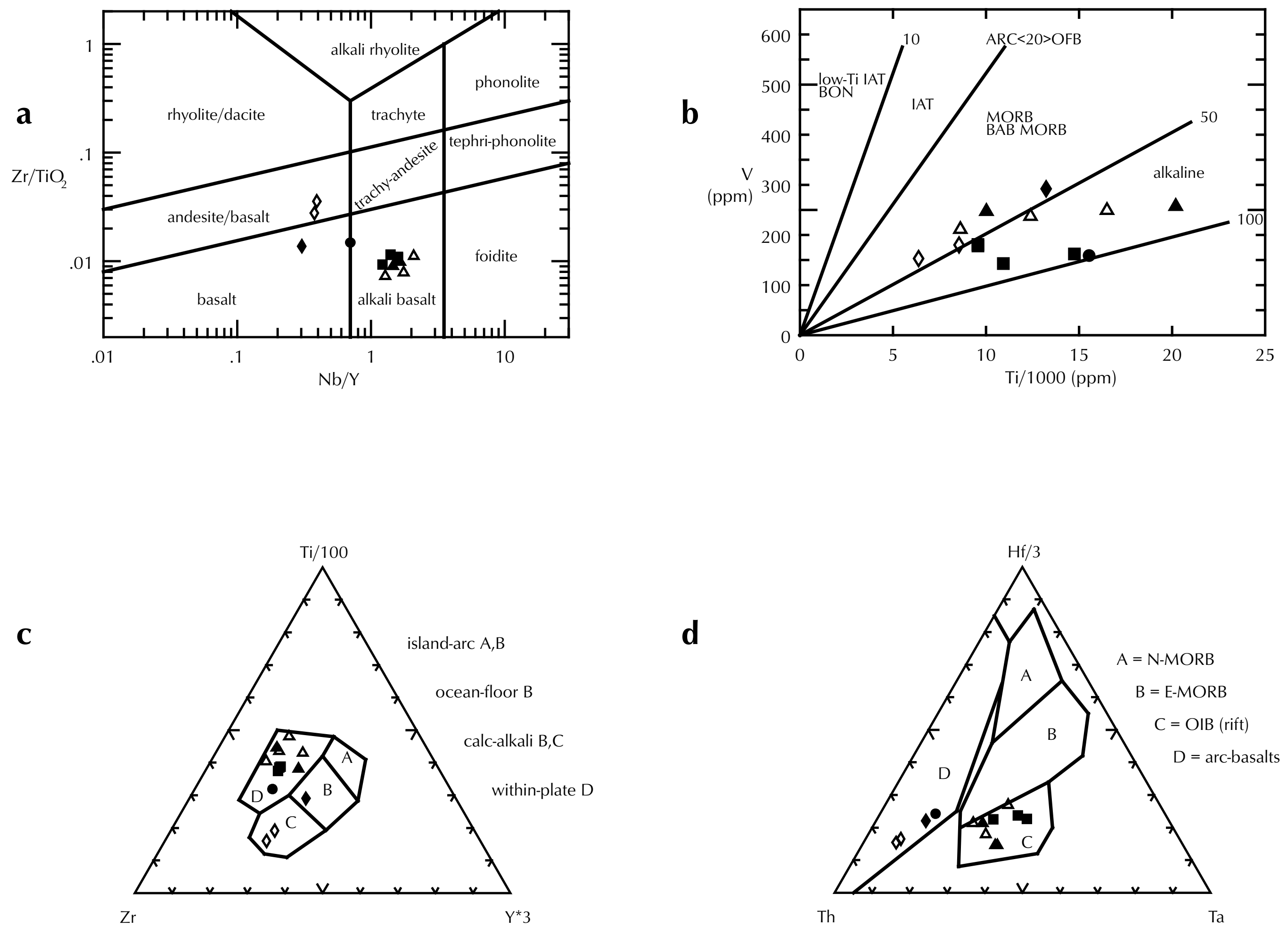


Figure 15. *XY plots of mobile and immobile elements and element ratios vs LOI for samples from northern Toobally Lake (NTS 95D/8).*

may be caused by addition of detrital zircon to the samples. Interestingly, the basalt clast in the Toobally Formation is transitional between the Pool Creek and Toobally basalt samples. These fields are consistent with plotted locations of the samples in the titanium-vanadium (Ti-V) diagram (Fig. 16b; Shervais, 1982). The Ti-Zr-Y diagram plots all the Toobally samples in the within-plate basalt field (Fig. 16c; Pearce and Cann, 1973). Pool Creek samples plot in the ocean-floor and calc-alkali fields in the same diagram. Pool Creek volcaniclastic siltstone samples are displaced toward higher Zr values (as in Fig. 16a). Using the hafnium-tantalium-thorium (Hf-Ta-Th) diagram (Fig. 16d; Wood, 1980), the only Toobally sample not contained within the oceanic island basalt field is the



northern Toobally Lake - 95D/8

- ■ Neoproterozoic(?) volcanic rocks west of Toobally Lakes
- ▲ gabbro/diabase dykes and sills in Toobally Formation
- △ altered dykes and sills in Toobally Formation
- ● basalt clast in Toobally Formation

Pool Creek - 95C/5

- ◊ Neoproterozoic green laminated siltstone (Pls)
- ♦ basalt clast in Neoproterozoic green laminated siltstone (Pls)

Figure 16. *Discriminant diagrams for Toobally and Pool Creek analyses using immobile elements.* ***(a)*** *Winchester and Floyd (1977) composition diagram of* Zr/TiO_2 *vs Nb/Y as modified by Pearce (1996);* ***(b)*** *Ti-V diagram from Shervais (1982);* ***(c)*** *Ti-Zr-Y diagram from Pearce and Cann (1973);* ***(d)*** *Hf-Th-Ta diagram from Wood (1980).*
Abbreviations: IAT – island arc tholeites; BON – boninites; MORB – mid-ocean ridge basalt, N – normal, E – enriched; BAB – back-arc basin; ARC – island arc basalt; OIB – ocean island basalt; OFB – ocean floor basalt.

basalt clast in the Toobally Formation. The Pool Creek samples plot in the same arc-basalt field as the Toobally basalt clast sample. The Pool Creek volcaniclastic siltstone samples are displaced toward higher Th values; this may also be related to incorporation of a detrital component in the Pool Creek samples.

All samples have an oceanic island basalt signature in multi-element diagrams normalized to primitive mantle (Fig. 17). As in Figure 16, the pattern for the altered and unaltered dykes/sills in the Toobally Formation is essentially identical to that of the samples from the overlying Neoproterozoic-Cambrian (?) volcanic rock unit (Fig. 17b). The Pool Creek samples (Fig. 17d) have a different chemistry than the Toobally samples, being more strongly enriched in Th and heavy rare earth elements (REE) and showing a negative Nb anomaly. The basalt clast in the Toobally Formation (Fig. 17c) lacks a negative Nb anomaly but has a similar Th and heavy REE pattern to that in the Pool Creek samples. It also displays a marked positive Zr anomaly.

Dykes/sills in the Toobally Formation are inferred to be subvolcanic equivalents of the extrusive Neoproterozoic-Cambrian (?) volcanic rock unit because of the strong similarity of immobile element patterns in Figures 16 and 17. Geochemistry of the samples is consistent with alkalic volcanism associated with rifting in a within-plate tectonic setting. Geochemistry of the Pool Creek samples and Toobally clast sample is also consistent with rift volcanism. In the above discussion we have suggested that the Pool Creek samples and the Toobally clast sample may be skewed into unrepresentative fields because of crustal contamination. Enrichment in Th/Yb ratio relative to the mantle array in Figure 18 (Pearce and Peate, 1995) is related to either crustal contamination or subducted slab

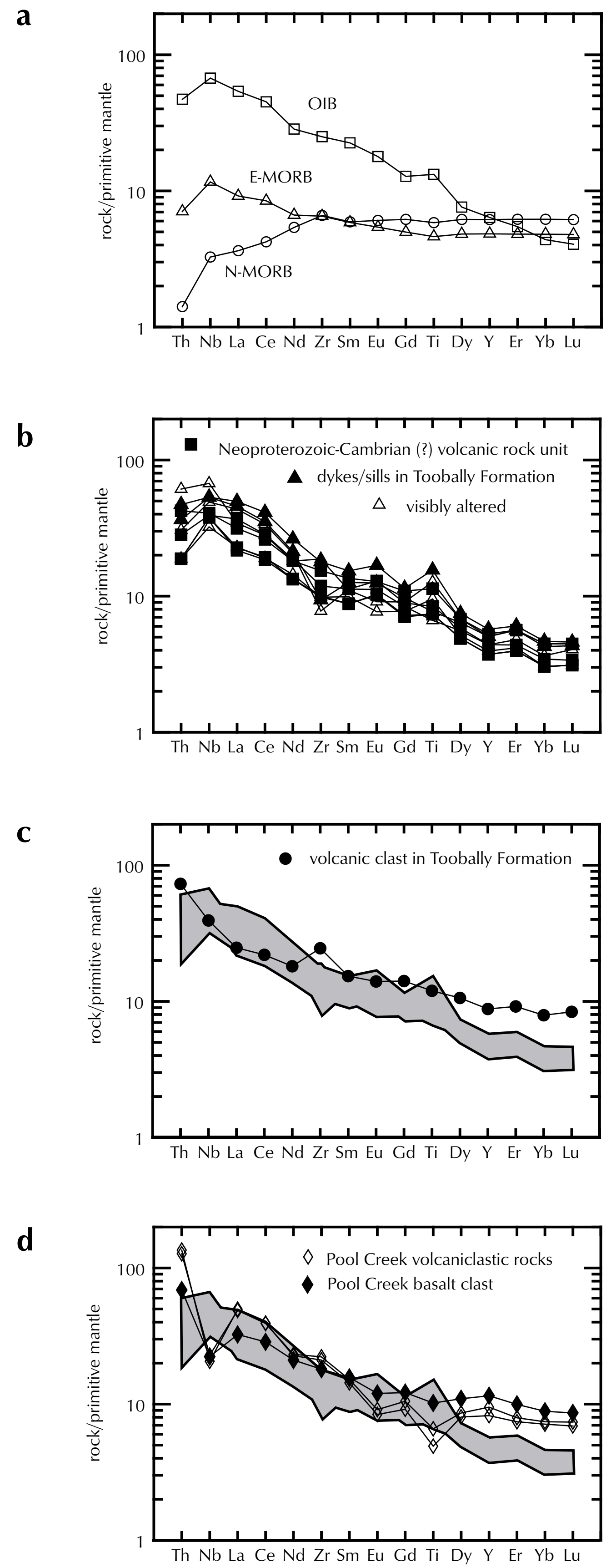


Figure 17. *Multi-element plots normalized to primitive mantle. Primitive mantle values are from Sun and McDonough (1989).*

(a) *reference diagrams for average OIB, E-MORB and N-MORB. Values are from Sun and McDonough (1989). Abbreviations in Figure 16 caption;*

(b) *dykes/sills in Toobally Formation and extrusive rocks from Neoproterozoic-Cambrian (?) volcanic rock unit;*

(c) *volcanic clast in Toobally Formation. Shaded area is envelope of values plotted in 17b;*

(d) *Pool Creek volcaniclastic rocks and Pool Creek basalt clast. Shaded area is envelope of values plotted in 17b.*

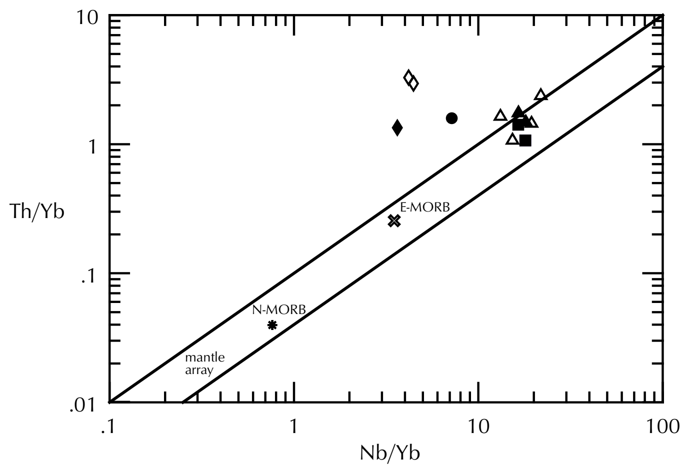


Figure 18. *Discriminant diagram Th/Yb vs Nb/Yb (Pearce and Peate, 1995) for Toobally and Pool Creek samples. Average values for E-MORB and N-MORB (Sun and McDonough, 1989) are shown for reference. Legend same as for Figure 16.*

metasomatism. The Pool Creek samples and Toobally basalt clast both are offset away from the mantle array, supporting our suggestion of crustal contamination and/or influx of a detrital crustal component.

In an earlier study of volcanism within the northern Canadian Cordilleran miogeocline, Goodfellow et al. (1995) studied volcanic successions ranging in age from Cambrian through Devonian. They subdivided the volcanic rocks into four main groups. The volcanic rocks from the Toobally and Pool Creek areas are most consistent with their alkali basalts of Group IV. In all groups, volcanism was associated with episodic rifting within Selwyn Basin.

STRUCTURAL GEOLOGY

The Toobally fault (Gabrielse and Blusson, 1969) is the dominant structural element in the area (Fig. 3). The inferred trace of the fault trends north to northeast in the major valley containing the northern Toobally Lake. Outcrop of dark shale (Besa River Formation ?) near shoreline on the west margin of the lake indicates that the fault trace occurs west of the lake in that immediate area (Fig. 3). Gabrielse and Blusson (1969) estimated a maximum stratigraphic throw of approximately 3950 m (9000 ft) with the east side down. In this report, it is interpreted as an east-verging reverse fault, placing Neoproterozoic sedimentary rocks on Paleozoic sedimentary rocks.

The hanging wall of the Toobally fault in the field area has been interpreted as a west-dipping, homoclinal succession of Neoproterozoic through Cambrian(?) sedimentary and volcanic rocks. Bedding through much of the succession is difficult to find. Eastward dipping beds in streamcuts just west of the lake are not considered representative because the observed bedding is within a dolostone interpreted as a large olistolith. The one other observed bedding measurement in the Toobally Formation near the lake has a moderate to gentle west dip (28 degrees), in keeping with regional westward dip west of the Toobally fault.

Only a few outcrops of sedimentary rocks in the footwall of the Toobally fault were observed during the summer fieldwork. Bedding in sandstones of the Mattson Formation in the southeast corner of the map area is essentially vertical. Based on the regional map pattern (Gabrielse and Blusson, 1969), this suggests that the Mattson Formation on the ridge top immediately east of the northern Toobally Lake outcrops in the core of an asymmetric to overturned, east-verging syncline. Bedding in limestone on the east shoreline dips steeply to gently to the west. Assuming this bedding is structurally upright, the limestone on the lakeshore is considered to be on the upright limb of an anticline occurring immediately west of the Mattson syncline. This interpretation is shown in cross-section in Figure 3b.

ECONOMIC GEOLOGY

Following their regional mapping program, Gabrielse and Blusson (1969) reported the occurrence of disseminated chalcopyrite in all of the volcanic rock units. Their map showed a copper occurrence in Cambrian strata west of the northern Toobally Lake; this represents the only Yukon MINFILE database record for 95D/8 map sheet (Fig. 3; Gusty occurrence, 95D 002, Deklerk, 2002).

One outcrop of Toobally Formation (coordinates 650123E, 6698395N) contains quartz veins up to 5 cm thick cross-cutting both the pebbly mudstone and carbonate-altered mafic dykes. Quartz veins are oriented subparallel to the slaty cleavage. These veins are internally fractured with quartz infilling the fractures. Veins contain fine pyrite and lesser disseminated chalcopyrite. Although not economic, sulphide-mineral-bearing veins, carbonate-altered mafic dykes, and a basalt volcanic unit all suggest the possibility of mineralizing systems in the area, possibly related to volcanism.

CONCLUSIONS

Fieldwork around northern Toobally Lake yielded some surprising results relative to expectations based on previous mapping. Toobally fault juxtaposes Neoproterozoic-Cambrian sediments on the west against Devonian-Carboniferous sedimentary rocks on the east. Neoproterozoic-Cambrian sedimentary rocks and volcanic rocks on the west side of the lake have a consistent westward dip. Devonian-Carboniferous sedimentary rocks on the east side of the lake are interpreted as folded into an anticline-syncline couplet.

The structurally lowest and therefore oldest unit in the hanging wall of Toobally fault is a coarse-grained, noncalcareous sandstone unit, presumably Neoproterozoic on the basis of stratigraphic and structural position. Stratigraphically and structurally overlying the sandstone unit is a thick unit of orange-weathering, matrix-supported, muddy conglomerate to conglomeratic mudstone which has not been previously mapped. This new unit is herein called the Toobally Formation. We have tentatively correlated the Toobally Formation with upper Windermere Supergroup glacial deposits represented by the Ice Brook and Vreeland formations. If this correlation is correct, deposition occurred at approximately 570 Ma, probably in a relatively deep-water, glaciomarine setting.

Overlying the Toobally Formation is a Neoproterozoic-Cambrian (?) volcanic rock unit consisting largely of volcaniclastic rocks, dominantly lapilli tuffs with lesser breccias and mudstones. Thickness of the volcanic unit has been revised downward from earlier mapping to approximately 850 m. The volcanic rocks are alkali basalts that chemically correspond to light rare earth element (LREE)-enriched within-plate basalts, consistent with a rift setting. Although these rocks are similar in general lithology to volcaniclastic rocks in Pool Creek area (95C/5), chemistries of the two suites are different and suggest that the volcaniclastic units from Toobally Lakes and Pool Creek should not be correlated. This is substantiated by the implied age difference if the Toobally Formation is correlated with the Ice Brook and Vreeland formations.

Mafic dykes and sills, some extensively carbonate-altered, are present in the underlying Toobally Formation. These are chemically similar to the overlying Neoproterozoic-Cambrian (?) volcanic rock unit and are considered their subvolcanic equivalents.

Toobally Formation contains cross-cutting quartz veins with disseminated pyrite and chalcopyrite. These, together with carbonate-altered dykes and sills in the Toobally Formation, suggest the possibility of mineralizing systems, perhaps associated with volcanism.

Exposures in the footwall of the Toobally fault consist of dark shale; dark, locally bioturbated limestone; and fine-grained, noncalcareous, quartz sandstone. The shale, limestone, and sandstone are assigned to Besa River Formation, an unnamed Devonian limestone (map unit Dl of Pigage and Allen, 2001), and Carboniferous Mattson Formation, respectively.

Discontinuous and patchy outcrop presented challenges in completing detailed structural and stratigraphic studies in a short field season. Stratigraphic relations and correlations presented in this report are tentative pending further detailed studies, including additional fieldwork, micropaleontology and palynology.

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Hu Gabrielse provided early advice on stratigraphy and outcrop extent. Keith Dewing and Dave Morrow provided helpful discussions on stratigraphic procedures with Rob MacNaughton. The manuscript was reviewed by Maurice Colpron of the Yukon Geological Survey.

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Drift prospecting in the region of the Yukon-Tanana Terrane, southern Yukon[1]

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Plouffe, A. and Bond, J.D., 2004. Drift prospecting in the region of the Yukon-Tanana Terrane, southern Yukon. *In:* Yukon Exploration and Geology 2003, D.S. Emond and L.L. Lewis (eds.), Yukon Geological Survey, p. 221-257.

ABSTRACT

Regional till geochemistry surveys were conducted in the Finlayson Lake, Glenlyon and eastern Carmacks map areas. Detailed till sampling was completed at the Kudz Ze Kayah and Clear Lake massive sulphide deposits to evaluate glacial dispersal near mineralized rock in a mountainous region and a plateau, respectively. A comparative evaluation of the silt-and-clay-sized fraction versus the clay-sized fraction geochemistry indicates that the clay-sized fraction presents higher metal concentrations than the silt and clay, but both size fractions generally delineate the same base metal exploration targets. The correlation between the high gold concentrations in both size fractions is not as good as for base metals because gold occurrences are only reflected in the silt- or clay-sized particles of till. The beryllium content of till might provide an indication of the occurrence of beryl in bedrock but the low analytical precision of beryllium analyses limits this approach.

RÉSUMÉ

Des levés géochimiques du till ont été effectués dans les régions des feuillets topographiques de Finlayson Lake et Glenlyon ainsi que de la partie est du feuillet de Carmacks. Un échantillonnage plus détaillé du till a été réalisé près des gîtes de sulfures massifs de Kudz Ze Kayah et de Clear Lake pour évaluer la dispersion glaciaire près d'une minéralisation connue dans une région montagneuse et sur un plateau. L' étude comparative de la composition géochimique de la fraction argileuse et de la fraction silteuse-argileuse du till montre que la fraction argileuse contient de plus fortes teneurs en métaux que la fraction silteuse-argileuse. Par contre, de façon générale, la géochimie des deux fractions granulométriques permet de définir les mêmes cibles d'exploration pour les métaux de base. La corrélation entre les concentrations élevées en or des deux fractions granulométriques n'est pas aussi bonne que pour les métaux de base probablement parce que les indices d'or ne s'observent que dans la fraction silteuse ou argileuse du till. La teneur en béryllium du till pourrait donner une indication de la présence de béryl dans la roche en place mais la faible précision des analyses du béryllium limite la portée de cette approche.

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INTRODUCTION

The discovery of volcanogenic massive sulphide deposits in the mid-1990s (Schultze, 1996; Tucker et al., 1997) and an emerald occurrence in 1998 (Groat et al., 2002; Neufeld et al., 2003), both in the Yukon-Tanana Terrane (YTT) of southeastern Yukon, has demonstrated the potential of this terrane to host such mineral deposits (Hunt, 1997; 2002). As part of the Targeted Geoscience Initiative, a joint project between the Yukon Geological Survey (YGS; formerly the Yukon Geology Program) and the Geological Survey of Canada (GSC) was initiated in 2000 to further evaluate the mineral potential and to promote mineral exploration in the YTT. As part of this project, regional till geochemistry surveys were conducted over two regions: the Finlayson Lake map area (NTS 105G), and the Glenlyon (NTS 105L) and eastern Carmacks (NTS 115I) map areas (Fig. 1). In addition, detailed till sampling was completed at the Kudz Ze Kayah and the Clear Lake deposits to define glacial dispersal near known massive sulphide deposits in a mountainous region and a plateau. The regional till geochemistry was released as joint YGS and GSC open files (Bond et al., 2002; Colpron et al., 2003b; Plouffe and Bond, 2003). Interpretation of the geochemistry of the silt-and-clay-sized fraction of till (except for beryllium which was analysed after the publication of these reports) was provided by Bond and Plouffe (2002; 2003).

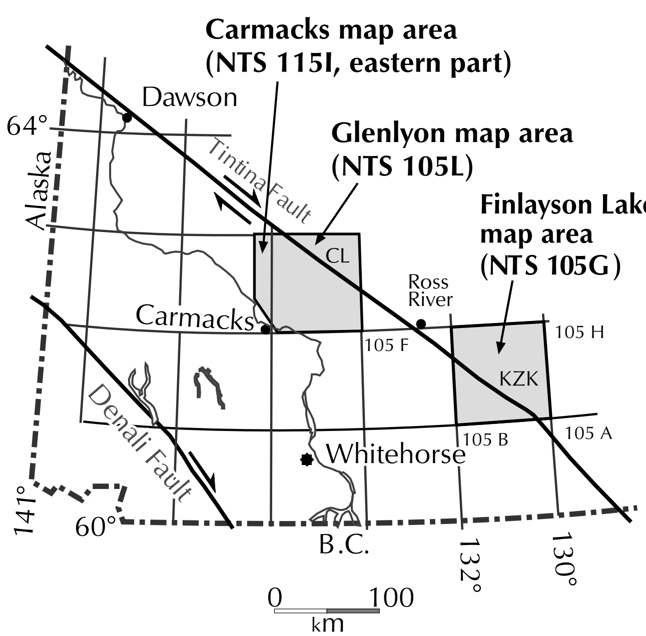


Figure 1. Location of Finlayson Lake, Carmacks and Glenlyon map areas in southern Yukon; CL – Clear Lake, KZK – Kudz Ze Kayah.

The objectives of this report are to present the interpretation of the geochemistry of the clay-sized fraction and beryllium analyses, and to compare the efficiency of the silt-and-clay- versus the clay-sized fractions of till as analytical media for drift exploration within the YTT.

BEDROCK GEOLOGY

The YTT is composed of polydeformed Devonian to Permian metasedimentary and metaigneous (including metaplutonic and metavolcanic) rocks which were accreted to North America during late Paleozoic time (Murphy et al., 2003). In the Finlayson Lake region, YTT is composed of thrust-imbricated metasedimentary and metaigneous rocks juxtaposed with the North American miogeocline along the Inconnu thrust (Murphy et al., 2002). Post-thrusting intrusions include Jurassic granitic intrusions, Tertiary gabbro in the YTT, and Cretaceous granite in both the YTT and the North American craton. Undeformed Eocene basalt, rhyolite and gabbro overlie and cross-cut older rocks. The major volcanogenic massive sulphide deposits in the Finlayson Lake district are hosted in Upper Devonian to Lower Mississippian (Kudz Ze Kayah, GP4F, Fyre Lake, and Wolverine properties; Yukon MINFILE 2002, 105G 117, 105G 012, 105F 071, 105G 072, Deklerk, 2002) and Early Permian (Ice property; Yukon MINFILE 2002, 105F 073, Deklerk, 2002) metavolcanic rocks of the Wolverine Lake and Grass Lakes groups which are considered promising exploration targets for massive sulphide deposits (Murphy et al., 2002; Murphy, this volume; Fig. 2). In addition, the Grass Lakes group has potential to host other types of deposits, such as sedimentary exhalative (SEDEX; e.g., Argus (HOO), Yukon MINFILE 2002, 105G 013, Deklerk, 2002). In the southern sector of the Finlayson Lake map area, at Regal Ridge (Yukon MINFILE 2002, 105G 147, Deklerk, 2002), emerald crystals (a form of beryl) are found in association with quartz-tourmaline veins in mafic metavolcanic rocks of the Fire Lake formation unit (a sub-division of the Grass Lake group) near their contact with a mid-Cretaceous granite (Fig. 2; Groat et al., 2002; Murphy et al., 2002; Neufeld et al., this volume). Electron microprobe analyses of the emerald crystals (N=25) from Regal Ridge revealed that they contain high chromium (average: 3208 ppm) and high vanadium (average: 171 ppm) concentrations (Groat et al., 2002). The granite is interpreted to be the source of beryllium, and the mafic and ultramafic rocks the source of chromium and vanadium (Groat et al., 2002).

In eastern Carmacks and Glenlyon map areas, the YTT is in fault-contact to the northeast with sedimentary rocks of the North American miogeocline and to the southwest with the mafic metavolcanic rocks of the Semenof block (Fig. 3). Following restoration of 425 km of right lateral displacement along Tintina Fault, rocks of the YTT in Glenlyon map area are on trend with the massive sulphide district of the Finlayson Lake district (Colpron and Yukon-Tanana Working Group, 2000). In Glenlyon and eastern Carmacks map areas, the YTT is composed of northwest-trending metasedimentary, metavolcanic and metaplutonic rocks varying in age from Devonian (and possibly older) to Pennsylvanian (Colpron et al., 2003a). In the western sector, granitic rocks of probable Late Triassic to Early Jurassic age form two large plutons: the McGregor and Tatchun batholiths. Smaller Cretaceous granitic intrusions are present in the eastern sector, in both the YTT and the North American miogeocline. Known mineral occurrences within the region include volcanic-hosted massive sulphide, fault-related epithermal gold, and intrusion-related and sedimentary-exhalative types (Colpron et al., 2003a). Volcanic rocks of the Little Kalzas and Little Salmon formations, both part of the YTT, are considered good exploration targets for volcanogenic massive sulphide deposits (Colpron et al., 2003a). The Clear Lake sedimentary-exhalative deposit (Yukon MINFILE 2002, 105L 045, Deklerk, 2002) is located in the northern part of the Glenlyon map area within the Earn Group strata of the Cassiar Terrane which is part of the North American miogeocline (Figs. 1 and 3).

More details on the regional bedrock geology of the Finlayson Lake, Glenlyon and eastern Carmacks map areas are presented in Murphy et al. (2001 and this volume), Bond et al. (2002) and Colpron et al. (2002; 2003b; 2003a).

PHYSIOGRAPHY AND GLACIAL HISTORY

Bond and Plouffe (2002; 2003) presented a detailed account of the physiography, Quaternary stratigraphy, and the glacial history of the Finlayson Lake, Glenlyon, and eastern Carmacks map areas which is only summarized here.

Most of the Finlayson Lake map area is part of the Yukon Plateau, an area of low relief with accordant uplands. The region was completely covered by ice during the Late Wisconsinan McConnell Glaciation (~20 000 years ago). Glaciers were generally flowing to the northwest from an ice-divide located over the Wolverine Lake region (Prest et al., 1967; Dyke, 1990; Jackson, 1994; Fig. 4). Southeast of Wolverine Lake, ice flow was to the southeast.

The Glenlyon and eastern Carmacks map areas, which are dominantly part of the Yukon Plateau, straddle the limit of the McConnell Glaciation in central Yukon. During the last glacial event, the Selwyn and Cassiar ice lobes invaded the region but the highest summits and the westernmost sector remained unglaciated (Jackson, 2000; Ward and Jackson, 2000; Fig. 5). Since the glaciers were relatively thin, topography played an influential role on ice-flow patterns and ice-lobe configuration. Ice flow was dominantly to the northwest with local diversion to the west, southwest and north (Jackson, 2000; Ward and Jackson, 2000).

METHODS

The details of the methodology of the regional till geochemistry surveys are given in Bond and Plouffe (2002; 2003) and Plouffe and Bond (2003). In summary, till samples were collected along foot traverses with a sample spacing averaging 1 km. At Kudz Ze Kayah and Clear Lake, where the orientation surveys were completed, sample spacing varied from 50 to 500 m. In total, 487 till samples were collected from the Finlayson Lake region (including the samples collected in 2000 as part of the Weasel Lake project; see Bond, 2001) and 285 from the Glenlyon and eastern Carmacks map areas. Till was collected at a depth > 50 cm below the surface to minimize the effect of soil weathering associated with the B-horizon. At each site, 50 pebbles were collected from the till. Pebble counts were completed at base camp for selected samples. Two size fractions were obtained from the till samples: 1) the silt-and-clay-sized fraction (<0.063 mm; -230 mesh) was separated by dry sieving in the commercial laboratory that conducted the geochemical analyses and 2) the clay-sized fraction (<0.002 mm) was obtained following the centrifuge method at the sedimentology laboratory of the Geological Survey of Canada in Ottawa (Lindsay and Shilts, 1995). Both size fractions were analysed for 40 elements in a commercial laboratory by inductively coupled plasma mass spectrometry (ICP-MS) following hydrochloric-nitric acid and demineralized water digestion ($HCl:HNO_3:H_20$). Beryllium analyses, on the silt-and-clay-sized fraction only, were conducted by ICP-MS following a lithium metaborate ($LiBO_2$) fusion. A fusion was

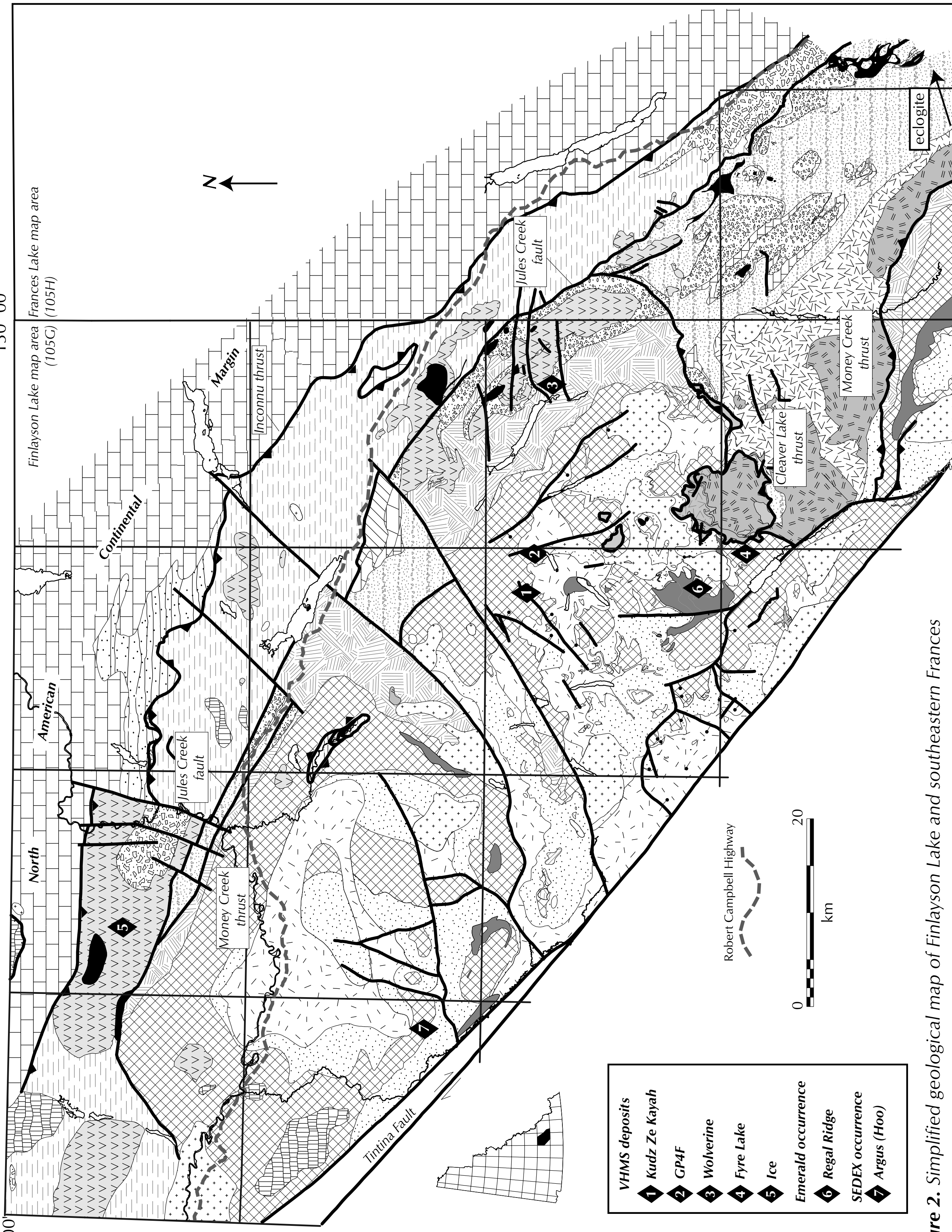


Figure 2. *Simplified geological map of Finlayson Lake and southeastern Frances Lake map areas (modified from Murphy et al., 2002). Legend on facing page.*

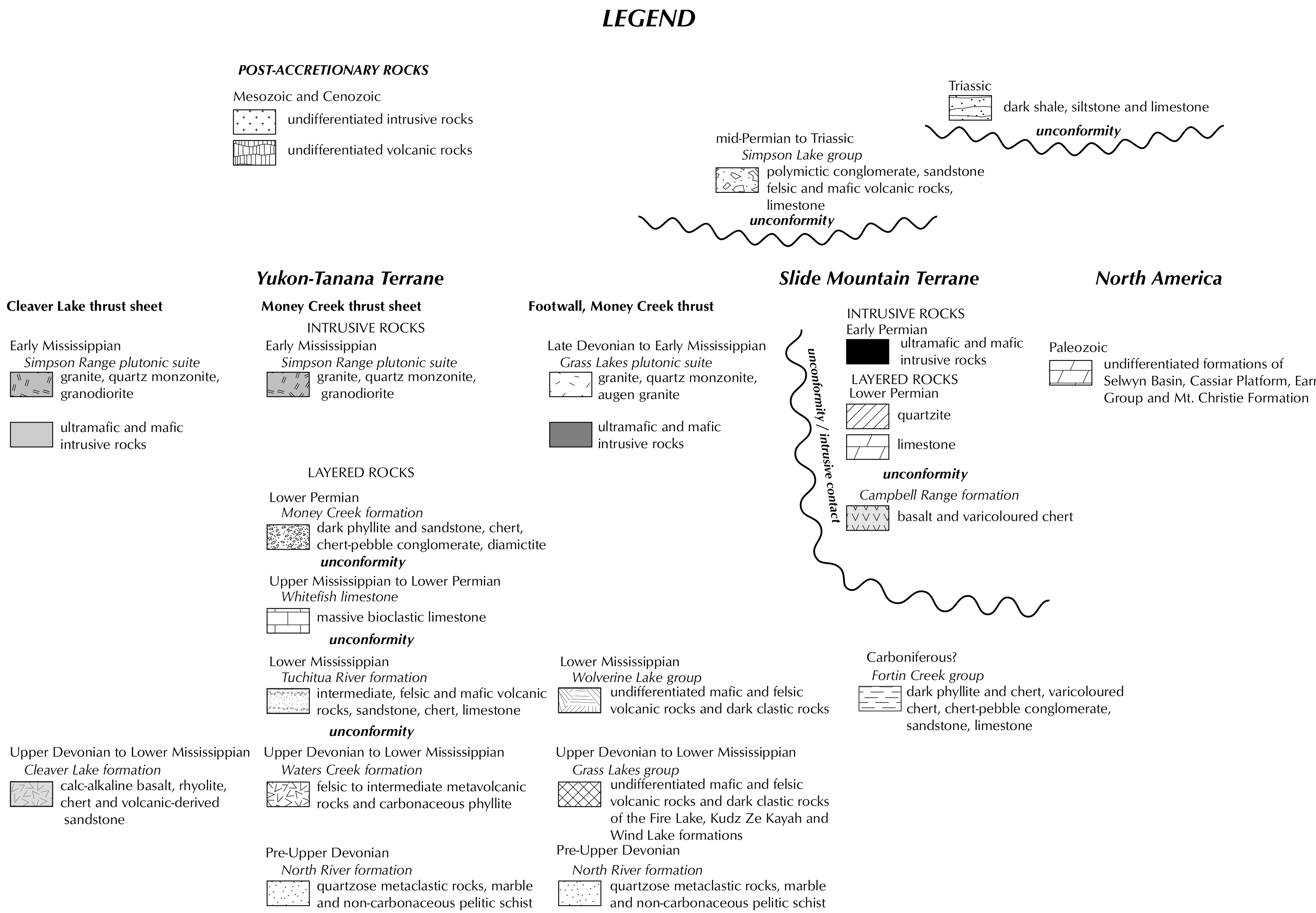


Figure 2. *Legend for map on facing page.*

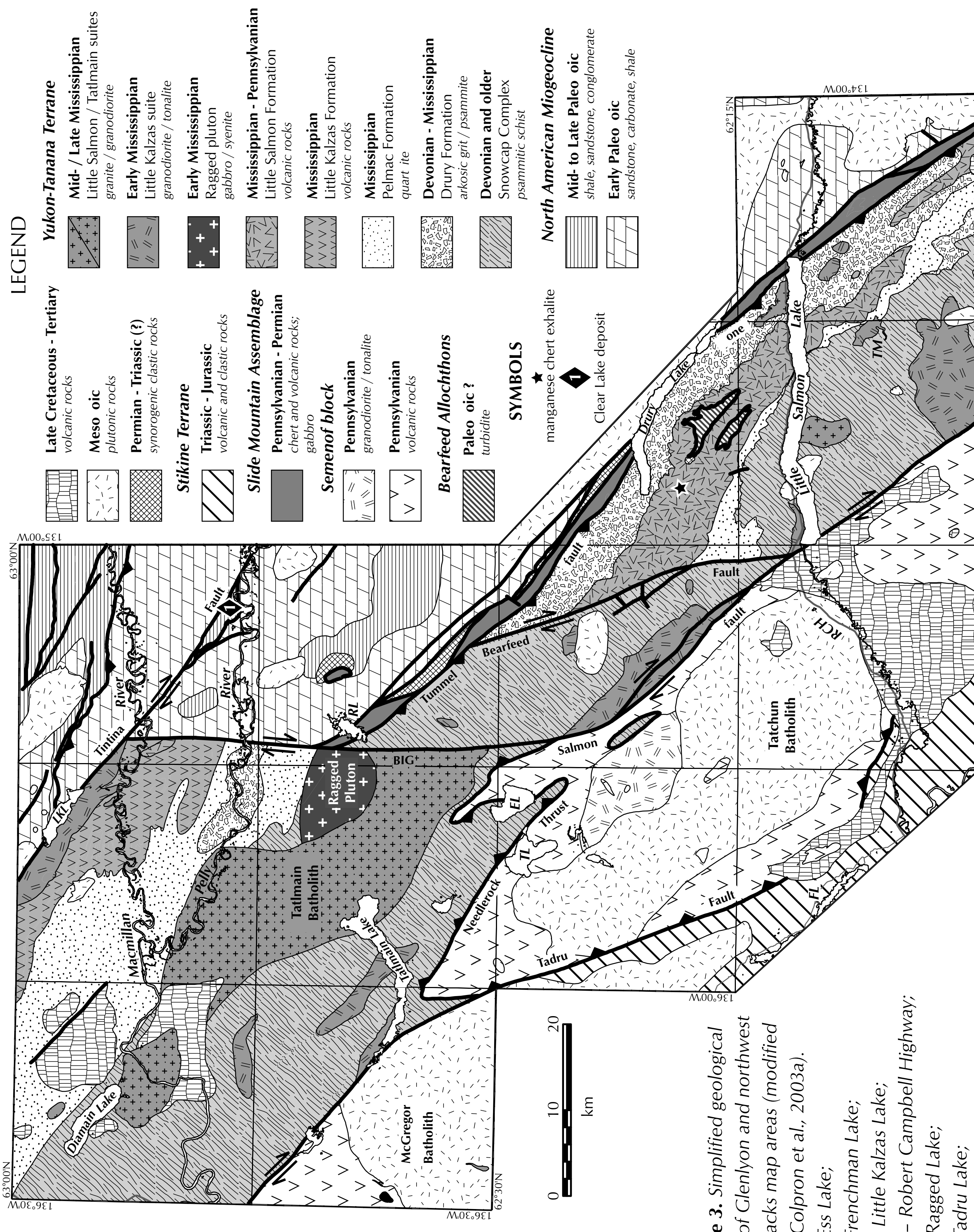


Figure 3. *Simplified geological map of Glenlyon and northwest Carmacks map areas (modified after Colpron et al., 2003a).*
EL – Ess Lake;
FL – Frenchman Lake;
LKL – Little Kalzas Lake;
RCH – Robert Campbell Highway;
RL – Ragged Lake;
TL – Tadru Lake;
TM – Telegraph Mountain.

selected for the beryllium analyses because of its effectiveness in breaking down silicates such as beryl. A complete list of elements along with their detection limits is given in Plouffe and Bond (2003). Field and laboratory duplicates, and analytical standards were randomly inserted in the suite of samples to monitor analytical precision and accuracy. All quality assurance and quality control information is given in Plouffe and Bond (2003). Analytical precision is best, that is generally ≤ ±15%, for elements which occur well above their detection limit (copper, lead, zinc, mercury, silver, arsenic, barium, cobalt, chromium, tungsten) and is worst for elements occurring in low concentrations (beryllium ±94%, palladium ±31%, platinum ±29%) or heterogeneously distributed within the sediment (nugget effect; gold ±50%).

RESULTS AND INTERPRETATION

GEOCHEMICAL PARTITIONING

Numerous studies have demonstrated the enrichment of several elements in the clay-sized fraction of sediments compared to the silt-and-clay-sized fraction (for example Shilts, 1975; 1984; Nikkarinen et al., 1984; Klassen, 1999). Such elemental enrichment in the clay-sized fraction is attributed to a combination of the high adsorption capacity of clay and oxide minerals which can scavenge elements during weathering (Shilts, 1984), and to the high concentrations of metals in the structure of phyllosilicates in the primary bedrock source (Räisänen et al., 1992; Shilts, 1996; Klassen, 2001). Metal enrichment in

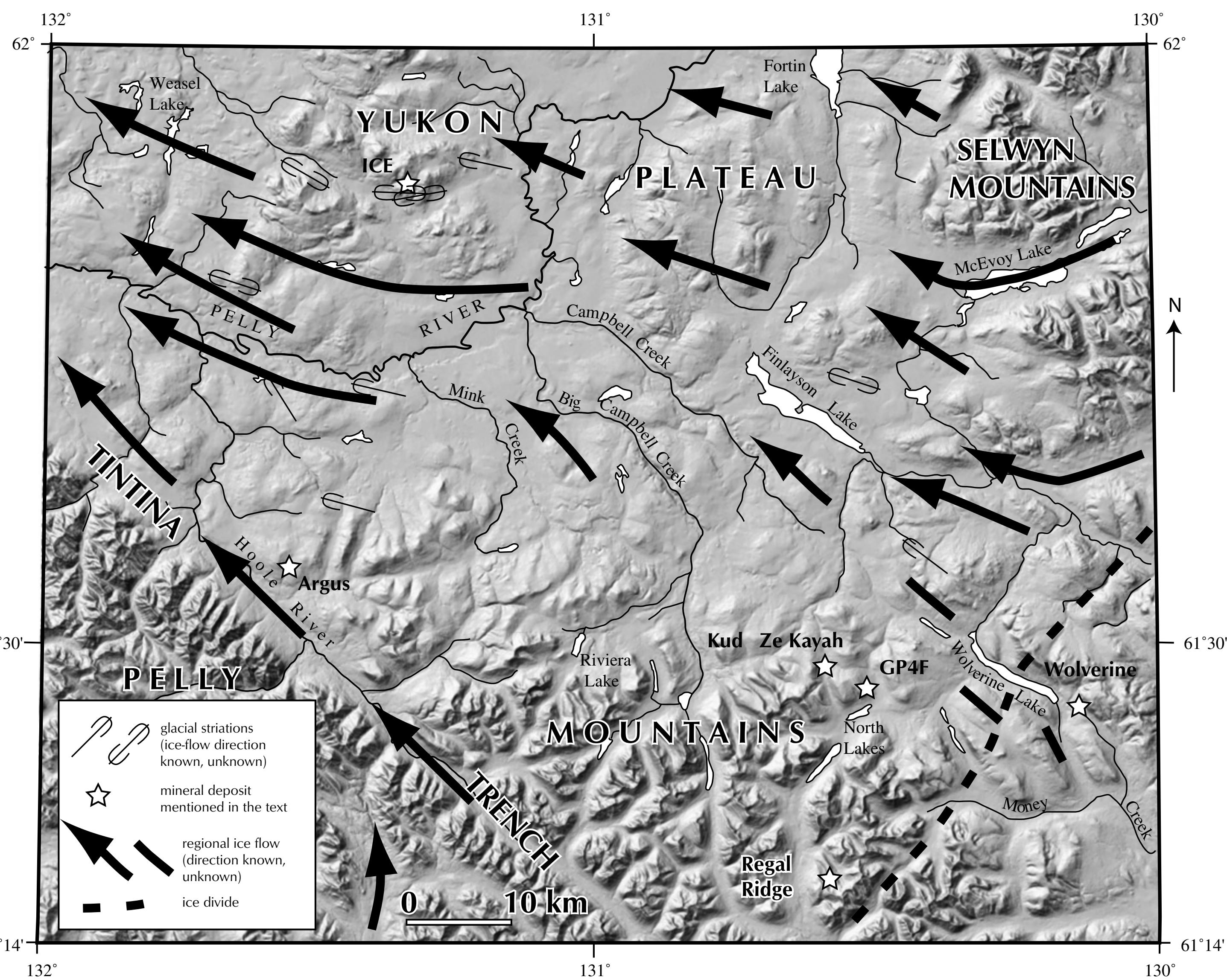


Figure 4. *Physiography and regional ice flow of the Finlayson Lake map area (modified from Bond and Plouffe, 2003).*

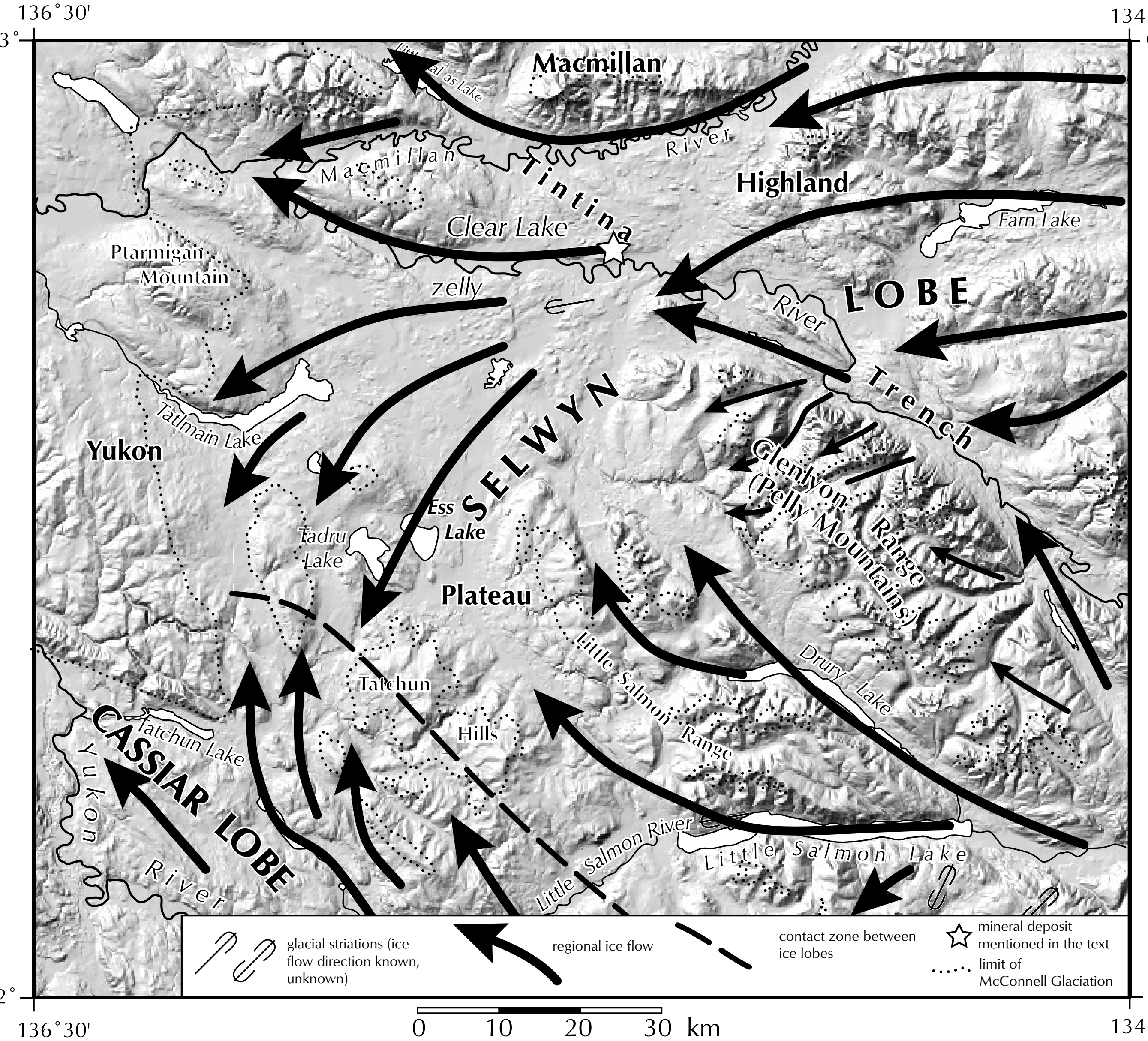


Figure 5. *Physiography and regional ice flow of the Glenlyon and eastern Carmacks map areas.*

phyllosilicate minerals in bedrock translates into high metal levels in the clay-sized fraction of till because phyllosilicates are easily comminuted to clay-sized particles during glacial erosion and transport. In addition, the lower metal concentrations in the silt-and-clay- compared to the clay-sized fraction is explained by the presence of metal-poor silicate minerals in the silt-sized fraction which act as dilutents (Shilts, 1984). Therefore, elemental partitioning between size fractions in till is controlled by mineralogy and glacial milling (DiLabio, 1982, 1988; Shilts, 1995; Plouffe, 1997). The analysis of the silt-and-clay-sized fraction of till has been used most commonly for mineral exploration by industries and geological surveys, principally because it is easy and inexpensive to obtain (by dry-sieving) and it defines glacial dispersal trains at the local scale (Parent et al., 1996; Levson, 2001). On the other hand, geochemistry of the clay-sized fraction of till has been used dominantly for regional till composition surveys because it defines regional trends without being affected by textural variation in till (for example Shilts, 1971, 1996; Peuraniemi, 1982; Salminen and Hartikainen, 1985; Peuraniemi et al., 1997; Plouffe, 1998; Klassen, 2001).

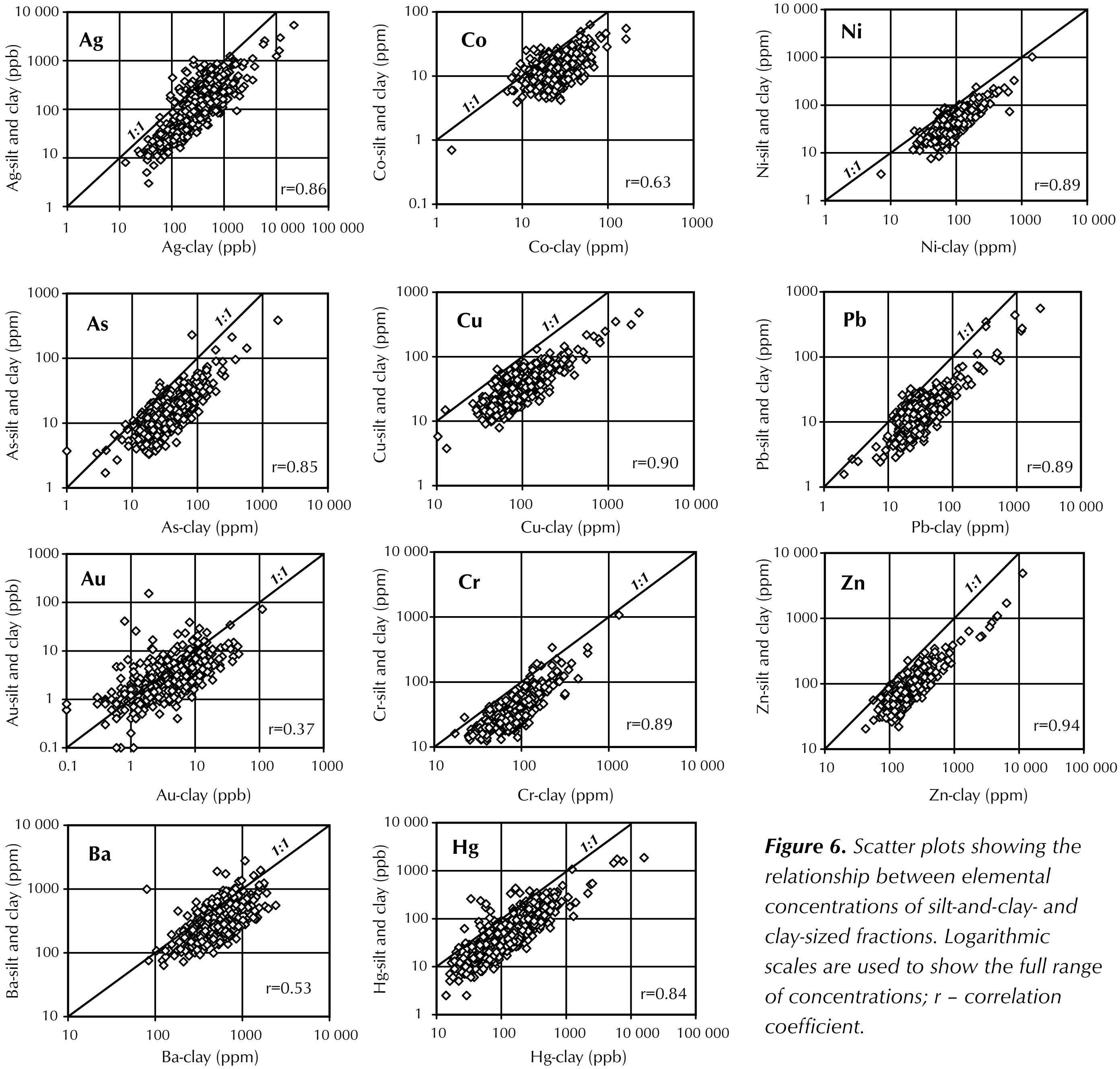


Figure 6. *Scatter plots showing the relationship between elemental concentrations of silt-and-clay- and clay-sized fractions. Logarithmic scales are used to show the full range of concentrations; r – correlation coefficient.*

With the data combined from the Finlayson Lake and Glenlyon regions, it is clear that for most elements of interest there is a general enrichment in the clay-sized compared to the silt-and-clay-sized fraction with gold being an exception (Fig. 6). The linear correlation between both size fractions, expressed as the correlation coefficient, is strongest for silver (r=0.86), arsenic (r=0.85), chromium (r=0.89), copper (r=0.90), mercury (r=0.84), nickel (r=0.89), lead (r=0.89) and zinc (r=0.94), lesser in strength for barium (r=0.53) and cobalt (r=0.63), and weak for gold (r=0.37). The relationship could not be evaluated for palladium and platinum because only a few silt-and-clay samples yielded concentrations above detection limit. The relationships shown in Figure 6 do not take into consideration variation in underlying bedrock lithologies which can influence partitioning between both size fractions because of the difference in mineralogy (see for example, Klassen, 1999). From the mineral exploration point of view, the strong relationships signify that a high metal level is usually reflected in both size fractions.

However, there are important exceptions to this general rule with some samples yielding high concentrations in only one of the two size fractions. In such cases, the partitioning is most likely due to the elements being dominantly concentrated into a mineral form which preferentially occurs in only one size fraction. In the case of gold, the poor relationship between the silt-and-clay- and clay-sized fractions is attributed in part to the poor precision of the analyses which is related to the heterogeneous distribution of this metal in till (nugget effect). In addition, free gold can occur preferentially in only one of the two size fractions depending on its size in the source bedrock and the intensity of glacial comminution.

FINLAYSON LAKE MAP AREA

Kudz Ze Kayah orientation survey

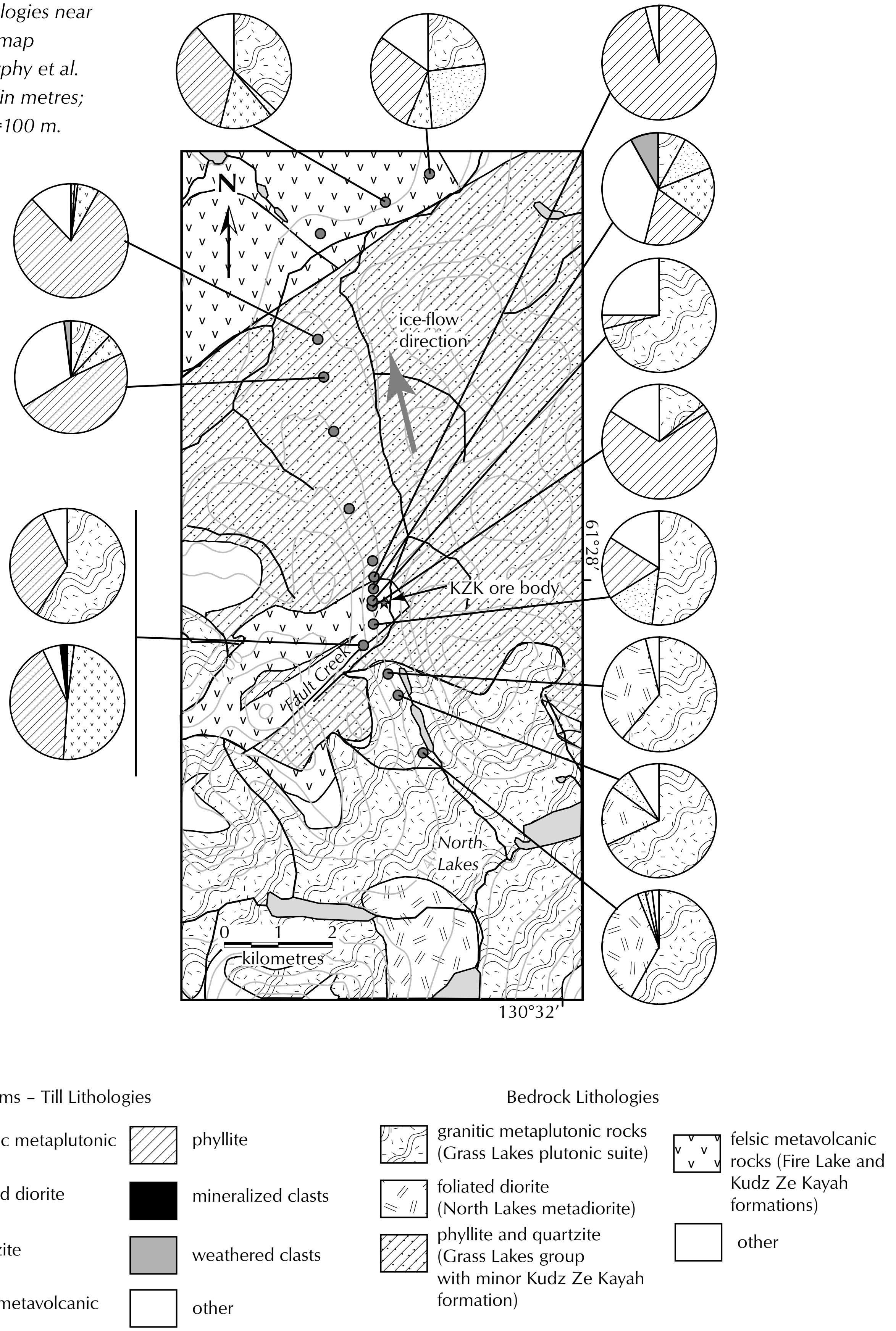
The Kudz Ze Kayah (KZK) deposit is located in the Pelly Mountains, approximately 20 km due south of Finlayson Lake, in an unnamed tributary valley of the Finlayson River. The mineralization at KZK consists of a volcanogenic massive sulphide body hosted in Devonian to Early Mississippian felsic metavolcanic rocks of the Grass Lakes group (Murphy et al., 2002; Murphy, this volume). It has an estimated open pit reserve of 11 million tonnes grading 5.9% Zn, 0.9% Cu, 1.5% Pb, 130 g/t Ag, and 1.3 g/t Au (Schultze, 1996). Sphalerite, chalcopyrite and galena are the main ore minerals (Yukon MINFILE 2002, 105G 117, Deklerk, 2002). The deposit lies under 2 to 20 m of ablation till, colluvium, and glaciofluvial sediments. The subcrop expression of the mineral deposit is lenticular in shape, being 2 to 39 m thick and 700 m long, and generally trending east-west, that is, transverse to the valley (Schultze, 1996). Based on the interpretation of the regional ice-flow patterns, ice in the KZK area was flowing to the north, parallel to the valley.

A till sampling transect was completed parallel to the KZK valley from approximately 3 km to the south (up-ice) to about 8 km north (down-ice) of the KZK mineral deposit (Fig. 7). Within 1 km of the mineralization, sample spacing averages 300 m, but beyond that distance it averages 1 km. Sampling of till within the valley was hampered by its scarcity; the till was either reworked as colluvium or covered by glaciofluvial sediments.

Till lithologies at KZK are thought to be related to bedrock provenance region, ice-flow direction, glacial process and till thickness. However, the interpretation of the till lithologies is limited by 1) the small clast size (pebbles) collected in the field from which the source bedrock cannot always be identified, and 2) potential unmapped and concealed bedrock units. The granitic metaplutonic pebbles in till are thought to be derived from the Grass Lakes plutonic suite of Murphy et al. (2002; Fig. 7). Samples with the greatest concentration of granitic metaplutonic pebbles are found in the southern part of the transect near the Grass Lakes plutonic suite. The high percentage of granitic metaplutonic pebbles in the northernmost samples (37 and 23%) could be related to concealed granitic metaplutonic bedrock north of the KZK mineralization. Clasts of foliated diorite are only present in the southern samples and are most likely derived from the North Lakes metadiorite approximately 5 km south of the KZK mineralization (Murphy et al., 2002). In the Fault Creek valley, two till samples collected on a small creek bluff attest to the variability of till composition with depth. Lithologies in the lower sample are dominated by local felsic metavolcanic and phyllite clasts, whereas the upper sample contains mostly southerly derived granitic metaplutonic rocks. No mineralized clasts are observed in till down-ice of KZK except in the Fault Creek valley, where concealed mineralization is suspected (Bond and Plouffe, 2002). Even in the field, massive sulphide boulders and cobbles were found only close (<100 m) to the site of the KZK mineral deposit. This suggests that coarse massive sulphide debris was rapidly comminuted to smaller-sized particles during glacial erosion, transport and deposition. In addition, postglacial weathering has contributed to the destruction of sulphide-rich debris in the near surface.

Elevated concentrations of copper, lead, zinc, silver, arsenic, gold and mercury are found in till immediately down-ice of the KZK mineral deposit, and clearly define its presence (Fig. 8). High concentrations of these elements to the south (up-ice) of the main mineralized zone are most likely derived from mineralized bedrock near Fault Creek (Bond and Plouffe, 2002). In the clay-sized fraction of till, the length of glacial dispersal at KZK, estimated with a threshold equivalent to the 95th percentile of the regional data, is 3.3 km for zinc, 1.8 km for lead and gold, and 0.5 km for silver, arsenic, copper and mercury (Fig. 8). It is assumed that there is no concealed mineralization north of KZK when estimating the length of glacial transport. Glacial dispersal trains for arsenic, mercury, and zinc as defined by the clay-sized fraction are longer than the ones in the silt-and-clay-sized fraction. Increasing glacial comminution of mineralized debris with increasing distance of glacial transport is considered a probable cause for this difference. On the

Figure 7. *Till lithologies near KZK; lithological map derived from Murphy et al. (2001). Contours in metres; contour interval =100 m.*



other hand, other elements (silver, gold, copper and lead) yielded similar dispersal distances in both the clay- and the silt-and-clay-sized fraction (Fig. 8).

The differences in the length of glacial transport amongst base metals at KZK are attributed to the elemental concentrations within the mineralization. For example, a direct relationship exists between base-metal concentrations in the mineralized zone and distance of glacial transport: zinc 5.9% and 3.3 km, lead 1.5% and 1.8 km, and copper 0.9% and 0.5 km. Such a relationship between metal concentrations in the ore zone and the distance of glacial transport is thought to be site-specific. The same relationship is not observed for precious metals: silver 130 g/t and 0.5 km, and gold 1.3 g/t and 1.8 km. This suggests that the length of glacial dispersal is not only influenced by the metal concentration in the ore zone but also by other factors such as the metal enrichment in the mineralized zone compared to the surrounding host rock and the physical and chemical properties of the host minerals.

As expected, copper, lead, zinc, silver, arsenic and mercury levels are generally higher in the clay- than in the silt-and-clay-sized fraction. In the case of gold, concentrations in both size fractions are similar, reflecting the fine-grained nature of the gold in the KZK mineral deposit. An obvious exception to this general rule is the sample located 3 km south of KZK which yielded gold concentrations of 153 ppb in the silt-and-clay- and only 2 ppb in the clay-sized fraction (Fig. 8). From this data, it could be speculated that the source of gold in this anomalous sample is coarser and derived from mineralization different in style from KZK. Bond and Plouffe (2002) suggested that the gold could be derived from intrusion-related mineralization associated with the nearby Grass Lake plutonic suite.

Regional survey

As indicated above, regional geochemical maps and the interpretation of the geochemistry of the silt-and-clay-sized fraction were presented in Bond and Plouffe (2002). Therefore, only the clay-sized fraction geochemistry is depicted in Appendix 1.

Base metals (copper, lead, zinc) – Because of the good correlation between the base metal content of the silt-and-clay- and the clay-sized fractions, both media reflect similar, known mineralized rock and potential exploration targets. For example, the highest copper, lead and zinc concentrations are located near the KZK, Wolverine and Argus mineralized zones (Appendix 1). On the other hand, a number of samples located 10 km northwest of Wolverine Lake contain high levels of lead and copper, and samples 17 km south of Wolverine Lake contain high lead concentrations. All of these are located above rocks of the Wolverine Lake group which host the Wolverine massive sulphide deposit and therefore are thought to reflect the presence of concealed mineralized rock. In the northern sector of the Finlayson Lake map area over the rocks of the North American miogeocline, zinc levels are slightly more elevated compared to the rest of the region (Bond and Plouffe, 2002). One of the highest zinc levels in both size fractions was obtained from this region.

The distribution of barium in till is discussed under the base metal heading because it can be used as a pathfinder element for massive sulphide deposits in the area. For instance, baritic iron formation is associated with the mineralization at Wolverine. However, barium results have to be interpreted with care because the leach used in this survey (similar to aqua regia) does not dissolve barite. Therefore, the reported barium concentrations relate to barium present in phases other than barite. As opposed to copper, lead and zinc, high barium concentrations in both size fractions are in several cases not located at the same sites. For instance, none of the high barium values in the silt-and-clay-sized fraction reported by Bond and Plouffe (2002) southwest of Finlayson Lake or southwest of Fortin Lake are present in the clay-sized fraction. On the other hand, the barium content of the silt-and-clay-sized fraction was generally low near both KZK and Wolverine and is more elevated in the clay-sized fraction. Two samples located 10 km northwest of Wolverine Lake, in a region with elevated lead and copper concentrations (see above) also yielded high barium levels.

Precious metals (gold, silver, platinum group elements) – As indicated above, there is a poor correlation between gold concentrations in the two size fractions. For example, at stations 24 and 45 km west of Finlayson Lake, two samples that yielded amongst the highest gold values in the silt-and-clay-sized fraction (01-PMA-075-01: 41 ppb and JB01-073: 39 ppb, see Bond and Plouffe, 2002) returned low gold levels in the clay-sized fraction (01-PMA-075-01 = 1 ppb and JB01-073 = 8 ppb). In contrast, 8 km northwest of Wolverine Lake, a series of samples collected at the northwestern extent of the Wolverine Lake group yielded high gold values (>11 ppb) in both the clay- and silt-and-clay-sized fraction indicating a range of gold particle sizes in till for that region. Some

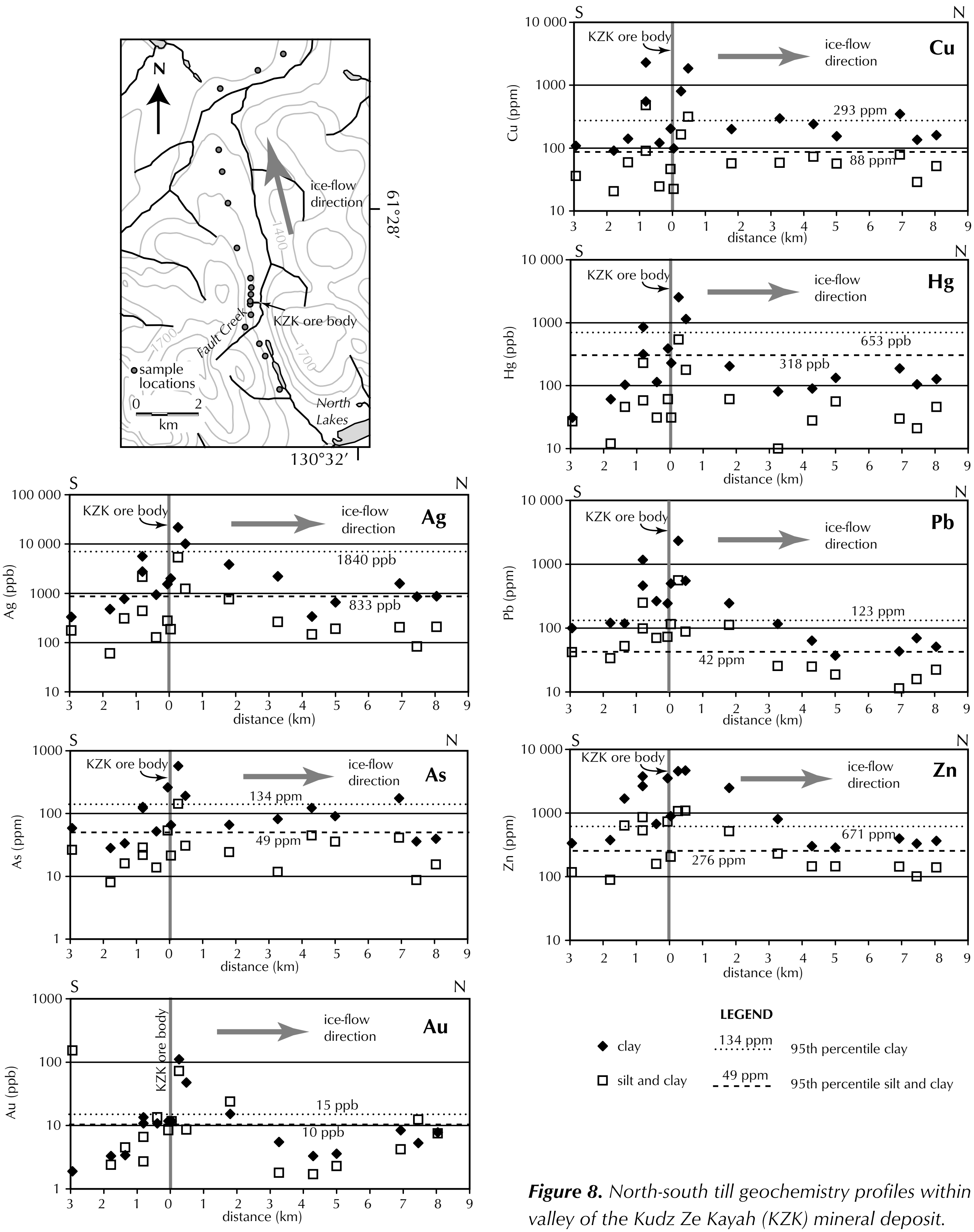


Figure 8. *North-south till geochemistry profiles within the valley of the Kudz Ze Kayah (KZK) mineral deposit. Contours in metres; contour interval =100 m.*

of the samples from that area returned elevated levels of lead, zinc, copper, barium, mercury, silver and arsenic. This region represents a key exploration target given its multi-elemental signature and its proximity to the Robert Campbell Highway (ca. 6.5 km). Similarly, 17 km south of Wolverine Lake, a sample containing high gold concentrations (01-PMA-169: 17 ppb) also returned elevated levels of arsenic and lead (01-PMA-169: arsenic = 383 ppm and lead = 259 ppm) in the clay-sized fraction. These are also located above the Wolverine Lake group.

Most of the high silver concentrations in the clay-sized fraction are located above the Wolverine succession and are thought to be indicative of the high background silver concentration of that rock unit. Similarly, the arsenic levels in the clay-sized fraction of till are generally higher over the footwall rocks of the Money Creek thrust (see Murphy et al., 2002) within the Yukon-Tanana Terrane compared to the rest of the region (see data in Plouffe and Bond, 2003).

In the silt-and-clay-sized fraction, palladium concentrations are below detection limit in all samples, and platinum levels are above detection in only three of them. In contrast, in the clay-sized fraction, palladium and platinum concentrations are above detection limit for 12% and 38% of the samples, respectively. Consequently, the palladium and platinum levels in the clay-sized fraction are of better use at delineating exploration targets for platinum group elements than the silt-and-clay. Given the known association of platinum group elements with ultramafic rocks, high palladium and platinum concentrations found in association with elevated levels of nickel, chromium and cobalt represent the most attractive platinum group element targets. A sample collected 16 km southwest of Finlayson Lake, at the northern end of a Late Devonian to early Mississippian ultramafic intrusion (Murphy et al., 2002; Murphy, 2004), returned elevated palladium (40 ppb), platinum (10 ppb), chromium (252 ppm) and nickel (182 ppm) concentrations, reflecting its ultramafic source (see Ni and Cr data in Plouffe and Bond, 2003). High platinum (9 ppb) and palladium (26 ppb) levels and moderately elevated cobalt concentration (60 ppm) were measured in a sample located approximately 28 km southwest of Finlayson Lake, with a source region most likely located in the mafic volcanic rocks of the Fire Lake formation (Murphy et al., 2002; Murphy, 2004). Sample 01-PMA-004, collected only 4 km southwest of Finlayson Lake, yielded elevated palladium (12 ppb), platinum (7 ppb), cobalt (95 ppm), and chromium (375 ppm) concentrations. The sample is located on top of a gossanous zone in the felsic volcanic rocks of the Grass Lakes group. Given the mafic to ultramafic signature of the sample (high cobalt and chromium) it could be derived from a concealed mafic or ultramafic bedrock source. Sample JB01-164, collected at the Wolverine deposit southeast of Wolverine Lake, and sample 01-PMA-122, located in the northwestern sector of the area yielded elevated palladium concentrations (29 and 32 ppb, respectively). In both cases, the source of the palladium is unknown.

Emerald – Beryllium in till is evaluated as a potential indicator of beryl occurrences in geological settings suitable for the formation of emerald. Beryllium concentrations in the silt-and-clay-sized fraction of till are low, with 27% of the samples returning concentrations below the detection limit of 1 ppm. The average concentration in the samples with measurable levels of beryllium is only 3 ppm. Given these low levels, analytical precision for beryllium is found to be low: ±90% (Plouffe and Bond, 2003) which implies that analytical results have to be evaluated with caution.

Obvious exploration targets for emerald occurrences are Cretaceous granitic intrusions in proximity to the mafic volcanic rocks of the Fire Lake formation, a setting similar to the Regal Ridge emerald occurrence. This study did not find any high beryllium levels in till associated with such a setting in the Finlayson Lake region. However, concealed or unmapped small Cretaceous granitic intrusions could be present in the area of the Fire Lake formation and be a source of beryllium in till. For example, approximately 7.5 km south of the Hoole and Pelly River confluence, three samples located near the contact zone of the Fire Lake and North River formations contain elevated beryllium concentrations (7, 11 and 11 ppm). Several other samples located above the Fire Lake formation in the western sector of the area contain moderately elevated beryllium concentrations (6 to 10 ppm). In addition, the potential of older granitic intrusive rocks (e.g., Jurassic) to host emeralds has yet to be evaluated. Detailed mineralogical analyses of till, similar to that applied to diamond exploration, might be required to provide a more thorough evaluation of the potential for emerald occurrences in this region.

GLENLYON AND EASTERN CARMACKS MAP AREAS

Clear Lake orientation survey

The Clear Lake deposit is located in the north-central sector of the Glenlyon map area, approximately 30 km west of Earn Lake and less than 2 km north of Pelly River. It is a zinc-lead-silver sedimentary exhalative deposit hosted in Devono-Mississippian sedimentary rocks of the Earn Group which is part of the North American strata (Deklerk, 2002, Yukon MINFILE 2002, 105L 045). It contains an estimated ore reserve of 6.1 million tonnes grading 11.34% Zn, 2.15% Pb, and 40.8 g/t Ag. The main ore minerals include sphalerite and galena with lesser pyrite (Deklerk, 2002). Except for a gossan exposed in the Pelly River valley, the deposit does not outcrop and is covered with a blanket of 10-25 m of till dating to the last (McConnell) glaciation during which it was glacially eroded (Bond and Plouffe, 2003). In subcrop, the ore body is sigmoidal in shape, approximately 1000 m long and up to 100 m wide with a general north-south orientation transverse to westward ice flow.

A detailed till sampling transect was completed parallel to ice flow extending from 200 m up-ice to 2.3 km down-ice of the mineralization (Bond and Plouffe, 2003). Sample spacing varied from 25 m over the deposit and up to 500 m down-ice from it. Till sampling was hampered by the presence of thick loess cover (on average >30 cm and exceeding 100 cm in places) and near-surface permafrost.

Till lithologies at Clear Lake are highly variable from one pebble sample to the next along the transect (Fig. 9). The dominant local bedrock lithologies (fine-grained sedimentary rocks: argillite, shale and sandstone) are not abundant as clasts in till, probably because they did not survive glacial comminution. On the other hand, the more indurated lithologies such as chert are commonly found as clasts in till. Given the high percentage of volcanic clasts in till, it is suspected that concealed volcanic units might be present in the local Earn Group rocks. In addition, till pebble lithologies seem to reflect bedrock composition only at some distance down-ice from the source. For example, the greatest percentage of oxidized and weathered clasts, potentially derived from the mineralized zone, only appear at surface at approximately 1 km down-ice from the ore body, probably because of the great till thickness in this region. Similarly, carbonate clasts are absent in till overlying carbonate bedrock and are only abundant (54%) in the westernmost sample. However, carbonate clasts may have been weathered from the surface till during post-glacial time especially close to the mineralization where the weathering of sulphide minerals is acid-generating (see also Bond and Plouffe, 2003).

Bond and Plouffe (2003) presented the geochemical results of the silt-and-clay-sized fraction of till at the Clear Lake deposit. These results are compared here with the clay-sized geochemistry. As expected, lead and zinc concentrations are generally higher in the clay- than in the silt-and-clay-sized fraction (Fig. 10). However, the two metals show contrasting patterns. Using a threshold arbitrarily selected as the 95th percentile of the regional data, lead concentrations in both size fractions are anomalously low, as close as 100 m down-ice from mineralized rock (Fig. 10). Anomalous lead concentrations in the silt-and-clay-sized fraction extend 1.4 km down-ice from the deposit and in the clay-sized fraction they sporadically occur as far as 2.5 km down-ice. In contrast, zinc concentrations are anomalously high in both size fractions of till only 800 m down-ice of mineralized rock, and remain anomalously high sporadically for approximately 2.5 km. It is suspected that acid-generating sulphide minerals in till might have leached and removed sphalerite, hence zinc, from till which was remobilized into the nearby Clear Lake, with galena being less affected in this environment (Bond and Plouffe, 2003). This interpretation is supported by the high dissolved-zinc concentration (>1 ppm) and the low pH (<3) in the water of Clear Lake as well as the lower pH of the till above the mineralized zone (5.7) compared to the surrounding areas (>7.0; Fletcher et al., 2003). In addition to lead and zinc, high concentrations of mercury and silver were detected in both size fractions down-ice of mineralization, and therefore are thought to be good pathfinder elements for similar mineralization (Fig. 10). The source of the anomalous silver and zinc levels, dominantly present in the clay-sized fraction up-ice from Clear Lake is unknown.

Regional survey

Results of the clay-sized fraction geochemistry for the Glenlyon and eastern Carmacks map areas are depicted in Appendix 2. Most of the exploration targets defined by the silt-and-clay-sized fraction geochemistry (Bond and Plouffe, 2003) are confirmed by the clay-sized geochemistry.

Base metals (copper, lead, zinc) – The Earn Group anomaly located near the contact zone of Earn Group and Askin Group rocks, i.e., in a stratigraphic setting

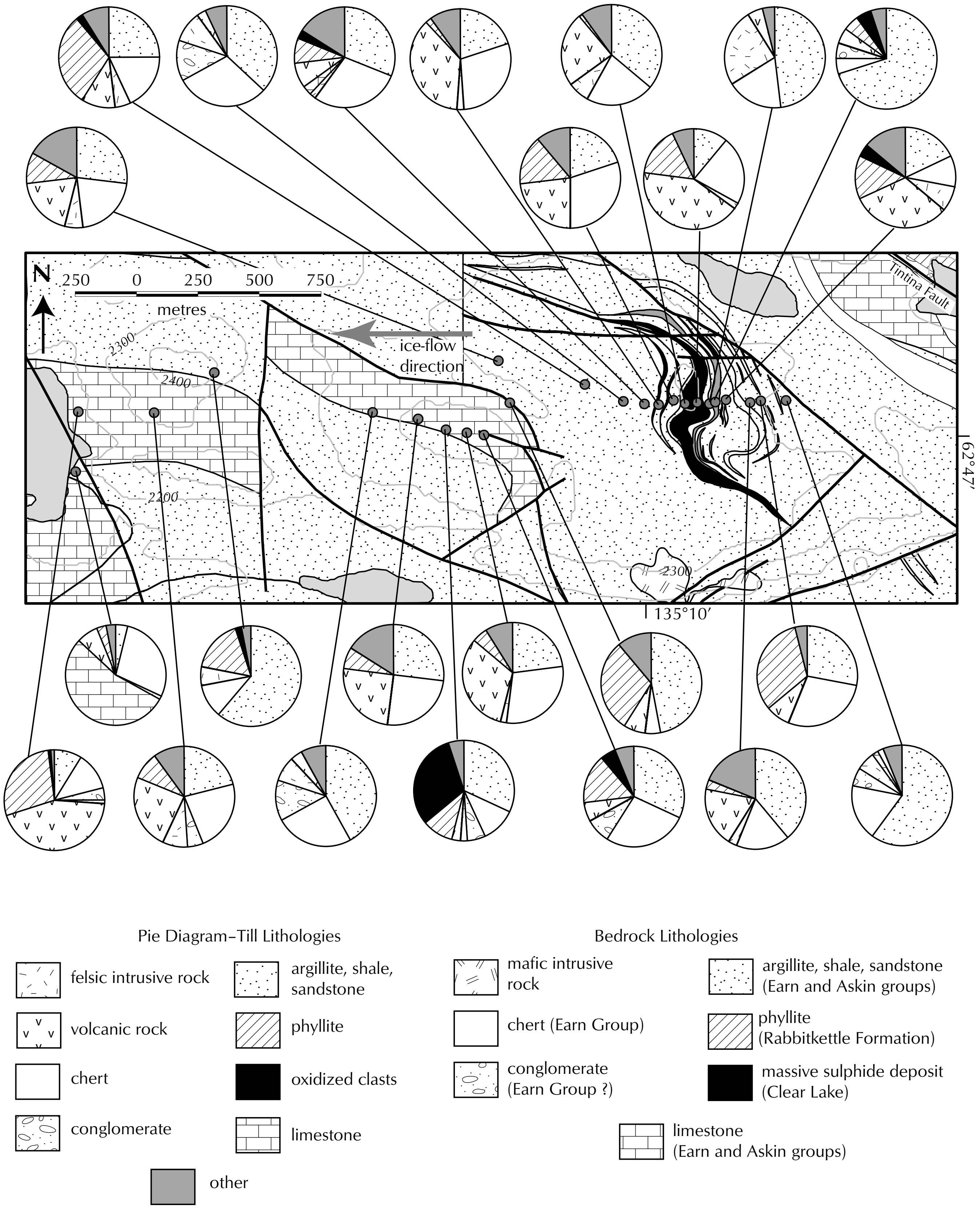


Figure 9. *Till lithologies at the Clear Lake deposit; lithological map derived from Colpron et al. (2002), and Zuran and Basnett (1992). Contours in feet; contour interval =100 ft.*

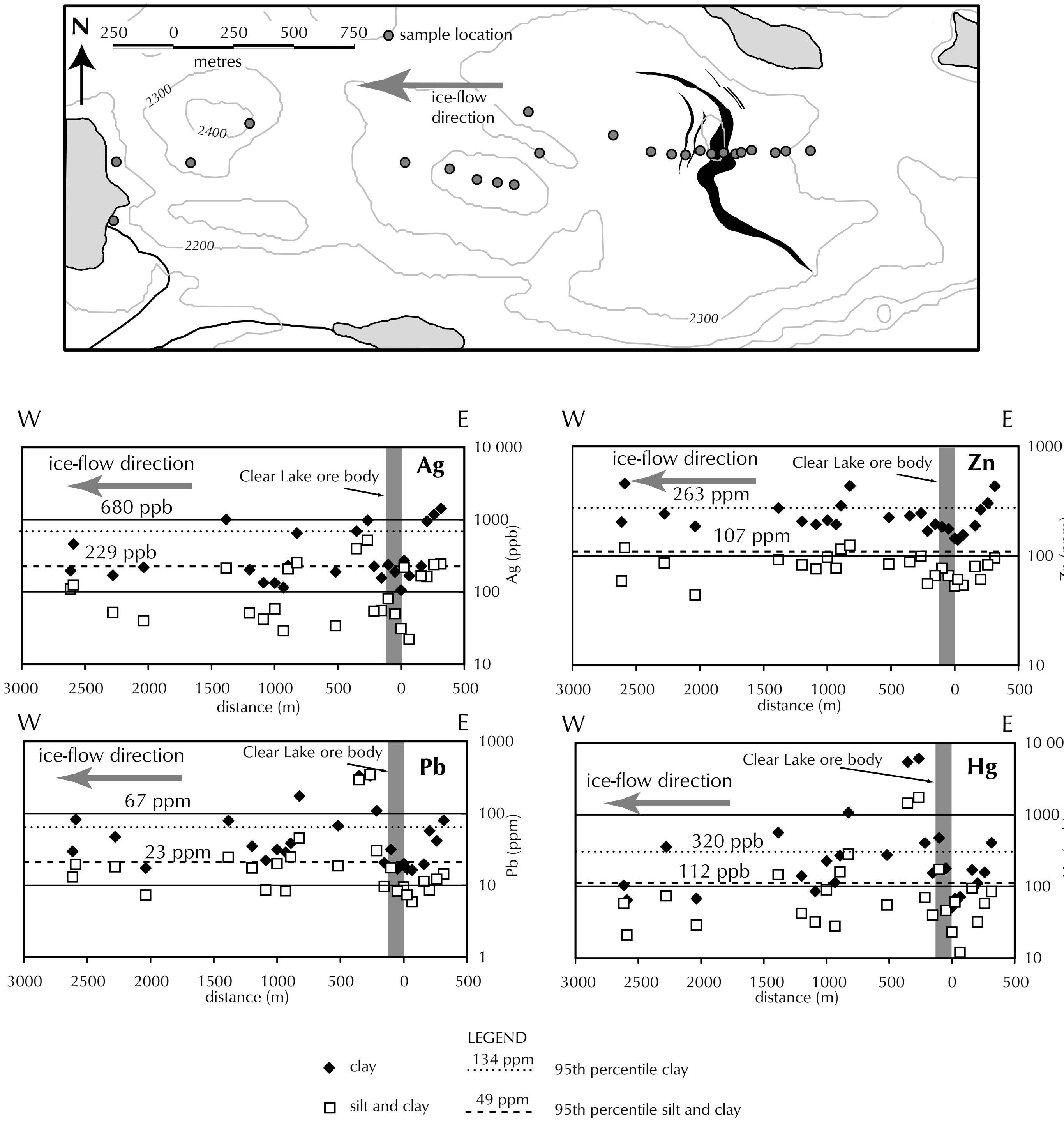


Figure 10. *East-west till geochemistry profiles near the Clear Lake deposit. Corresponds in area to Figure 9. Contours in feet; contour interval =100 ft.*

similar to the Clear Lake deposit, and only 18 km south-southeast from it, was originally defined by Bond and Plouffe (2003) and is well reflected by the clay-sized fraction geochemistry of till with high zinc (up to 503 ppm – 100th percentile), silver (up to 814 ppb – 98th percentile) and molybdenum (up to 15 ppm – 100th percentile) concentrations. A winter road originating from the Klondike Highway to the west, passes 9 km north of the anomaly.

The Frenchman Lake zinc anomaly defined by Bond and Plouffe (2003) above conglomerate of the Lower Jurassic Laberge Group (Stikine Terrane) is also well outlined with the clay-sized fraction geochemistry. The sampling transect that starts less than 1 km east of Frenchman Lake contains at least one sample with high concentrations of silver (683 ppb – 95th percentile), cadmium (2.22 ppm – 99th percentile), mercury (708 ppb – 99th percentile), molybdenum (5 and 6 ppm – 97th percentile) and zinc (389 ppm – 99th percentile). The most attractive signature of the transect is the gold content of the clay-sized fraction which varies between 11 ppb and 20 ppb (87th and 98th percentiles, respectively). Such elemental association could be characteristic of concealed epithermal mineralization (C. Hart, pers. comm., 2002).

Two regions are characterized by high copper concentrations and are potential exploration targets for volcanogenic massive sulphide deposits. Eleven kilometres east of Frenchman Lake (Frenchman Ridge copper anomaly of Bond and Plouffe, 2003), elevated copper concentrations were detected in both size fractions of till above volcanic and volcaniclastic rocks of the Semenof block. The number of samples along Frenchman Ridge with high copper concentrations in the clay-sized fraction are greater than in the silt-and-clay fraction. In addition, moderately elevated concentrations of silver (493 ppb) and gold (a few samples with >10 ppb) were detected in samples along the same transect.

Southwest of Drury Lake in the Little Salmon Range, above intermediate to mafic metavolcanic rocks of the Little Salmon Formation and near a thin exhalite unit (light green and red manganese-bearing chert; see Colpron et al., 2002), high copper concentrations (up to 387 ppm – 99th percentile) are present in both size fractions of till. The region is also characterized by one or more samples with elevated concentrations of silver (up to 735 ppb – 96th percentile), cobalt (up to 59 ppm – 98th percentile), chromium (573 ppm – 99th percentile), nickel (222 ppm – 99th percentile) and vanadium (191 ppm – 99th percentile). The high cobalt, chromium and nickel content of the till suggests an ultramafic bedrock source which might be more extensive than originally mapped by Colpron et al. (2002).

Precious metals (gold and platinum group elements) – Some of the gold exploration targets outlined in Bond and Plouffe (2003) based on the silt-and-clay-sized fraction geochemistry are also characterized by high gold and pathfinder element concentrations in the clay-sized fraction of till. For example, the east Detour gold anomaly (Bond and Plouffe, 2003) located northeast of Pelly River in Selwyn Basin is characterized by high gold (up to 35 ppb – 100th percentile), arsenic (up to 339 ppm – 100th percentile), bismuth (1.13 ppm – 97th percentile), lead (75 ppm – 96th percentile) and antimony (6.5 ppm – 99th percentile) concentrations in the clay-sized fraction of till. Similarly, 7 km southwest of the Clear Lake deposit, the Tummel River gold anomaly (Bond and Plouffe, 2003), likely related to the nearby Cretaceous granite, returned elevated gold (16 ppb – 96th percentile), arsenic (109 ppm – 99th percentile), silver (966 ppb – 98th percentile) and antimony (4.79 ppm – 98th percentile) levels in the clay-sized fraction. The Big Salmon Fault region northwest of Little Salmon Lake was identified as a potential target for fault-related hydrothermal mineralization by Bond and Plouffe (2003). Five out of the seven till samples collected in that region contain elevated concentrations of gold (12 to 25 ppb) and at least one sample from the same region contain elevated levels of arsenic (87 ppm – 97th percentile), silver (483 ppb – 91th percentile), mercury (609 ppb – 98th percentile), lead (78 ppm – 97th percentile), and antimony (7.3 ppm – 99th percentile) in the clay-sized fraction. In contrast, none of the sites with high gold concentrations in the silt-plus-clay-sized fraction in the vicinity of the McGregor Batholith (Bond and Plouffe, 2003) contain high gold values in the clay-sized fraction. This suggests that any gold mineralization associated with the McGregor Batholith is coarser than the clay fraction of the till.

A high gold concentration (33 ppb – 99th percentile) was measured in the clay-sized fraction of a sample south of Tatchun Lake above sedimentary and volcanic bedrock of the Whitehorse Trough. The same sample contains a moderately elevated gold level in the silt-plus-clay-sized fraction (14 ppb). No other element occurs in elevated concentration within that region.

Palladium and platinum concentrations in till are generally lower in the Glenlyon region compared to the Finlayson Lake area. The only potential exploration target outlined from this survey for platinum group elements is located southwest of Drury Lake, near Paleozoic ultramafic rocks, where the clay-sized fraction of a till sample yielded the highest platinum concentration (4 ppb). As indicated above, the bedrock ridge southwest of Drury Lake in the Little Salmon Range is characterized by high nickel, cobalt and chromium concentrations in till.

Emerald – The highest beryllium concentrations (13 ppm in two samples) are found south of Drury Lake over the Late Devonian to Early Mississippian Drury Formation (grit) and in the north-central part of the area over slate bedrock of the Earn Group. None of these sites seem to be in a geological environment favourable for the occurrence of emerald. On the other hand, seven till samples northwest of Little Salmon Lake have moderately elevated beryllium concentrations (four samples with 4 to 8 ppm; 79th to 98th percentile, respectively). These are located less than 2 km down-ice from a small outcrop of the Early Jurassic granitic Tatchun Batholith which intruded the Carboniferous mafic volcanic rocks of the Semenof block. Although no high chromium concentrations are observed in till of that region, mafic volcanic rocks of the Semenof block do contain high chromium concentrations (800 to 1000 ppm) similar to the Fire Lake formation which hosts the emerald occurrences at Regal Ridge (M. Colpron, pers. comm., 2003). Furthermore, late-phase rare pegmatite dykes were observed in the northern sector of the Tatchun Batholith (M. Colpron, pers. comm. 2003). Consequently, this region represents a potential geological environment for the occurrence of emerald. On the other hand, the beryllium content of till of this region might be related to epithermal mineralization along the Big Salmon Fault.

RECOMMENDATIONS FOR DRIFT PROSPECTING

In the region of the Yukon-Tanana Terrane of southern Yukon, till geochemistry is effective at delineating zones of mineralization as demonstrated here with examples from the Finlayson Lake (NTS 105G) and Glenlyon and eastern Carmacks (NTS 105L, 115I) map areas. The reported geochemical dispersal trains derived from known mineralization have different lengths which seems to be influenced by till thickness, elemental concentrations in the source rocks and enrichment compared to the country rocks, ore mineralogy, the nature of the ore subcrop, post-glacial weathering, and the size fraction analysed. Drift prospecting is efficient at delineating mineralized rock over plateaus and within valleys where till can be sampled at surface and where it directly overlies bedrock. Good results are achieved both where till is thin (<3 m) and where it is thick (e.g., 25 m of till at Clear Lake), but in such cases, anomalies are not found immediately above mineralized rock but some distance down-ice from it due to glacial transport. Areas underlain by thick deposits of glacial lake and glaciofluvial sediments should be avoided for sampling because of the complex transport history of those sediments.

For base metal mineral exploration, geochemical analyses of the silt-and-clay- and clay-sized fractions generally give similar regional results. The low cost of silt-and-clay (dry sieving) compared to clay separation (centrifuge) makes the former more attractive considering that large sample sets need to be analysed. However, for more detailed follow-up surveys, analysis of the clay-sized fraction can provide additional information. For example, at KZK, glacial dispersal trains for arsenic, mercury and zinc as defined by the clay-sized fraction are longer than the ones in the silt-and-clay-sized fraction. This has obvious implications for mineral exploration because a longer dispersal train translates into a larger exploration target. The correlation between the high gold concentrations in both size fractions is not as good as for base metals, probably because certain types of gold occurrences are reflected in only one size fraction. For example, potential intrusion-related gold occurrences do not seem to be reflected in the clay-sized fraction of till, probably because most of the gold associated in those occurrences is coarser than clay. Consequently, both size fractions provide complementary information for drift prospecting for gold. In addition, it should be noted that the analytical precision for gold is generally better with the clay- compared to the silt-and-clay-sized fraction because of the reduced nugget effect in the clay-sized material (Plouffe and Bond, 2003).

The beryllium content of till might provide indication of the occurrence of beryl in bedrock but the low analytical precision of beryllium analyses (Plouffe and Bond, 2003) limits this approach. Nevertheless, more testing is required to establish a drift prospecting method that is useful at detecting emerald occurrences. Furthermore, a mineralogical study of surficial sediments near the known emerald occurrence at Regal Ridge should be undertaken to identify indicator minerals associated with emerald occurrences and to develop an exploration strategy similar to the methodology used for diamond exploration.

Because of the known low analytical precision of certain elements (e.g., beryllium, gold; see Plouffe and Bond, 2003 for details), any extensive follow-up surveys near some of the anomalies mentioned in this report should only be undertaken after reproducing these anomalies using the same sediment (till), size fraction, and analytical methods.

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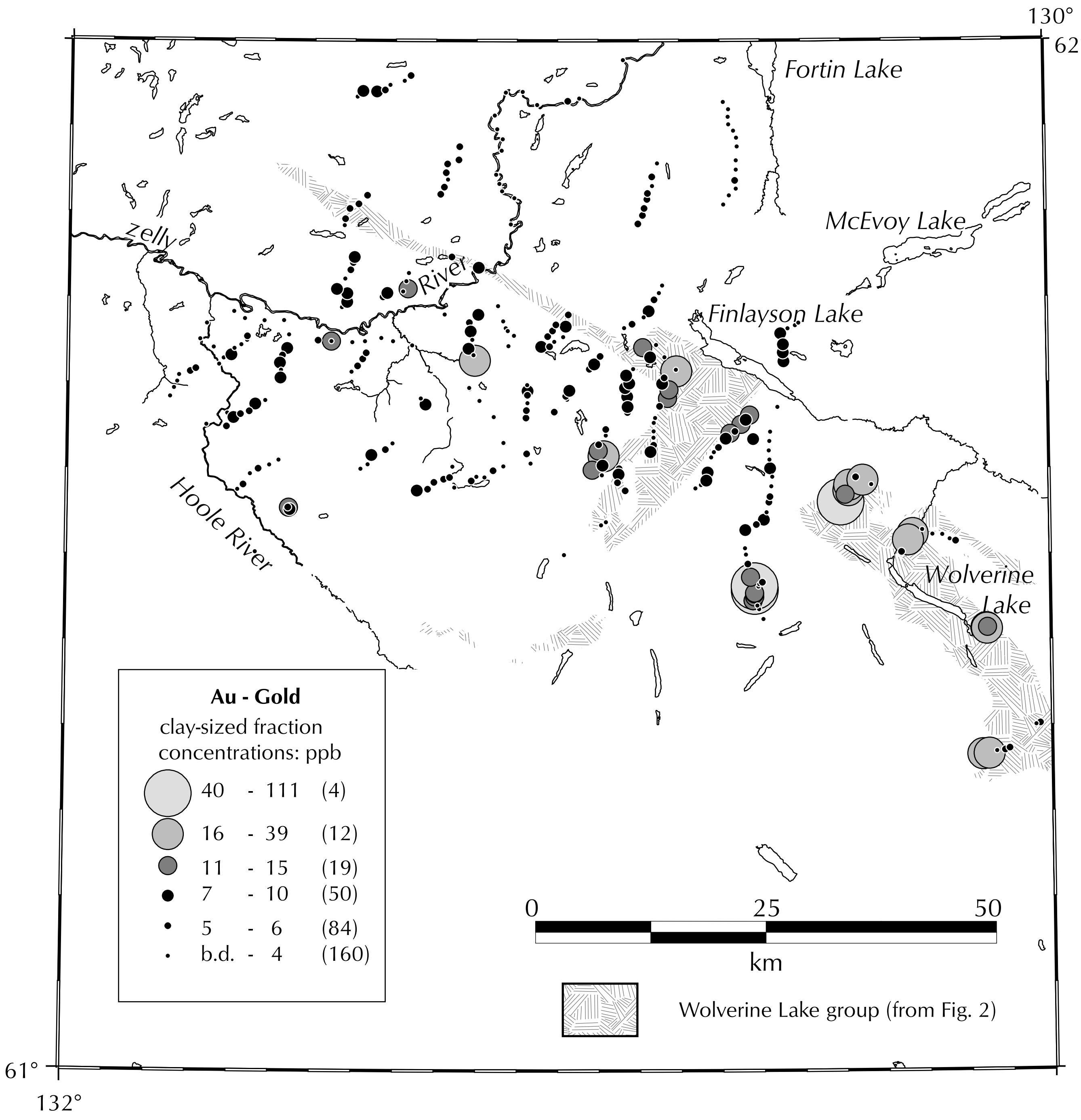
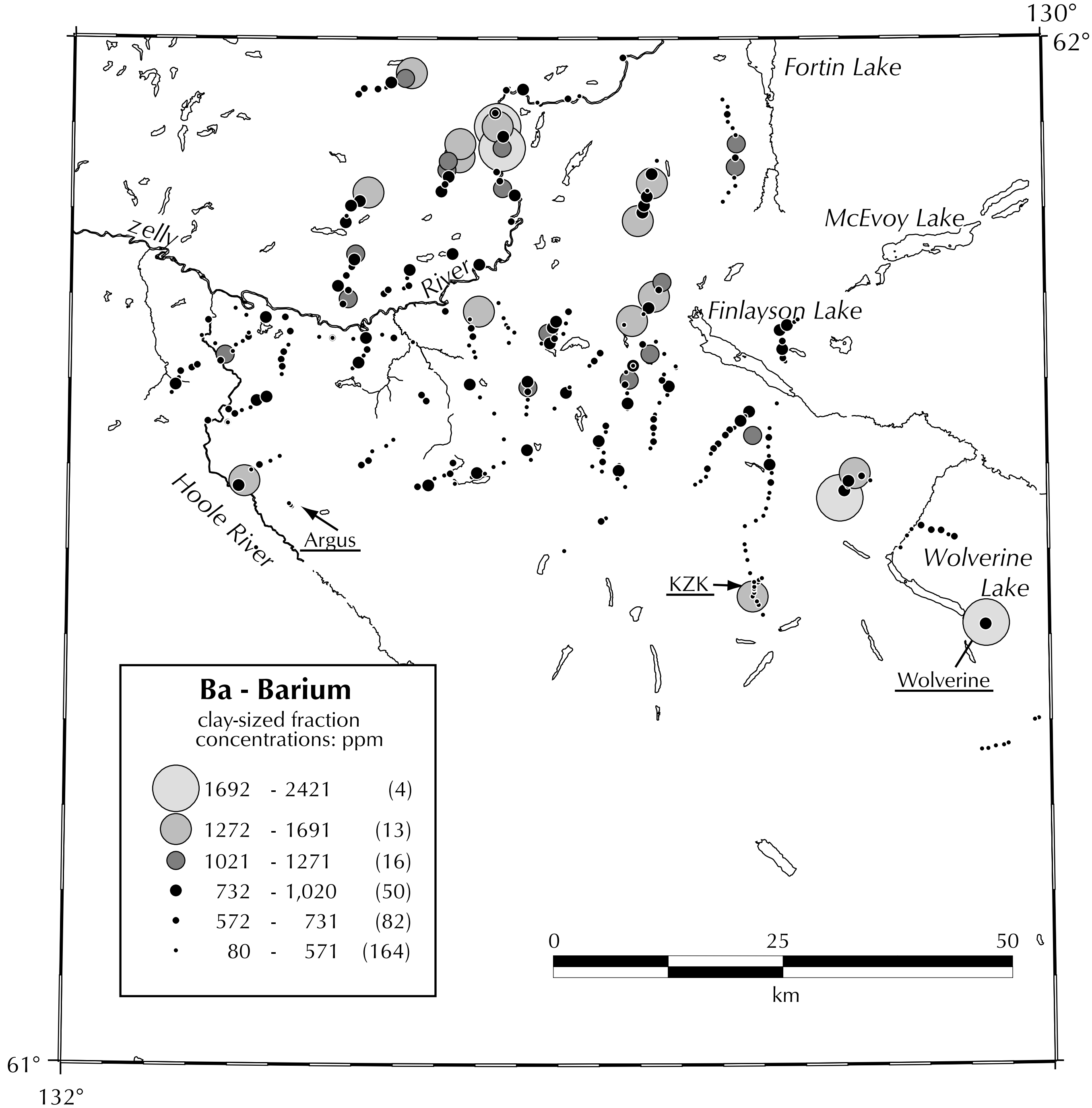
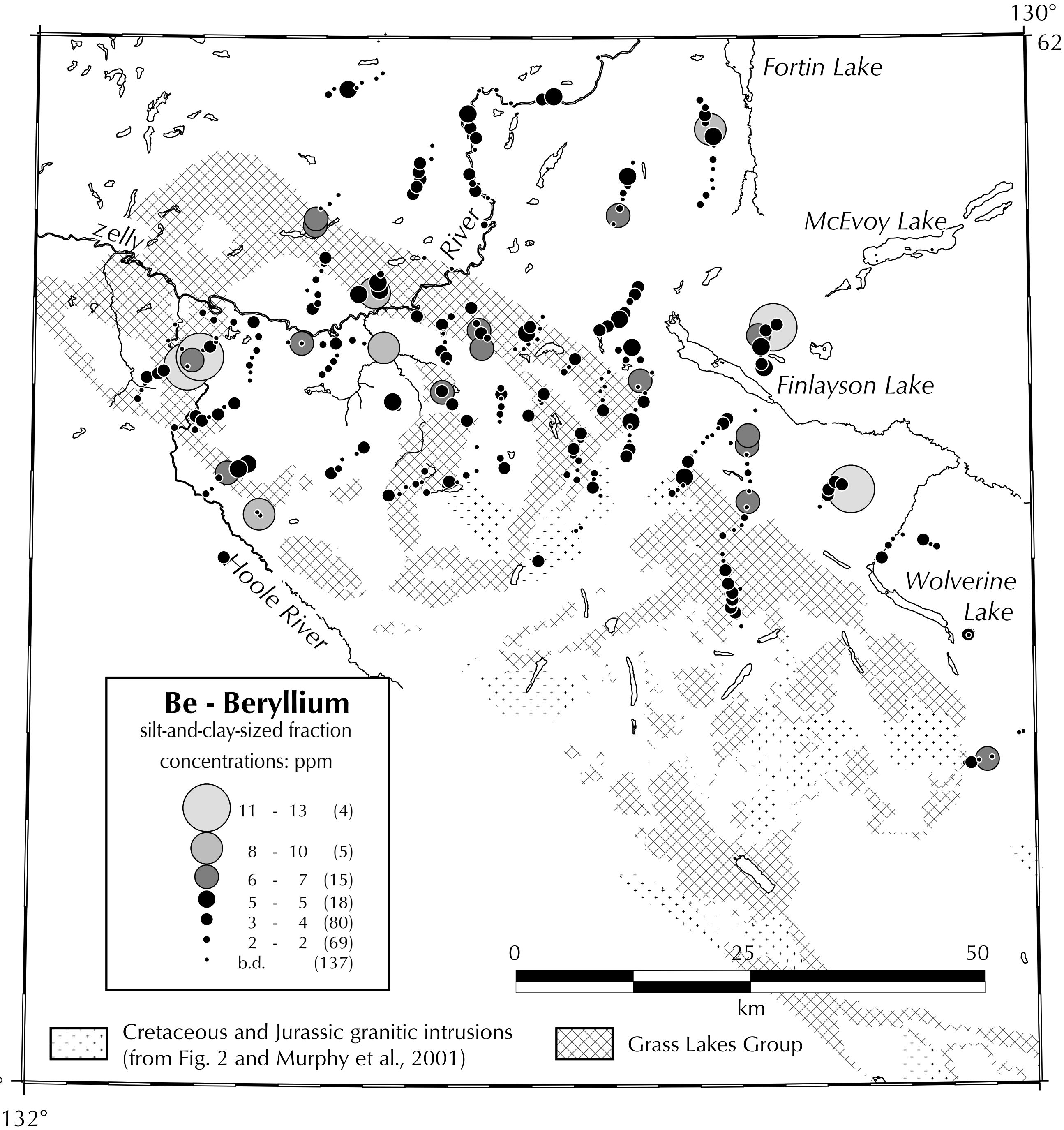
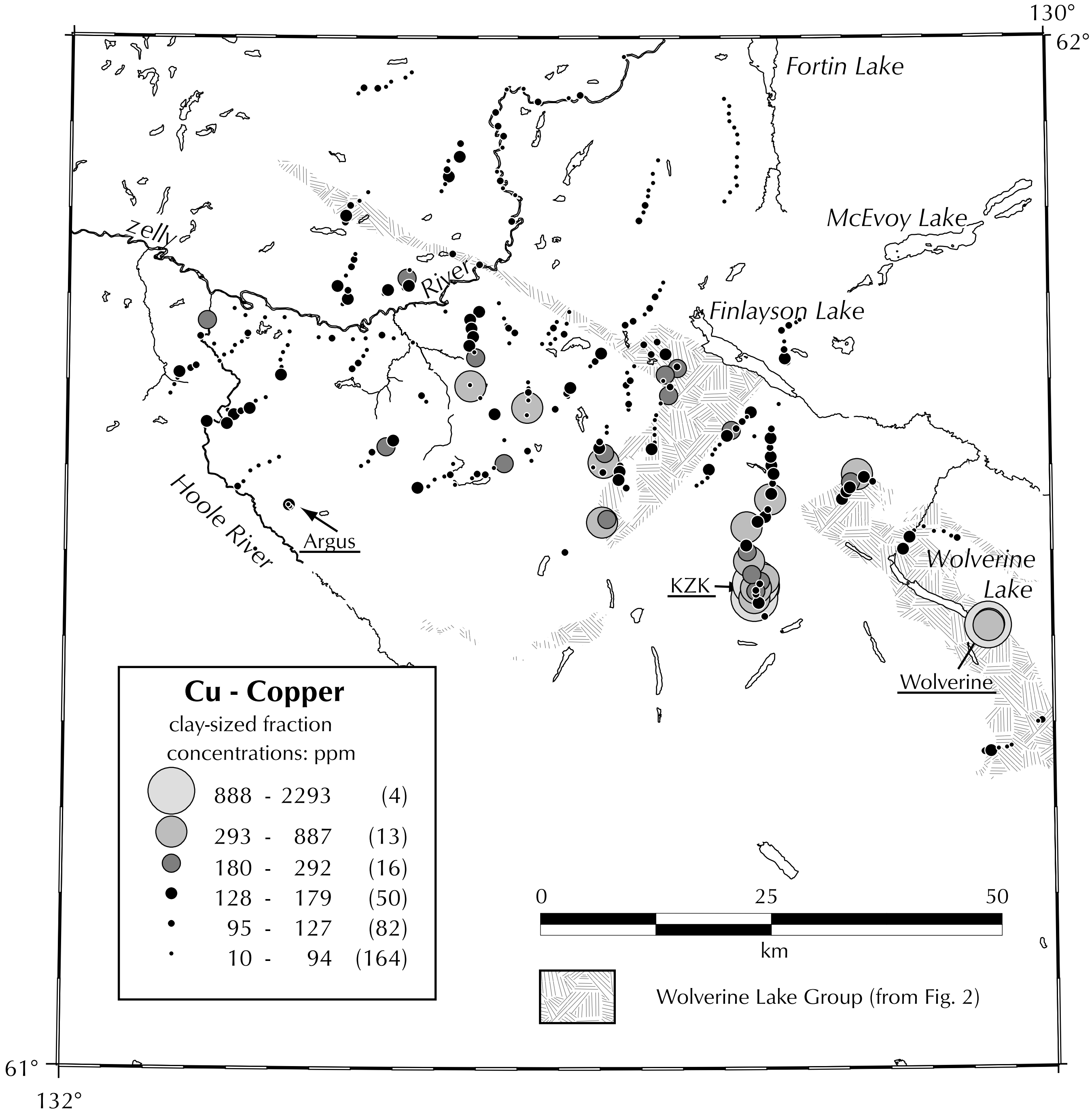
APPENDIX 1

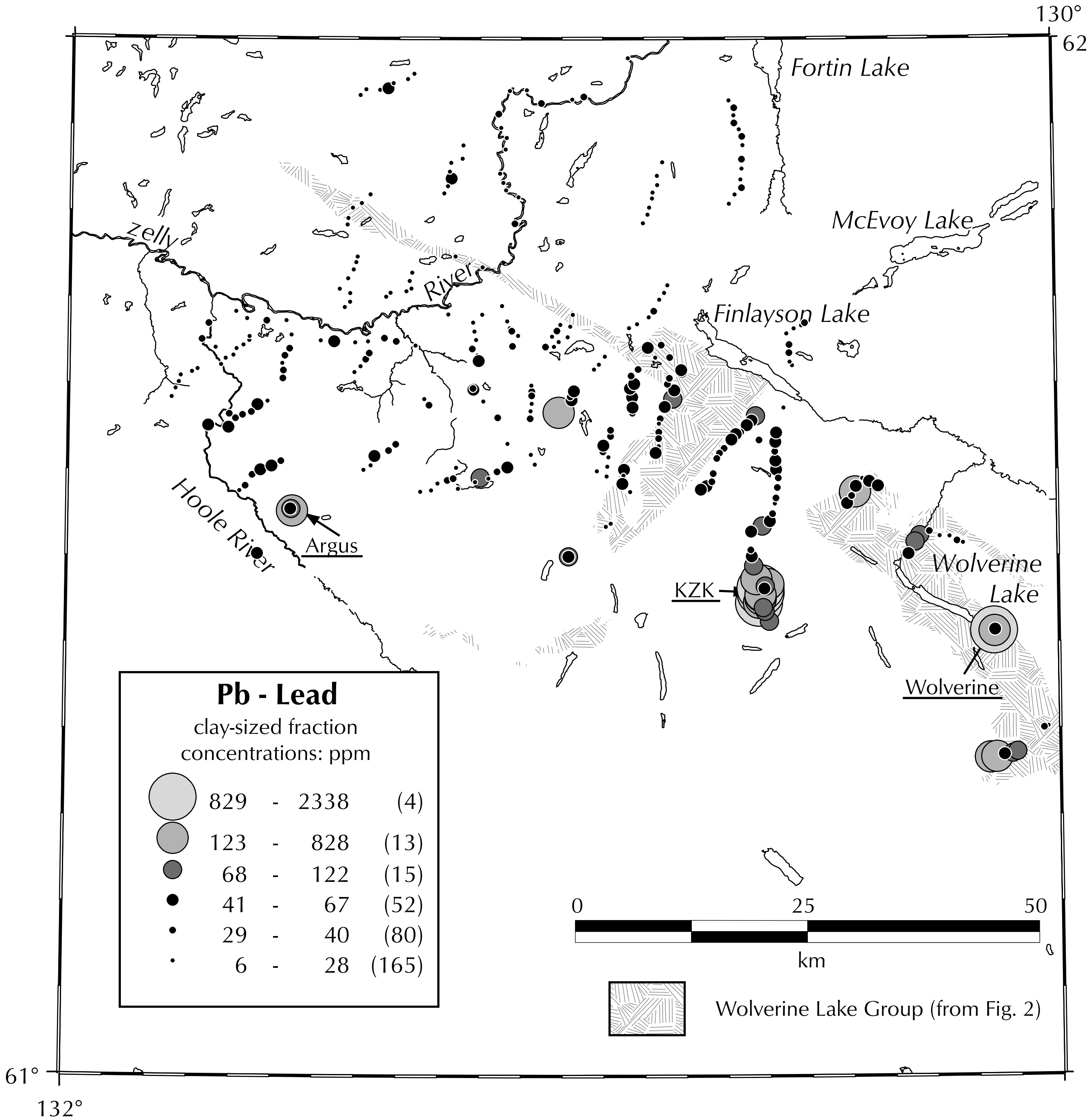
Geochemical maps of the clay-sized fraction for gold, barium, copper, lead, zinc, palladium, platinum and beryllium (silt-and-clay-sized fraction), Finlayson Lake map area. In the legend, numbers in parentheses define the number of samples within the concentration range; b.d. – below detection limit.

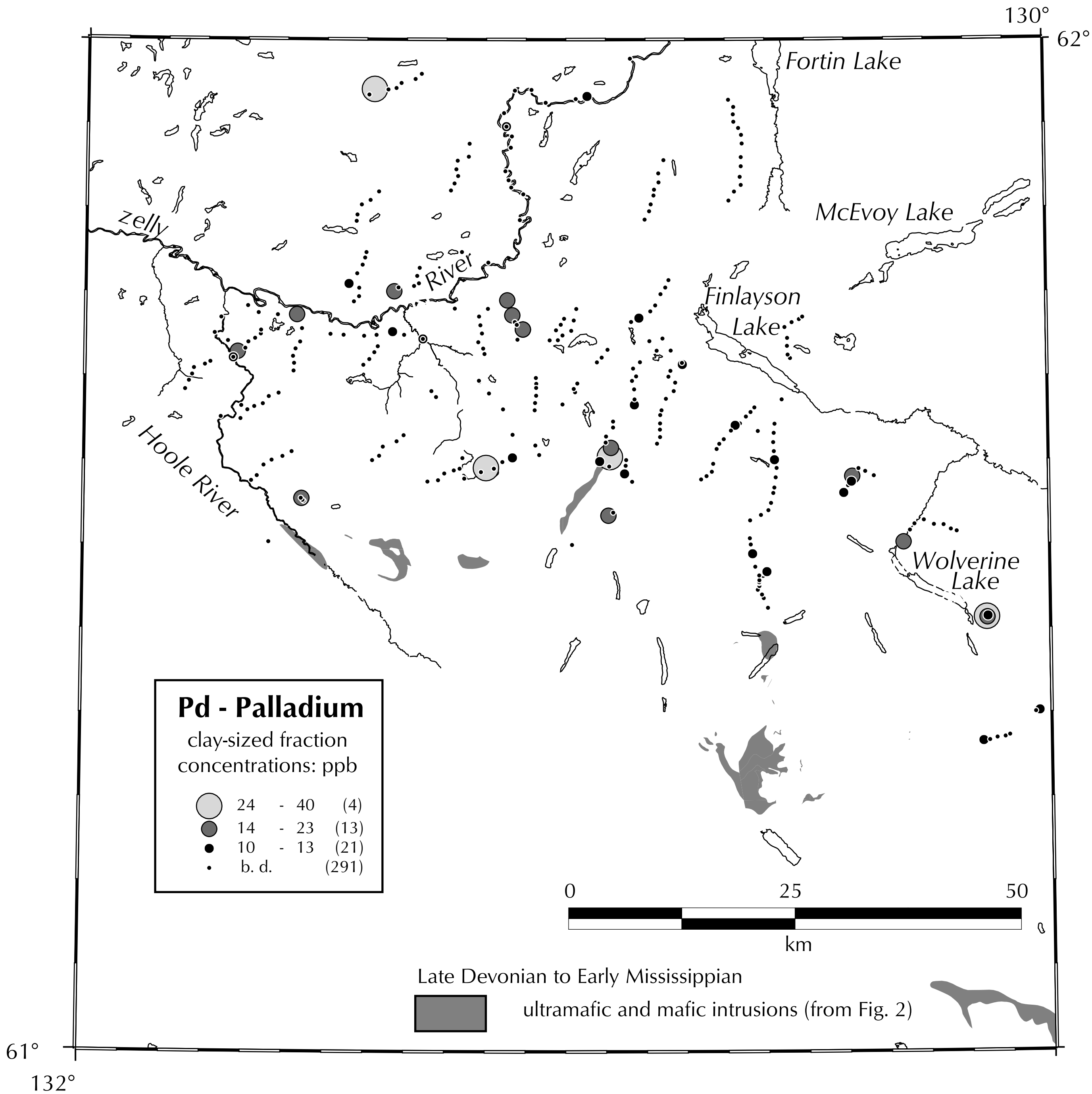


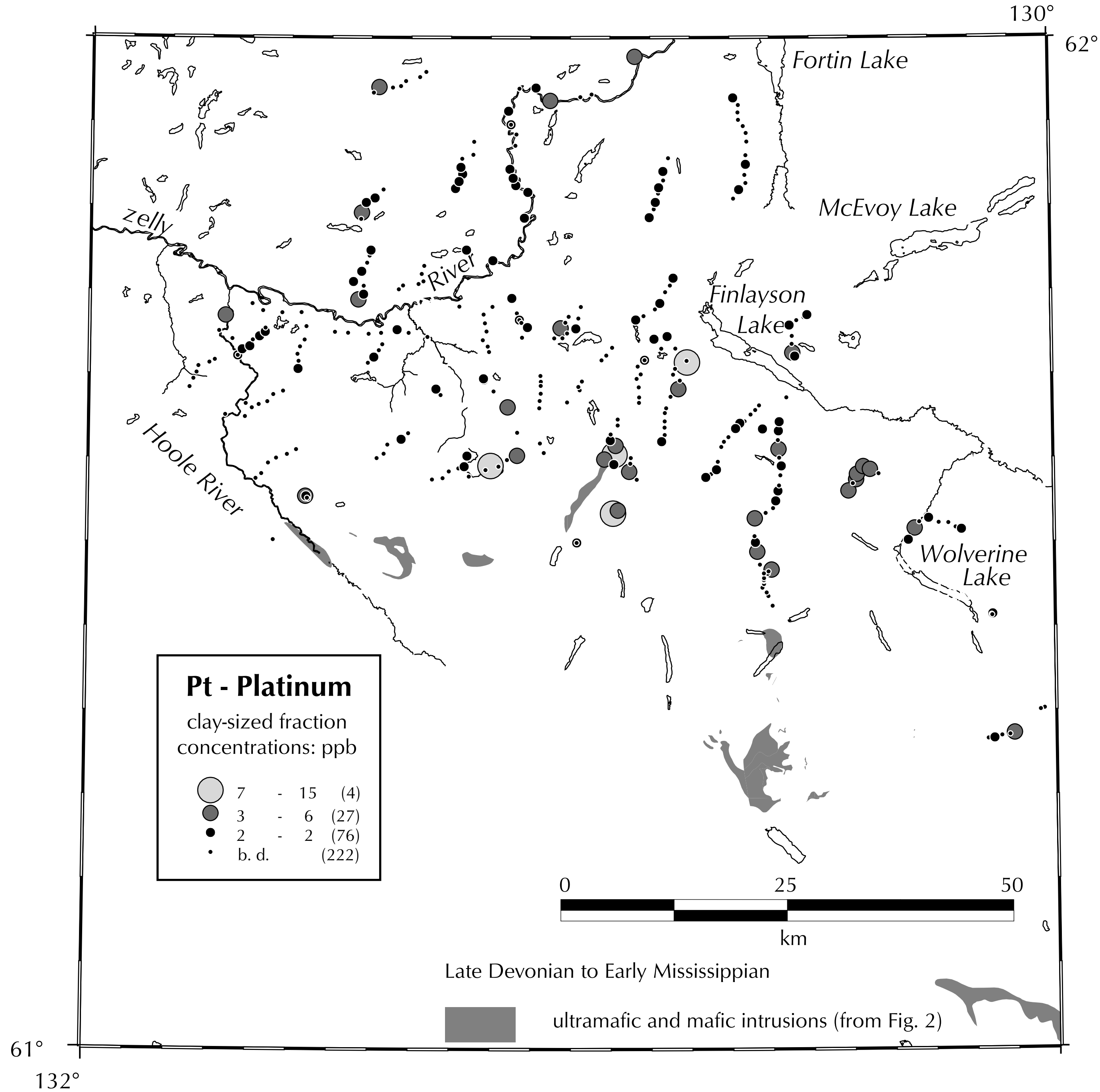

130°
62°
Fortin Lake
McEvoy Lake
Finlayson Lake
zelly
River
Hoole River
Argus
KZK
Wolverine Lake
Wolverine
Ba - Barium
clay-sized fraction
concentrations: ppm
1692 - 2421 (4)
1272 - 1691 (13)
1021 - 1271 (16)
732 - 1,020 (50)
572 - 731 (82)
80 - 571 (164)
0
25
50
km
61°
132°

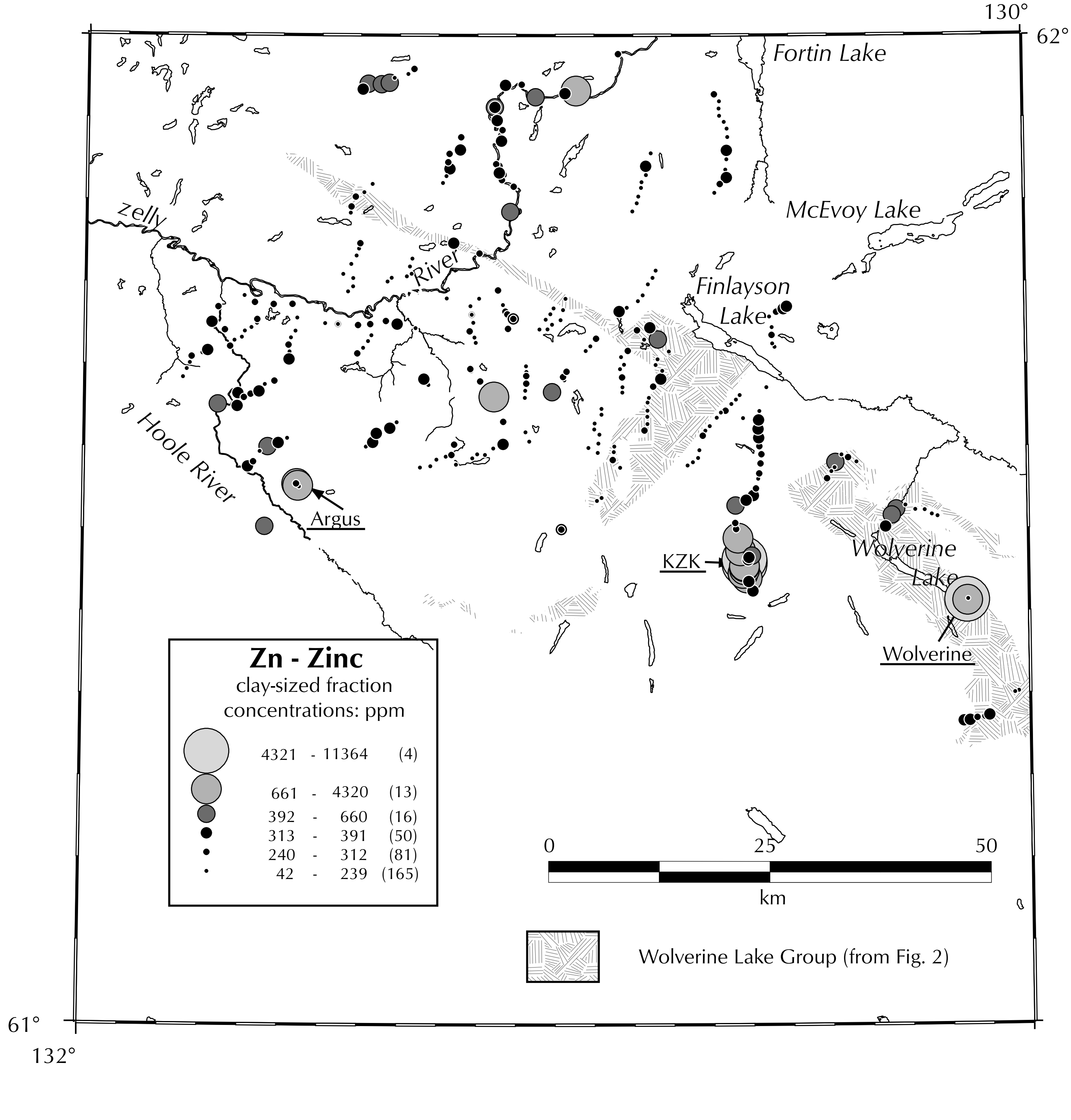

130°
62°
Fortin Lake
McEvoy Lake
Finlayson Lake
Wolverine Lake
zelly
River
Hoole River
Be - Beryllium
silt-and-clay-sized fraction
concentrations: ppm
11 - 13 (4)
8 - 10 (5)
6 - 7 (15)
5 - 5 (18)
3 - 4 (80)
2 - 2 (69)
b.d. (137)
0
25
50
km
Cretaceous and Jurassic granitic intrusions (from Fig. 2 and Murphy et al., 2001)
Grass Lakes Group
61°
132°


130°
62°
Fortin Lake
McEvoy Lake
Finlayson Lake
zelly
River
Hoole River
Argus
KZK
Wolverine
Lake
Wolverine
Cu - Copper
clay-sized fraction
concentrations: ppm
888 - 2293 (4)
293 - 887 (13)
180 - 292 (16)
128 - 179 (50)
95 - 127 (82)
10 - 94 (164)
0
25
50
km
Wolverine Lake Group (from Fig. 2)
61°
132°


130°
62°
Fortin Lake
McEvoy Lake
Pelly River
Finlayson Lake
Hoole River
Argus
KZK
Wolverine Lake
Wolverine
Pb - Lead
clay-sized fraction
concentrations: ppm
829 - 2338 (4)
123 - 828 (13)
68 - 122 (15)
41 - 67 (52)
29 - 40 (80)
6 - 28 (165)
0 25 50
km
Wolverine Lake Group (from Fig. 2)
61°
132°

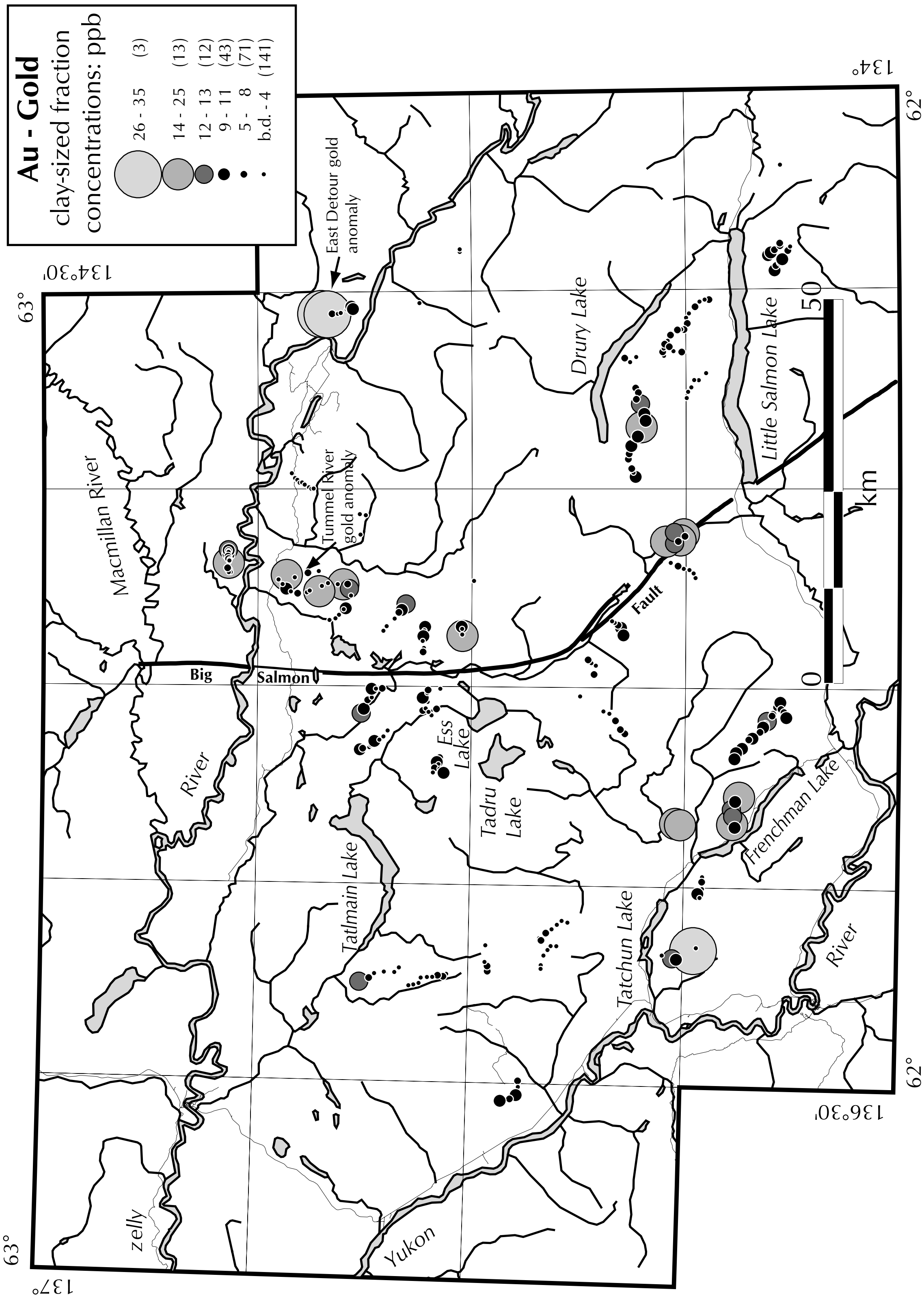

130°
62°
61°
132°
Fortin Lake
McEvoy Lake
Finlayson Lake
Wolverine Lake
zelly River
Hoole River
Pd - Palladium
clay-sized fraction
concentrations: ppb
24 - 40 (4)
14 - 23 (13)
10 - 13 (21)
b. d. (291)
0
25
50
km
Late Devonian to Early Mississippian
ultramafic and mafic intrusions (from Fig. 2)

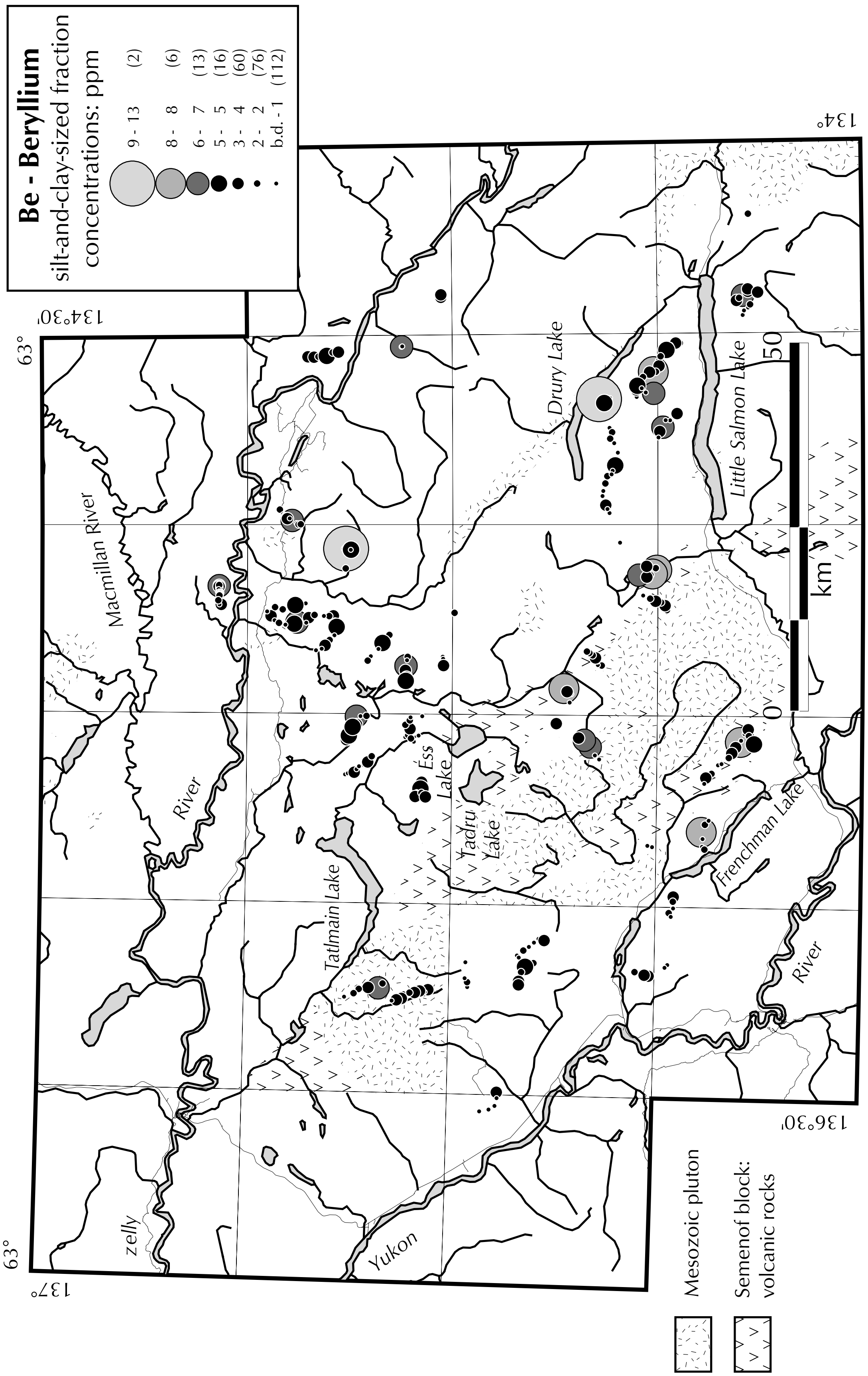

130°
62°
Fortin Lake
McEvoy Lake
zelly
River
Finlayson
Lake
Hoole River
Wolverine
Lake
Pt - Platinum
clay-sized fraction
concentrations: ppb
7 - 15 (4)
3 - 6 (27)
2 - 2 (76)
b. d. (222)
0
25
50
km
Late Devonian to Early Mississippian
ultramafic and mafic intrusions (from Fig. 2)
61°
132°

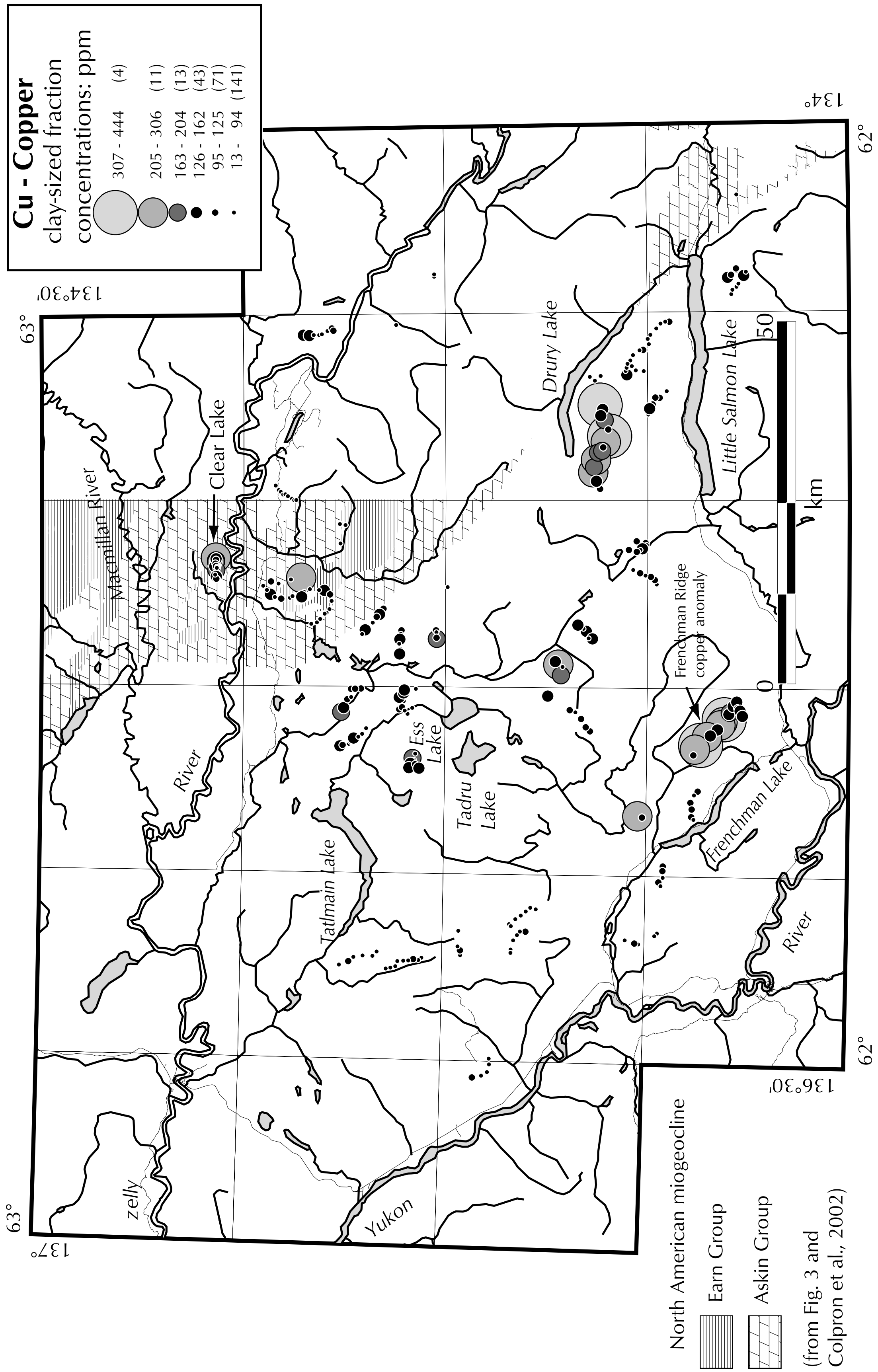

130°
62°
61°
132°
Fortin Lake
McEvoy Lake
Finlayson Lake
zelly
River
Hoole River
Argus
KZK
Wolverine Lake
Wolverine
Zn - Zinc
clay-sized fraction
concentrations: ppm
4321 - 11364 (4)
661 - 4320 (13)
392 - 660 (16)
313 - 391 (50)
240 - 312 (81)
42 - 239 (165)
0
25
50
km
Wolverine Lake Group (from Fig. 2)

APPENDIX 2

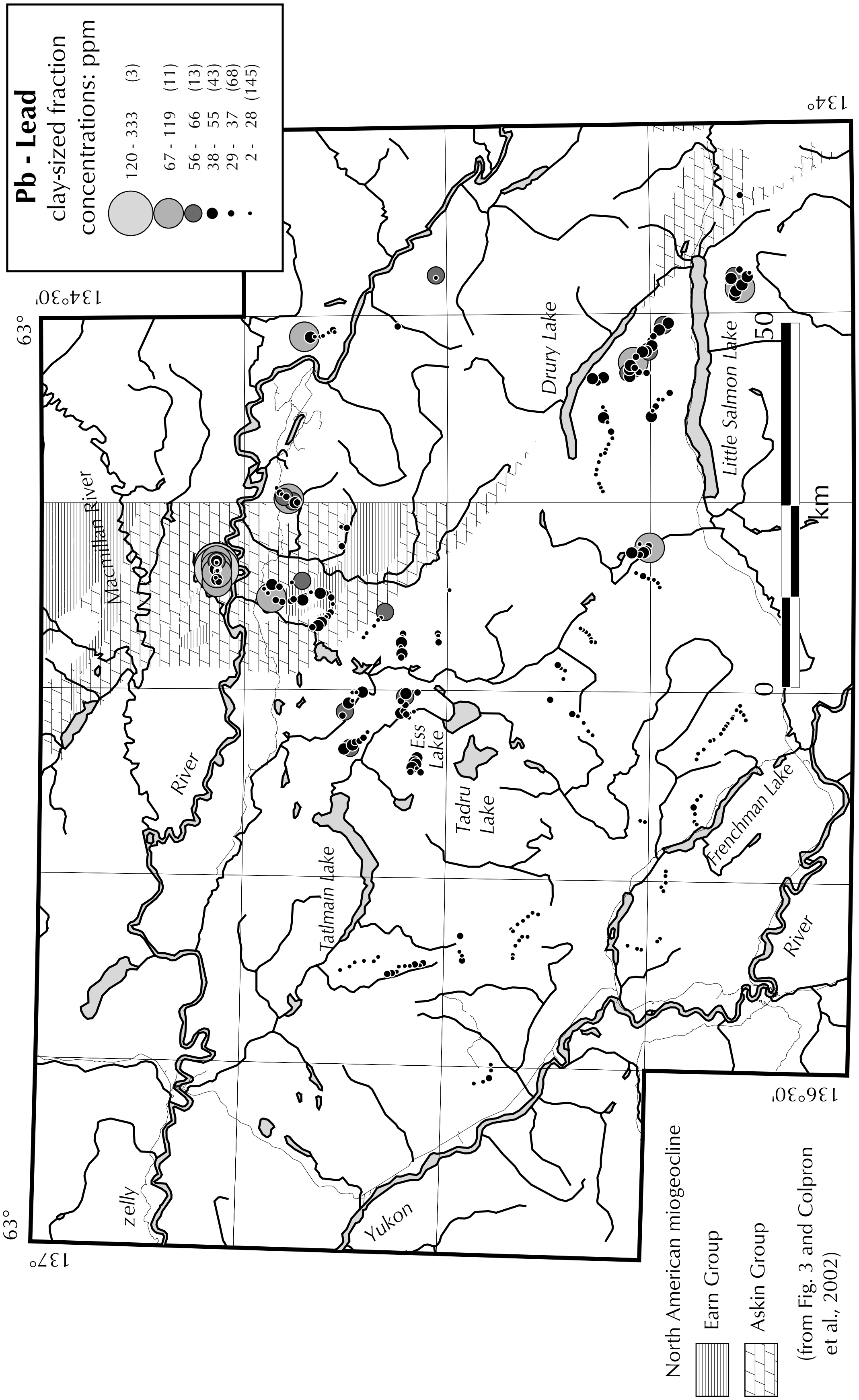
Geochemical maps of the clay-sized fraction geochemistry for gold, copper, lead, zinc, palladium, platinum and beryllium (silt-and-clay-sized fraction), Glenlyon and Carmacks (east) map areas. In the legend, numbers in parentheses define the number of samples within the concentration range; b.d. – below detection limit.



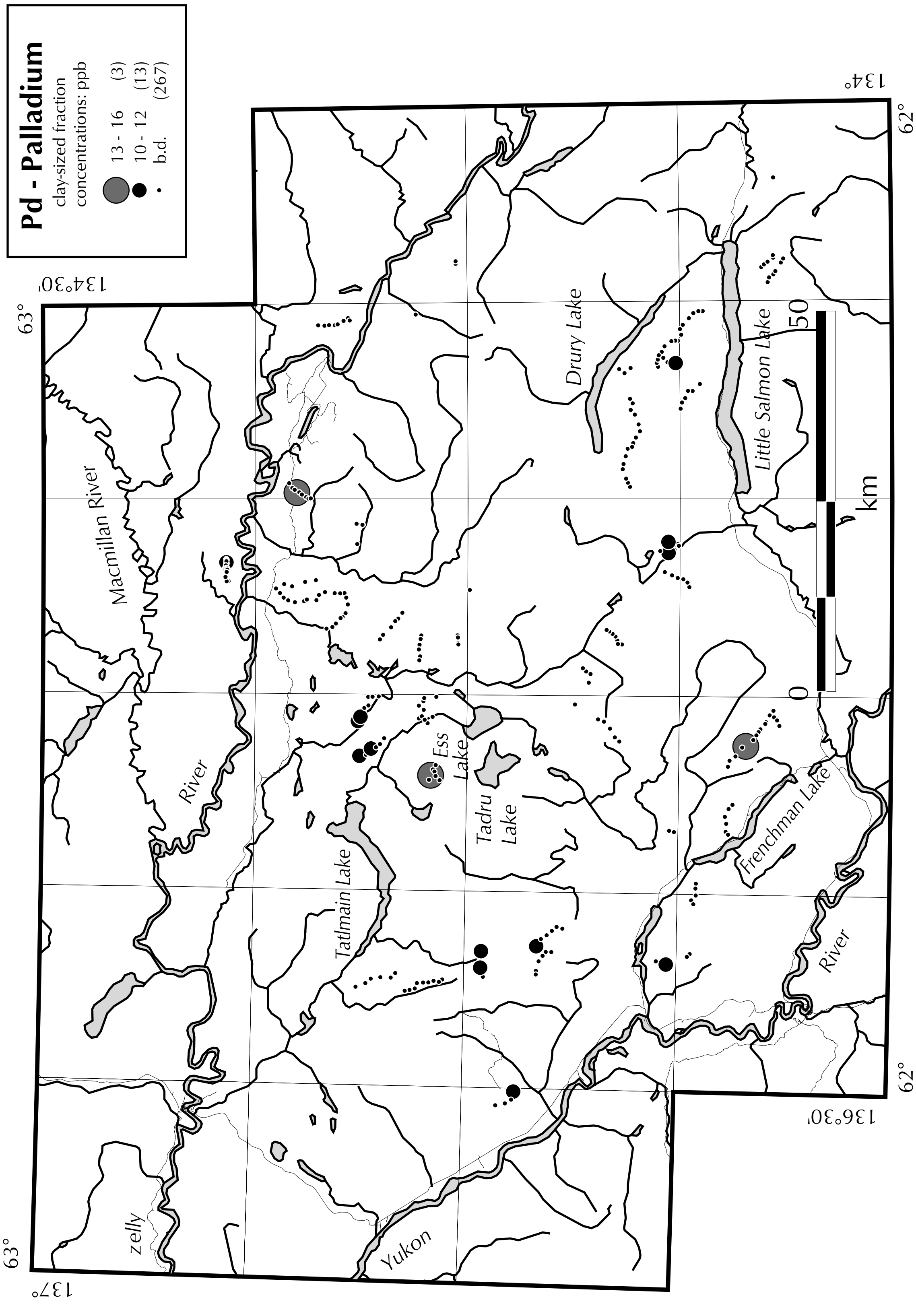

Be - Beryllium
silt-and-clay-sized fraction
concentrations: ppm
9 - 13 (2)
8 - 8 (6)
6 - 7 (13)
5 - 5 (16)
3 - 4 (60)
2 - 2 (76)
b.d. - 1 (112)
134°
134°30'
136°30'
137°
63°
62°
0 50
km
Macmillan River
River
Drury Lake
Little Salmon Lake
Ess Lake
Tadru Lake
Tatlmain Lake
Frenchman Lake
River
Yukon
zelly
Mesozoic pluton
Semenof block:
volcanic rocks

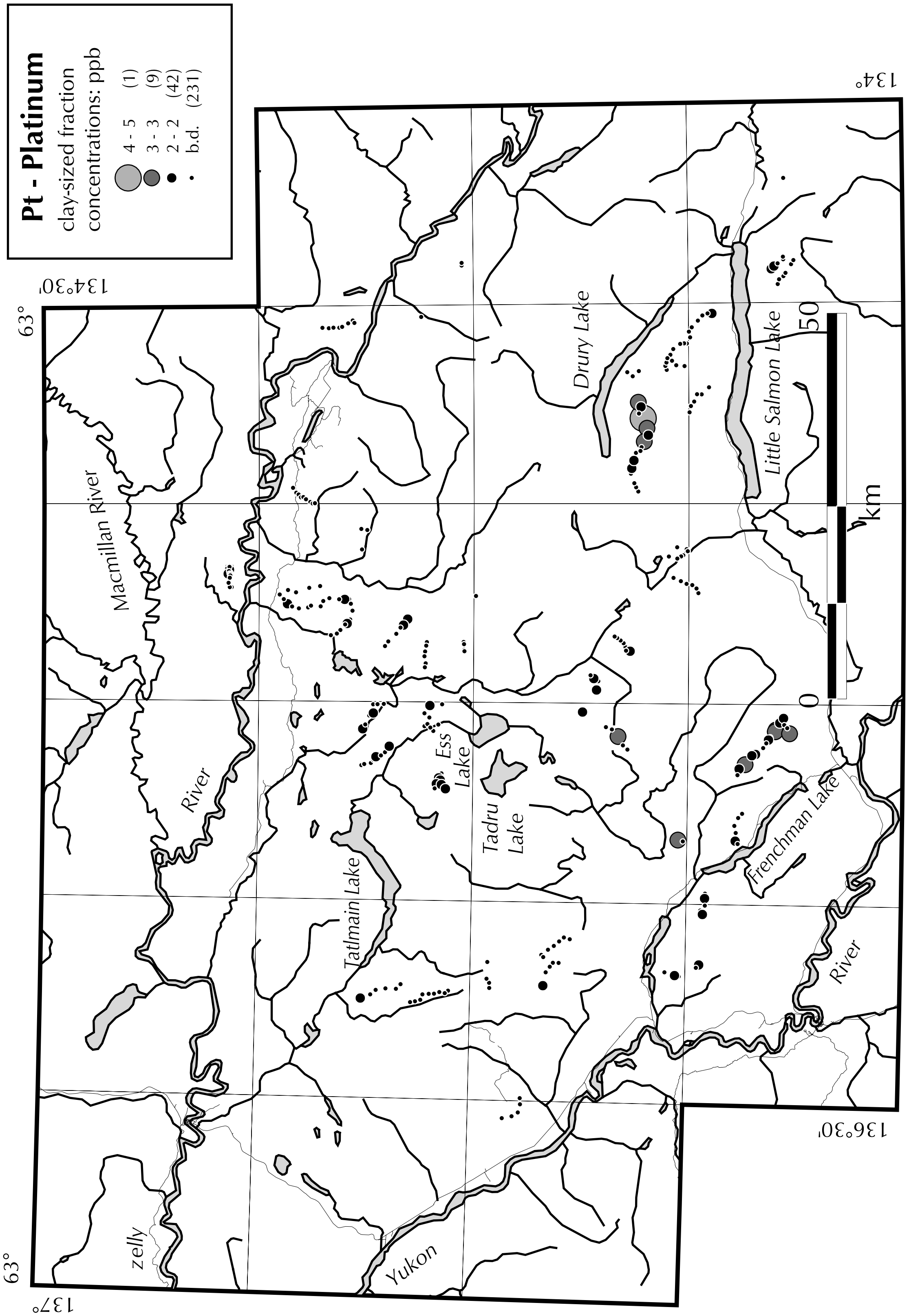


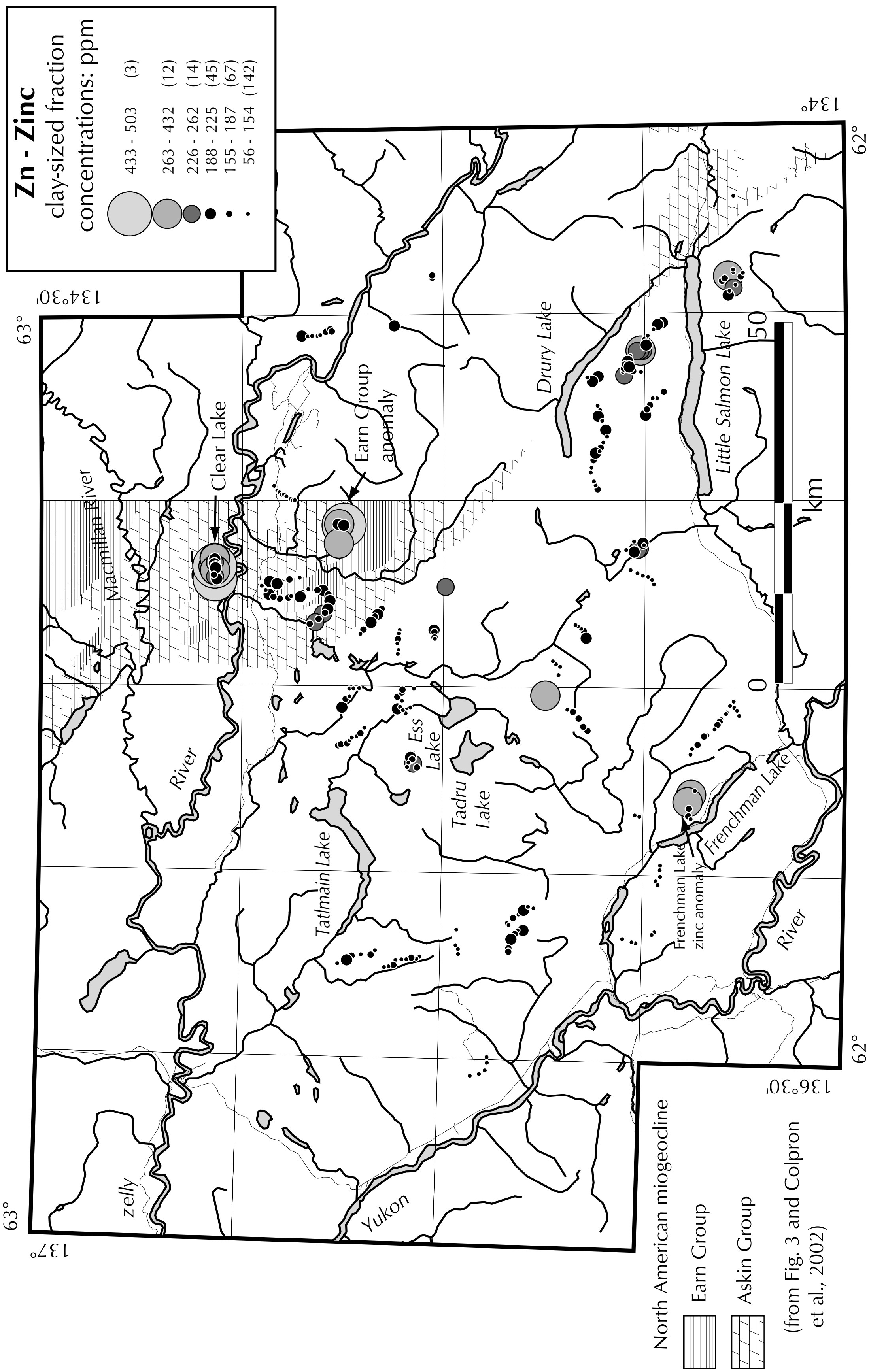
Cu - Copper
clay-sized fraction
concentrations: ppm
307 - 444 (4)
205 - 306 (11)
163 - 204 (13)
126 - 162 (43)
95 - 125 (71)
13 - 94 (141)
134°30'
134°
63°
62°
137°
136°30'
Clear Lake
Macmillan River
River
Drury Lake
Little Salmon Lake
Frenchman Ridge copper anomaly
Ess Lake
Tadru Lake
Tatlmain Lake
Frenchman Lake
River
Yukon
zelly
0
50
km
North American miogeocline
Earn Group
Askin Group
(from Fig. 3 and Colpron et al., 2002)



Pb - Lead
clay-sized fraction
concentrations: ppm
120 - 333 (3)
67 - 119 (11)
56 - 66 (13)
38 - 55 (43)
29 - 37 (68)
2 - 28 (145)
134°
62°
134°30'
63°
137°
63°
136°30'
62°
Drury Lake
Little Salmon Lake
Macmillan River
River
Ess Lake
Tadru Lake
Tatlmain Lake
Frenchman Lake
River
Yukon
zelly
0
50
km
North American miogeocline
Earn Group
Askin Group
(from Fig. 3 and Colpron et al., 2002)


Pd - Palladium
clay-sized fraction
concentrations: ppb
13 - 16 (3)
10 - 12 (13)
b.d. (267)
134°
62°
134°30'
63°
136°30'
137°
Macmillan River
River
Drury Lake
Little Salmon Lake
Ess Lake
Tadru Lake
Tatlmain Lake
Frenchman Lake
Yukon
zelly
0
50
km


Pt - Platinum
clay-sized fraction
concentrations: ppb
4 - 5 (1)
3 - 3 (9)
2 - 2 (42)
b.d. (231)
134°
62°
134°30'
63°
137°
136°30'
Drury Lake
Little Salmon Lake
Macmillan River
River
Ess Lake
Tadru Lake
Tatlmain Lake
Frenchman Lake
River
Yukon
zelly
0
50
km


Zn - Zinc
clay-sized fraction
concentrations: ppm
433 - 503 (3)
263 - 432 (12)
226 - 262 (14)
188 - 225 (45)
155 - 187 (67)
56 - 154 (142)
134°
62°
134°30'
63°
Macmillan River
Clear Lake
Earn Group anomaly
Drury Lake
Little Salmon Lake
0
50
km
River
Ess Lake
Tadru Lake
Tatlmain Lake
Frenchman Lake
Frenchman Lake zinc anomaly
River
62°
136°30'
zelly
Yukon
63°
137°
North American miogeocline
Earn Group
Askin Group
(from Fig. 3 and Colpron et al., 2002)

Hydrothermal alteration, mineralization and exploration potential of the Mars alkalic copper-gold-molybdenum porphyry occurrence, Laberge map area (105E/7), Yukon

James R. Lang[1]
Lang Geoscience Inc.[1] *and Saturn Minerals Inc.*[2]

Murray McClaren
Saturn Minerals Inc.[2]

Lang, J.R. and McClaren, M., 2003. Hydrothermal alteration, mineralization and exploration potential of the Mars alkalic copper-gold-molybdenum porphyry occurrence, Laberge map area (105E/7), Yukon. *In:* Yukon Exploration and Geology 2004, D.S. Emond and L.L. Lewis (eds.), Yukon Geological Survey, p. 261-269.

ABSTRACT

The Mars property occurs on the southwestern margin of the Teslin Crossing pluton, a composite intrusion of intermediate, alkalic composition that was emplaced into sedimentary rocks of the Middle Jurassic Tanglefoot formation at about 175 Ma. Exposed alteration and mineralization define a northwest-trending zone 2.8 by 1.5 km. New field and petrographic data document a core zone dominated by sodic and magnetite-rich alteration, surrounded by more extensive calc-potassic alteration; each assemblage contains disseminated and fracture-hosted copper-gold mineralization. Subzones of younger quartz veins with strong copper-molybdenum±gold mineralization are widely distributed. Sericitic and propylitic alteration is minor and weakly mineralized. The system has low sulphide mineral content with a high ratio of chalcopyrite to pyrite. Hornfels in the Tanglefoot formation has stronger pyrite-pyrrhotite and also carries copper-gold mineralization. The Mars system is a silica-oversaturated alkalic copper-gold-molybdenum porphyry deposit with strong similarities to the Cadia and Goonumbla deposits in Australia.

RÉSUMÉ

La propriété de Mars est située sur la marge sud-ouest du pluton de Teslin Crossing, une intrusion composite de composition alcaline intermédiaire mise en place dans des roches sédimentaires de la Formation de Tanglefoot du Jurassique moyen vers 175 Ma. L'altération et la minéralisation exposées permettent de définir une zone de 2,8 sur 1,5 km à direction nord-ouest. Les nouvelles données pétrographiques recueillies sur le terrain documentent une zone centrale où domine une altération sodique et magnétitifère entourée d'une altération calco-potassique plus étendue; chaque assemblage renferme une minéralisation de cuivre-or disséminée et logée dans des fractures. La répartition des sous-zones à filons de quartz plus jeunes fortement minéralisées en cuivre-molybdène±or est large. L'altération séricitique et propylitique est mineure et faiblement minéralisée. Le système a une faible teneur en sulfures et affiche un rapport élevé de chalcopyrite à pyrite. La cornéenne dans la Formation de Tanglefoot a une teneur plus élevée en pyrite-pyrrhotite et renferme également une minéralisation en cuivre-or. Le système de Mars est un gîte porphyrique de cuivre-or-molybdène alcalin sursaturé en silice très apparenté aux gisements de Cadia et Goonumbla en Australie.

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INTRODUCTION

The Mars property is located about 65 km north-northeast of Whitehorse, Yukon (Fig. 1). It was first explored for traditional calc-alkalic copper-molybdenum porphyry potential in 1971 (Wark, 1998). Recognition of its gold potential did not occur until the mid-1990s (A. Doherty, internal report by Aurum Geological Consultants, 1996), and the property is now known to host porphyry-style copper-gold-molybdenum mineralization genetically related to alkalic intrusions in the Teslin Crossing pluton (Hart, 1997; Wark, 1998). Major alkalic copper-gold±molybdenum porphyry deposits are globally widespread and include the Copper Mountain/Ingerbelle, Afton-Ajax, Mount Polley, Galore Creek and Mount Milligan deposits in British Columbia (Barr et al., 1976; Lang et al., 1995), Goonumbla/North Parkes (Muller et al., 1994) and Cadia-Ridgeway (Holliday et al., 2002) in New South Wales, Marian and Dinkidi in the Philippines (Wolfe et al., 1999), and Skouries in Greece (Kroll et al., 2002). Many of these deposits are active or former mines, and the economic potential of the Mars property is being currently tested under option by Saturn Minerals Inc.

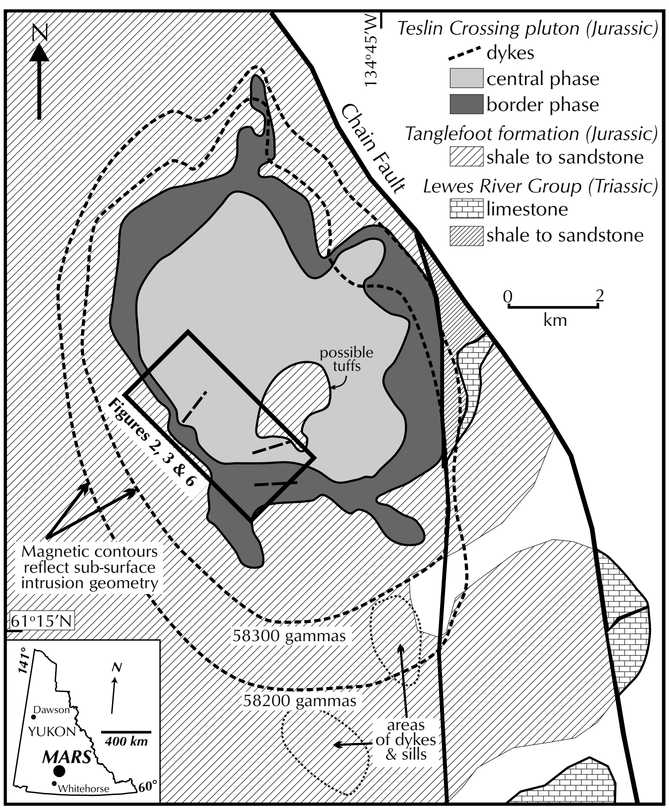

Figure 1. *Geological setting of the Teslin Crossing pluton. Contours of aeromagnetic data suggest that the pluton extends significantly to the south and southwest, beneath the Tanglefoot formation. See text for further discussion. Box shows the location of Figures 2, 3 and 6. Map modified slightly from Hart (1997).*

The Mars property is the only currently recognized example of this deposit type in Yukon, yet it has only received very limited exploration and geological study. This paper first briefly reviews the regional and local geology of the property. It then focuses on new field and petrographic observations on the mineral assemblages and distribution of alteration and mineralization. It concludes with a more specific classification of the deposit and presents an updated exploration model.

REGIONAL GEOLOGY

The regional setting of the Teslin Crossing pluton has been discussed in greatest detail by Hart (1997) and Bostock and Lees (1938), who are the sources for most of this summary. The pluton is located within the Stikine Terrane (Stikinia), which accreted to the margin of ancestral North America during the Middle Jurassic. Stikinia consists of an Upper Paleozoic volcanic arc basement overlain by the Lewes River volcanic arc of Middle and Late Triassic age. The Whitehorse Trough developed as a marginal basin during this time, and was infilled by up to 7 km of strata that include Late Triassic volcanic-rich detritus and carbonate of the Lewes River Group, and Jurassic clastic rocks of the Laberge Group. Amalgamation of the adjacent Cache Creek Terrane and accretion to North America resulted in deformation of these rocks during the Middle and Late Jurassic.

The Teslin Crossing pluton (Fig. 1) is an isolated body that was emplaced near the axis of the Whitehorse Trough in the Middle Jurassic. Although the pluton occurs at the approximate centre of a 35-km-long, northwest-trending belt that contains numerous small stocks, sills and dykes, it does not appear to be part of an extensive igneous suite (Hart, 1997), although Gordey and Makepeace (2001) correlate it with the Bryde plutonic suite.

Host rocks to the Teslin Crossing pluton are mostly fissile, black, well-bedded, carbonaceous, variably limey, poorly indurated shale and siltstone with minor, thin, chert-rich sandstone interbeds (Hart, 1997). Tempelman-Kluit (1984) assigned these rocks to the Middle Jurassic Tanglefoot formation, and fossils yield biostratigraphic ages of

Toarcian or Aalenian (Hart, 1997). The rocks occur in a block that is fault-bounded against older rocks; the eastern margin of this block, and of the Teslin Crossing pluton itself, is cut by north and north-northwest faults that form part of the southern end of the Chain Fault (Fig. 1). The sedimentary rocks dip steeply away from their contact with the Teslin Crossing pluton. Volcanic rocks of Aalenian age are found 10 km north-northwest of the pluton and may be temporally associated (Hart, 1997). A poorly exposed roof pendant of hornfels of possible tuffaceous origin (Hart, 1997; Wark, 1998) occurs in the east-central part of the pluton (Fig. 1), but the age and composition of these rocks have not been established.

THE TESLIN CROSSING PLUTON

The Teslin Crossing pluton, although not mapped in detail, generally comprises a central phase bounded by a more mafic border phase, with both units cut by dykes of variable composition and orientation (Fig. 1; Bostock and Lees, 1938; Hart, 1997). The pluton is bounded on the east by strands of the Chain Fault. On the north and west, contacts against host rocks are sharp and steep (Pangman, 1973; Pangman and VanTassell, 1972). The south contact may dip more shallowly, and airborne magnetic data indicate that the intrusion extends well outboard of the exposed contact. The >57 200 gamma magnetic contour indicates a body at least twice the exposed size of 8 by 5 km (Hart, 1997); a large-scale sill geometry has also been suggested but has not been favoured (Hart, 1997). Sedimentary rocks above the buried part of the pluton and adjacent to steeper contacts have been converted to hornfels.

The central phase of the pluton has been described by Hart (1997) as a texturally and compositionally variable suite dominated by a medium to light grey-pink, hornblende-bearing monzonite that contains magnetite, rare biotite and, possibly, pyroxene (Pangman and VanTassell, 1972). The border phase is a grey, texturally variable, crowded monzodiorite to monzonite porphyry; it contains abundant pyroxene, lesser biotite, and locally minor hornblende. Phenocrysts comprise pyroxene and plagioclase. Minor phases of the pluton include younger tan syenite that lacks ferromagnesian minerals, and small zones of hornblende-bearing alkali syenite of uncertain timing. The central and border phases contain abundant xenoliths of hornfelsed Tanglefoot formation, pyroxenite and gabbro. All intrusive phases contain titanite, magnetite, apatite, rutile and zircon.

Swarms of sills have been described from south of the pluton (Hart, 1997; Fig. 1). They are similar to the border phase but are finer grained, locally more mafic, and commonly have a trachytic texture. Trachytic hornblende-feldspar porphyry syenite dykes are common within the pluton. Narrow, less common hornblende-rich mafic dykes are also present; these were described by Pangman and VanTassell (1972) as lamprophyres, but other authors have called them monzonite to monzogabbro (Hart, 1997; Wark, 1998). Dykes within the pluton are reportedly unaltered and unmineralized (Wark, 1998). They strike northeast to east-northeast with nearly vertical dips, whereas sills south of the pluton strike north and dip to the west (Hart, 1997).

Isotopic ages on the Teslin Crossing pluton include four potassium-argon (K-Ar) dates on biotite and hornblende between 164 and 186 Ma (Stevens et al., 1982; Tempelman-Kluit, 1984), and a single uranium-lead (U-Pb) date on zircon of 175.6±2.0 Ma from a sill south of the pluton (Hart, 1997). Geochemical data (Hart, 1997; R.C. Wells, private report to Placer Dome North America Ltd., 1998) from the intrusions indicate a weakly alkalic, metaluminous to locally and weakly peraluminous composition. Normative compositions indicate silica-saturation to weak silica-oversaturation for the central and border phases of the pluton, and a nepheline-normative composition was determined for a pyroxenite xenolith (Hart, 1997).

LOCAL GEOLOGY IN THE PRINCIPAL ZONE OF MINERALIZATION

The area of greatest interest to this study is located on the southwest margin of the pluton and encompasses most of the known alteration and mineralization (Figs. 1 and 2). Only general comments on the area are possible due to the absence of detailed mapping. The area contains mostly border phase that, in part, surrounds an embayment of hornfels of Tanglefoot formation. The central phase is located to the north and northwest of the border phase, but sharp contacts were not observed between them. The roof pendant of hornfelsed, possible volcanic rock, noted above enters the northeastern margin of the area. The area has a northwesterly elongation parallel to the overall orientation of the pluton contact. Many faults are broadly parallel to this contact, but north to north-northeast, northeast and east-northeast faults are also present. Data are insufficient to document movement history or relative timing of the various structures. Many veins trend northwest (see next section), but the predominantly to wholly post-hydrothermal dykes have east-northeast, northeast and north-northeast strikes.

ALTERATION AND MINERALIZATION

Previous work on the Mars property has focused on mineralized 'prospects' (Figs. 2 and 3; Wark, 1998) that include the Cliff, X, Kelly, Pluto, New, Windy Ridge South and Moon Knob zones, as well as the JL, Andrew and TA zones newly discovered by Saturn Minerals. The distribution of these zones and the more recent field work by the authors suggest that larger scale alteration patterns provide a better framework for an improved exploration model. The field and petrographic work of this study have therefore been combined with previous work (Pangman and VanTassell, 1972; Hart, 1997; Wark, 1998) to subdivide alteration into assemblages that have distinct relationships to copper-gold-molybdenum mineralization. The main types of alteration are: 1) hornfels; 2) potassium- and potassium-calcium silicate; 3) sodium-silicate; 4) magnetite; 5) silica, including swarms of quartz-sulphide veins; 6) propylitic; and 7) sericite. These assemblages cover a northwest-trending area at least 2.8 by up to 1.5 km that is open in most directions, and is broadly coincident with copper values in soils of >100 ppm (Fig. 3). The distribution of individual alteration types is shown schematically in Figure 3, but work is not yet sufficient to fully define either the boundaries of any of the zones or the complete mineralogical associations that they represent.

HORNFELS

Contact metamorphism formed in Tanglefoot formation adjacent to the Teslin Crossing pluton, prior to the onset of hydrothermal activity related to copper-gold-molybdenum mineralization. Hornfels extends for at least a few hundred metres away from the southwestern contact of the pluton, but its full extent is concealed by alluvium. Major and minor minerals include biotite, quartz, plagioclase, potassium feldspar, pyrite and pyrrhotite, with local traces of chalcopyrite. Some intervals have returned highly anomalous copper and gold values, which have been related petrographically to later potassium-calcium-silicate, sodium-silicate and/or magnetite-bearing alteration and veins.

POTASSIUM- AND POTASSIUM-CALCIUM-SILICATE ALTERATION

Potassium-feldspar is the most widespread and, on average, the earliest alteration mineral. The most common expression of this alteration is envelopes of potassium-feldspar around tight, planar fractures or narrow veinlets that contain potassium-feldspar, actinolite, calcite, and rare quartz and biotite. These veinlets locally contain traces of pyrite and chalcopyrite. In many parts of the system these veins are widely spaced (up to a few per metre), but they are also commonly found in higher densities where they are associated with stronger pervasive alteration and higher concentrations of pyrite and chalcopyrite. This type of alteration encompasses the entire area of mineralization, and according to Hart (1997) may extend well beyond the boundaries shown in Figure 3. The veins commonly have the appearance of altered joints and lack preferred orientations; this may indicate formation as a high-temperature, possibly deuteric event consistent with their early timing. Pervasive biotite-dominated alteration is not common. A siliceous breccia with a biotite-rich matrix was observed at Moon Knob (see "Silica-rich alteration" section).

SODIUM-SILICATE ALTERATION

Sodium-silicate alteration occurs in the central and eastern parts of the mineralized area, but distribution of the alteration is very poorly defined (Fig. 3). Limited evidence suggests that it overprints potassium-silicate alteration, and is cut by magnetite-bearing veins. The assemblage is dominated by incipient to intensely pervasive albite. In some locations, diffuse veinlets of albite and albite-quartz were observed. Disseminated pyrite and chalcopyrite are more abundant than is typical of potassium- and potassium-calcium-silicate alteration zones.

MAGNETITE ALTERATION

An extensive zone in the southeastern part of the property contains abundant veinlet-hosted and pervasive magnetite alteration (Fig. 3), but to the northwest it is less common and its distribution is more erratic. Veins are dominated by magnetite, commonly contain minor biotite and/or quartz, and typically have prominent potassium-feldspar envelopes. They range from hairline fractures to > 0.5 m in width, and wider examples can extend for at least tens of metres along strike. Veins range from planar to sinuous, and contacts with host rock can be sharp or diffuse. There is a general and locally strong relationship

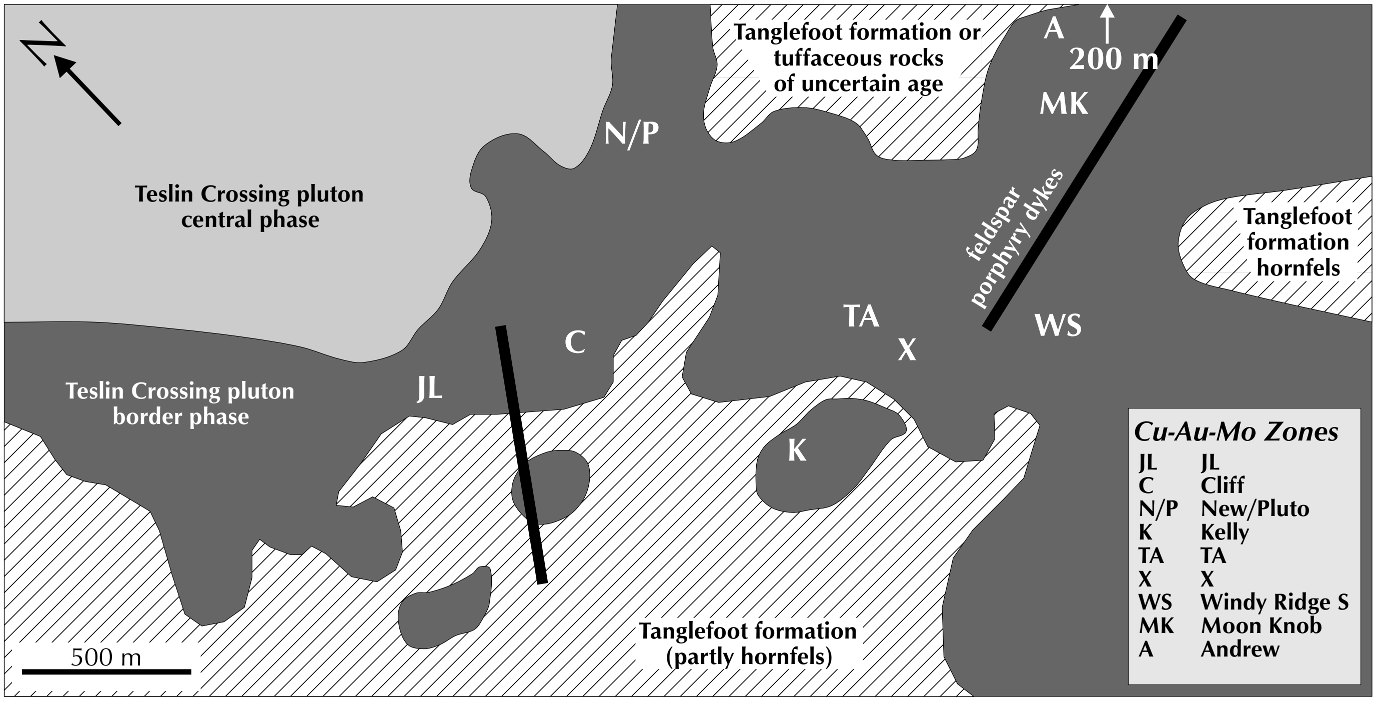

Figure 2. *Geology of the Mars study area. Note the rotation of the map from north, and that the Andrew zone is located about 200 m northeast of the edge of the map. Geology modified from Wark (1998). Location of this figure is shown as outline on Figure 1.*

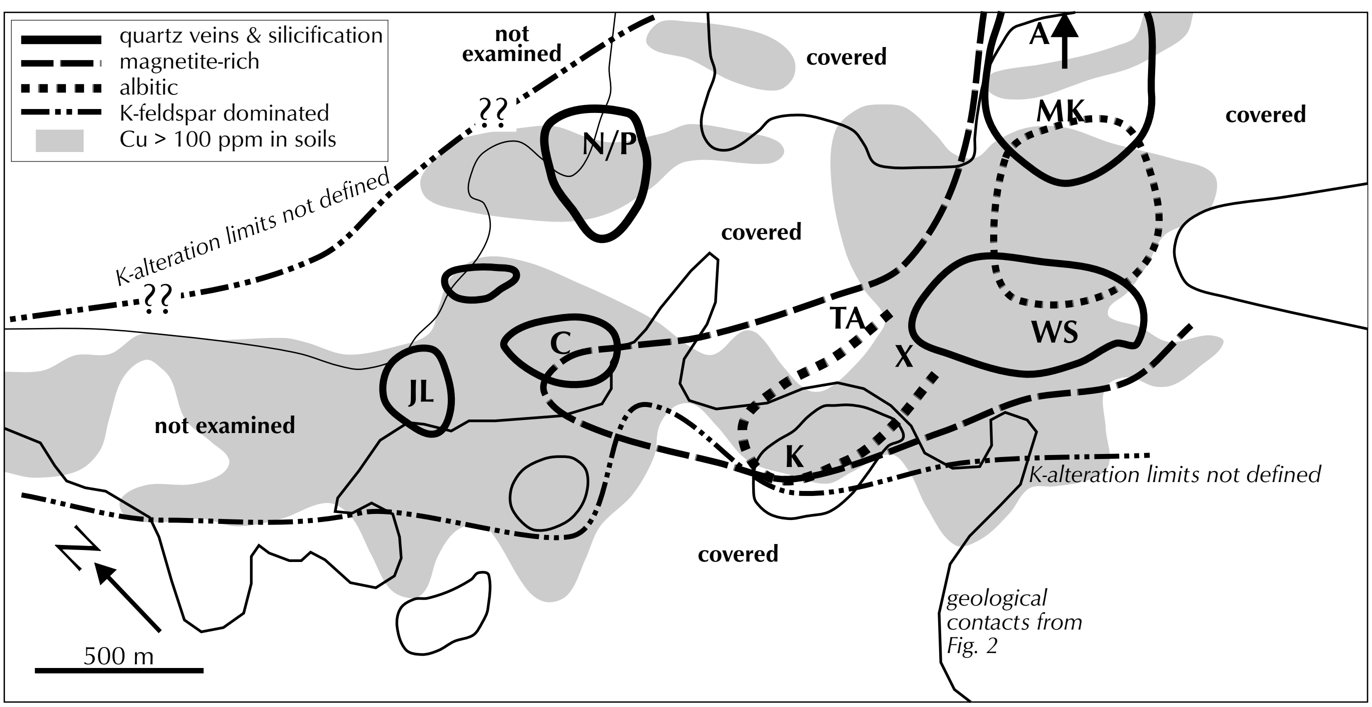

Figure 3. *Distribution of alteration assemblages in the Mars magmatic-hydrothermal system. Boundaries for alteration zones are not fully defined, as discussed in the text. Grey area outlines Cu-in-soils values > 100 ppm (Wark, 1998). Geological contacts from Figure 2 have been retained for reference, but patterns have been deleted. Mineralized zones as in Figure 2. Location of this figure is shown as outline on Figure 1.*

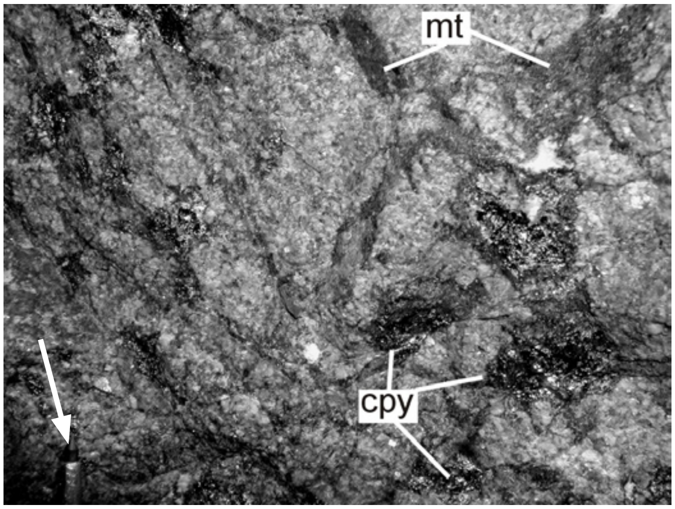

Figure 4. Photograph illustrating the relationship between magnetite alteration and sulphide minerals. Host rock is the moderately albitized border monzodiorite phase cut by wispy magnetite veins (mt; dark, irregular features). The bright zones within the magnetite zones are coarse clots of chalcopyrite (cpy). Sample is from the Kelly zone. Arrow points to scriber at bottom left for scale.

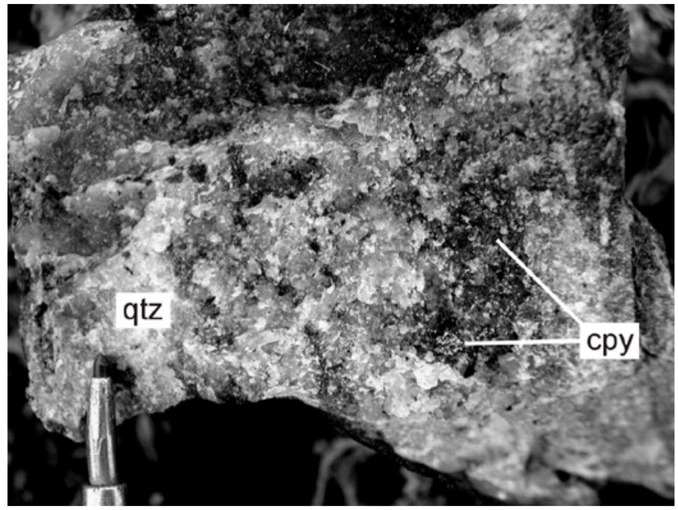

Figure 5. Photograph of a quartz-sulphide mineral vein from the Moon Knob zone. The entire sample is quartz vein (qtz), and a vuggy, open space texture is evident. Chalcopyrite (cpy) is abundant in this sample, particularly in the dark, vuggy area at right-centre. Sample is about 7 cm across.

between magnetite alteration and copper-gold mineralization (but not with molybdenum). Some samples with among the highest grades of copper and gold in the system are associated with magnetite alteration (R.C. Wells, private report to Placer Dome, 1998), where it contains both chalcopyrite and bornite (Fig. 4). Elsewhere, magnetite alteration either lacks or has an unclear association with copper-gold. It is probable that magnetite alteration comprises more than one sub-stage.

SILICA-RICH ALTERATION

Silica-rich alteration is widespread (Fig. 3) and is characterized by sulphide mineral-bearing, quartz-rich veins (Fig. 5). Many veins contain later interstitial or cross-cutting calcite, and minor magnetite, actinolite and/or chlorite are common. Sulphide minerals are almost ubiquitous but are very irregularly distributed within individual veins; they include chalcopyrite, lesser pyrite and molybdenite, and reportedly trace galena (R.C. Wells, private report to Placer Dome, 1998). Many veins lack envelopes, but others have silicified or narrow potassium-feldspar envelopes. Quartz veins range from hairline fractures to >30 cm in width. Wider veins are steeply dipping and have a preferred northwest orientation; they are commonly related to high densities of narrower veins that form conjugate splays off the main vein. The veins initially filled open space (Fig. 5), but the quartz in many is strongly undulose and recrystallized, suggesting that weak, post-precipitation deformation has been widespread. A small (< 3-m exposure) hydrothermal breccia on Moon Knob contains transported fragments of silicified hornfels and intrusive rock in a matrix of biotite, quartz, pyrite, bornite, magnetite and chalcopyrite. Quartz veins cut potassium-silicate, potassium-calcium silicate, sodium-silicate and magnetite-rich alteration.

PROPYLITIC ALTERATION

Propylitic alteration was observed only locally, and mostly in the northwestern part of the system where it is very restricted in both extent and intensity. The most common manifestation is veinlets with various combinations of epidote, albite, actinolite, chlorite, quartz, carbonate and hematite. Veins of this type cut potassium-feldspar bearing veins, but relationships to other alteration types were not established.

SERICITE ALTERATION

Sericite is widespread, and no definite pattern of distribution has been recognized. Most occurs as a weak, selectively pervasive replacement of feldspar in intrusive rocks affected by potassium- and potassium-calcium-silicate alteration, to which it may be temporally related. No additional information is available.

MINERALIZATION

The copper-gold-molybdenum mineralization at the Mars property is widely distributed (Figs. 2 and 3). At the current level of exposure, the overall sulphide mineral concentration in intrusive host rocks is low (up to a few but mostly < 2%) and the ratio of chalcopyrite to pyrite is high. Pyrrhotite is found only in veins located close to the outer contact of the pluton where it is proximal to hornfels. Bornite is common in areas affected by magnetite alteration, but is also present in other alteration types. Molybdenite is found mostly in late quartz-sulphide mineral veins where it is associated with some of the highest concentrations of chalcopyrite on the property. Gold occurs in native form and is associated with chalcopyrite, bornite and pyrite (R.C. Wells, private report to Placer Dome North America Ltd., 1998). Historical sampling has not been systematic, but many surface rock chip and grab samples exceed 1% Cu, 1 g/t Au and/or several hundred ppm Mo. The PGE potential of the property has not been tested, although these metals are commonly present in alkalic copper-gold porphyry deposits (Thompson et al., 2001; Kroll et al., 2002). Hornfels contains several percent disseminated pyrite, lesser pyrrhotite, and trace chalcopyrite; where copper-gold mineralization is more strongly developed, it can be related petrographically to an overprint by other alteration types and/or veins.

INTERPRETATION AND EXPLORATION MODEL

The characteristics of the Mars magmatic-hydrothermal system are compatible with the alkalic copper-gold porphyry model (Barr et al., 1976; Lang et al., 1995). These deposits include silica-undersaturated, silica-saturated and silica-oversaturated sub-types, based on the modal or normative composition of the associated alkalic intrusions and, to a lesser extent, on alteration (Lang et al., 1995; in review). The Mars system should be considered a silica-oversaturated alkalic copper-gold porphyry deposit on the basis of: 1) abundant quartz-sulphide veins and siliceous alteration; 2) widespread, but weak, sericite alteration; 3) the quartz-normative composition of the intrusions (Hart, 1997; R.C. Wells, private report to Placer Dome North America Ltd., 1998); and 4) the presence of strong molybdenum mineralization. Important examples of silica-oversaturated alkalic copper-gold-molybdenum deposits that share many similarities with Mars include Goonombla/North Parkes (Muller et al., 1994) and Cadia-Ridgeway (Holliday et al., 2002) in Australia, and Skouries in Greece (Kroll et al., 2002), all of which are active mines.

Classification of the Mars property as a *silica-oversaturated* alkalic copper-gold porphyry deposit has implications for exploration potential and methods. Silica-oversaturated systems contain, on average, a greater tonnage of mineralization than other alkalic copper-gold porphyry types. Magnetite-bearing potassium-silicate alteration in silica-oversaturated alkalic deposits is commonly an important environment for ore, but more critically, a substantial proportion of mineralization is typically related to sheeted or stockwork quartz-sulphide veins. This contrasts sharply with the nearly complete absence of quartz-sulphide veins in other types of alkalic copper-gold porphyry deposits, in which disseminated mineralization hosted by pervasive, magnetite-bearing potassium-feldspar and/or biotite alteration is the norm.

The exploration significance of these patterns to mineralization in silica-oversaturated alkalic systems generally, and to observations at Mars more specifically, is evident in a reinterpretation of induced polarization (IP) data (Fig. 6). The initial interpretation of the IP results by Wark (1998) focused on chargeability highs. These are concentrated at the southwestern contact of the pluton and clearly indicate the distribution of sulphide-rich hornfels; copper-gold mineralization has been documented within the hornfels and it indeed comprises a viable exploration target. Alkalic copper-gold systems are, however, typified by a low overall sulphide mineral concentration with a high ratio of chalcopyrite and/or bornite to pyrite (Lang et al., 1995; in review), and IP chargeability highs are correspondingly less important as indicators of ore than in sulphide-rich deposits such as calc-alkalic copper-molybdenum porphyry systems. Figure 6 shows an excellent correlation between IP resistivity highs and exposed zones of quartz-sulphide mineral veins. The resistivity anomalies are much larger than, and have northwest trends parallel to the preferred orientation of, the exposed zones of quartz-sulphide mineral veins. The resistivity highs are therefore

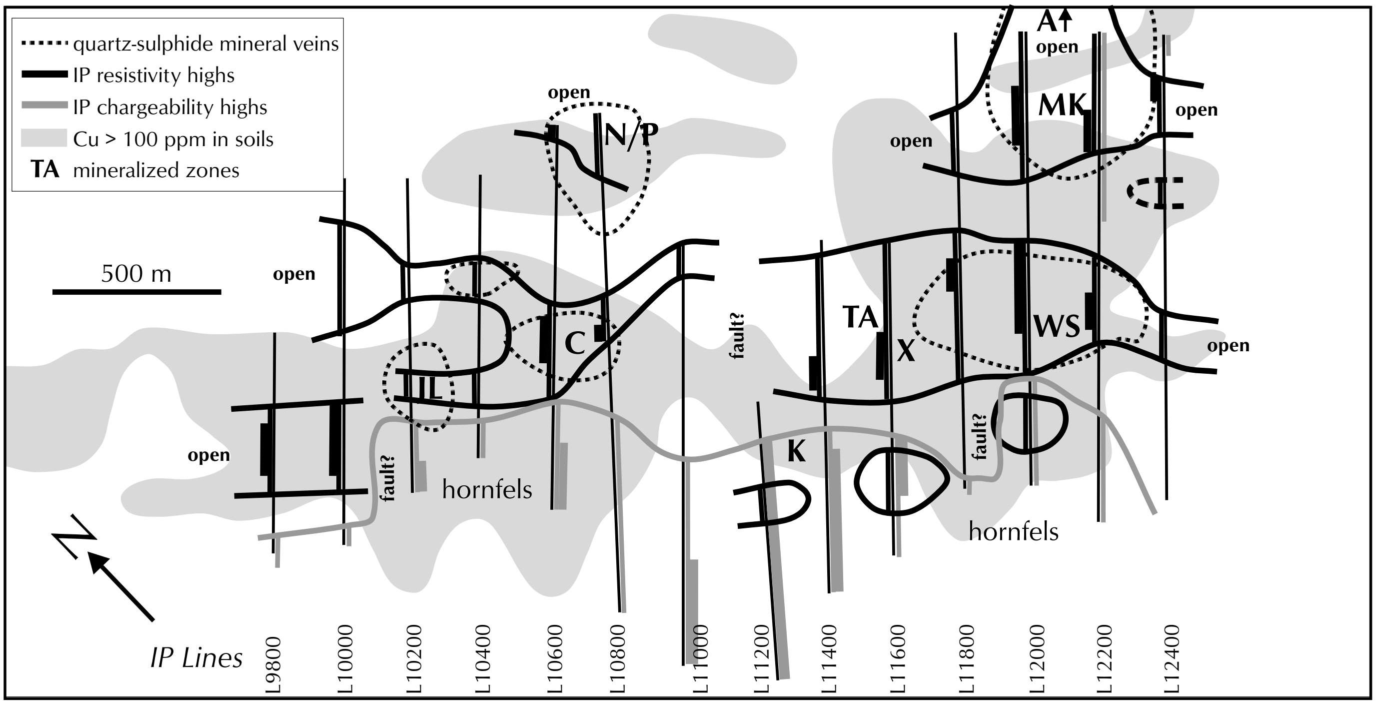

Figure 6. *Schematic reinterpretation of IP data for the Mars system. Relative strength of chargeability and resistivity highs indicated by thickness of lines. Chargeability anomalies reflect hornfels in the sedimentary host rocks to the pluton. Most resistivity anomalies are located within the pluton, and correlate spatially with exposed areas of abundant quartz-sulphide mineral veins. See text for further discussion. Geological contacts removed for clarity. Mineralized zones and Cu soil geochemistry as in Figure 2. Location of this figure is shown as outline on Figure 1. Data originally described by Wark (1998).*

provisionally considered reflective of relatively more prospective environments at the Mars property.

The observations and interpretations described in this paper are very preliminary, and additional work is required before the proposed exploration model for the Mars property can be sufficiently refined to undertake a comprehensive testing of its copper-gold-molybdenum potential. Mapping, prospecting, geochemical sampling, petrography and an initial stage of reconnaissance drilling are planned for the summer of 2004 in order to advance development of this interpretive framework.

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Post-mining hydrogeochemical conditions, Brewery Creek gold deposit, central Yukon

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ABSTRACT

A reconnaissance-level study of post-mining hydrogeochemical conditions was carried out at the Brewery Creek gold deposit within the Tintina Gold Province. The deposit is characterized by epizonal mineralization with a consistent arsenic-gold-mercury-antimony geochemical signature. Surface discharges and seeps in the area are naturally alkaline (pH=7.6-8.2), Ca-HCO_3^--SO_4^{2-} waters. Upstream from the recognized mineralization, waters contain <3 µg/L As and <1 µg/L Sb. Water samples immediately downstream from the ore bodies show maximum concentrations of 18 µg/L dissolved and 47 µg/L total arsenic, and 18 µg/L dissolved and 21 µg/L total antimony. Two kilometres below the mineralization, on lower Laura Creek, arsenic concentrations are diluted to background levels of <3 µg/L, and antimony levels are still slightly elevated at 9-10 µg/L. Comparison with hydrogeochemical data from Donlin Creek, an undeveloped epizonal deposit in Alaska, indicates that elevated concentrations of a few tens of µg/L arsenic and antimony are typical of waters draining such gold systems, regardless of their state of development. In addition to their usefulness for the construction of geoenvironmental models, these data also provide information for establishing exploration programs utilizing water sampling.

RÉSUMÉ

Une étude de reconnaissance des conditions hydrogéochimiques postérieures à l'exploitation minière a été réalisée au gîte aurifère de Brewery Creek dans la province aurifère de Tintina. Le gîte est caractérisé par une minéralisation épizonale affichant une signature géochimique cohérente d'arsenic-or-mercure-antimoine. Les rejets de surface et les infiltrations dans la zone sont des eaux de Ca-HCO_3^--SO_4^{2-} naturellement alcalines (pH=7,6-8,2). En amont de la minéralisation connue, les eaux contiennent <3 µg/L de As et <1 µg/L de Sb. Les échantillons d'eau prélevés tout juste en aval des massifs minéralisés ont des concentrations maximales de 18 µg/L de As dissous et de 47 µg/L de As total, ainsi que 18 de Sb dissous et 21 de Sb total. À deux kilomètres au-dessous de la minéralisation, sur le ruisseau Laura inférieur, les concentrations d'arsenic sont diluées à des niveaux de fond de <3 µg/L et celles d'antimoine sont légèrement plus élevées à 9-10 µg/L. En comparant ces données avec les données hydrogéochimiques de Donlin Creek, un gisement épizonal non exploité en Alaska, il ressort que les concentrations élevées de quelques dizaines de µg/L d'arsenic et d'antimoine sont représentatives des eaux qui drainent des systèmes aurifères quel que soit leur état de mise en valeur. Ces données servent non seulement à la construction de modèles géoenvironnementaux, mais aussi à la conception de programmes d'exploration à partir d'échantillons d'eau.

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INTRODUCTION

The Tintina Gold Province (TGP) extends from southwestern Alaska to eastern Yukon and comprises numerous individual gold belts and districts. The province is characterized by gold lodes showing a spatial association with mid-Cretaceous plutons in its east and central parts, and with latest Cretaceous plutons in the west. Mineralization styles differ greatly throughout the TGP. Most deposits, surrounding a central, causative pluton, typically occur as auriferous sheeted quartz-feldspar veins where mineralized rock is localized in the apical parts of the plutons or in immediately adjacent hornfels (Hart et al., 2002). These veins are characterized by a gold-bismuth-tellurium-tungsten geochemical signature and low sulphide mineral content (< 0.5% volume), such as those found at the Fort Knox deposit and the Dublin Gulch prospect (Hart et al., 2000; Goldfarb et al., 2000). A less understood deposit style, also associated with the Cretaceous plutons, is epizonal fracture networks within carbonaceous sedimentary rocks and/or felsic dykes and sills. These deposits have a lower temperature arsenic-gold-mercury-antimony signature and a high sulphide mineral content (>2% volume). The most notable of these are True North and Donlin Creek in Alaska, and Brewery Creek in the Yukon (Hart et al., 2002).

As part of an ongoing study to characterize the environmental geochemistry of epizonal deposits throughout the TGP, the U.S. Geological Survey, in collaboration with the Yukon Geological Survey, is examining the pre-, syn- and post-mining, geochemistry of ground and surface water at the Donlin Creek, True North and Brewery Creek (Yukon MINFILE 2002, 116B 160, Deklerk, 2002) deposits, respectively. During the 2002 field season, a reconnaissance-level sampling program was undertaken at Brewery Creek. One aim of this work is to create a comprehensive geoenvironmental model that will help decision makers better understand the mobility of potentially toxic metals, such as arsenic, antimony and mercury within the environment surrounding this style of gold mineralization. In addition, these trace element data, as well as stable isotope information, can be evaluated as potential pathfinders for future exploration work across the TGP. In this paper, we present the results from this investigation and interpret these in the context of the deposit, and also provide comparisons with water geochemistry at the undeveloped Donlin Creek deposit and presently producing True North deposit.

GEOLOGIC SETTING AND MINERALIZATION

The Brewery Creek property is located approximately 60 km east of Dawson City in the foothills of the Ogilvie Mountains and along the northeastern boundary of the Tintina Trench (Fig. 1). In this area, the Tintina Fault juxtaposes Proterozoic and Paleozoic rocks of the Selwyn Basin against metamorphic rocks of the Yukon-Tanana Terrane. The dominant lithologies on the property are Paleozoic clastic sedimentary rocks of the Selwyn Basin that are described by Diment, (1996), Diment and Craig (1999), and Lindsay et al. (1999), and are only briefly mentioned below. The stratigraphically lowest unit consists of Cambrian to Upper Devonian Road River Group, which includes tan-weathering, wispy laminated siltstones of the Steel Formation with interbeds of graphitic shale and chert. These rocks overlie massive black chert of the Duo Lake Formation and calcareous andesite flows, tuffs and breccias similar to the Menzie Creek volcanic rocks. A conglomerate unit deposited at the top of the sequence consists of fragments of volcanic rock in a tuffaceous or calcareous matrix. The top of the Road River Group is marked by wispy laminated siltstone. An unconformity separates the Road River Group from the Devono-Mississippian Earn Group that is made up of a heterogeneous package of rocks including shale, black graphitic argillite, greywacke, tuffaceous chert and conglomerate, overlain by a sequence of tuffaceous sandstone and shale. Minor units include limestone and bedded barite. Sills and dykes of quartz-monzonite to syenite, belonging to the mid-Cretaceous Tombstone Plutonic Suite (Diment and Craig, 1999), intrude the deformed and faulted Paleozoic stratigraphy (Fig. 1).

The most important structures in the property area are a series of imbricated, low-angle faults that strike west-northwesterly and dip to the south. These are inferred to be thrust faults (Diment and Craig, 1999; Lindsay et al., 1999, 2000) that subsequently endured left-lateral wrench, then extensional movement. These faults may have served as fluid pathways and thus host the bulk of the mineralization.

Mineralization occurs as numerous ore bodies along a 12-km structural corridor (Fig. 1). Ore bodies consist of pyrite, arsenopyrite, and, to a lesser extent, marcasite within quartz veinlets and disseminated in areas of pervasive silicification, as well as in veins in the more competent sedimentary units (Diment and Craig, 1999). In addition, chalcopyrite, sphalerite, pyrrhotite, and late

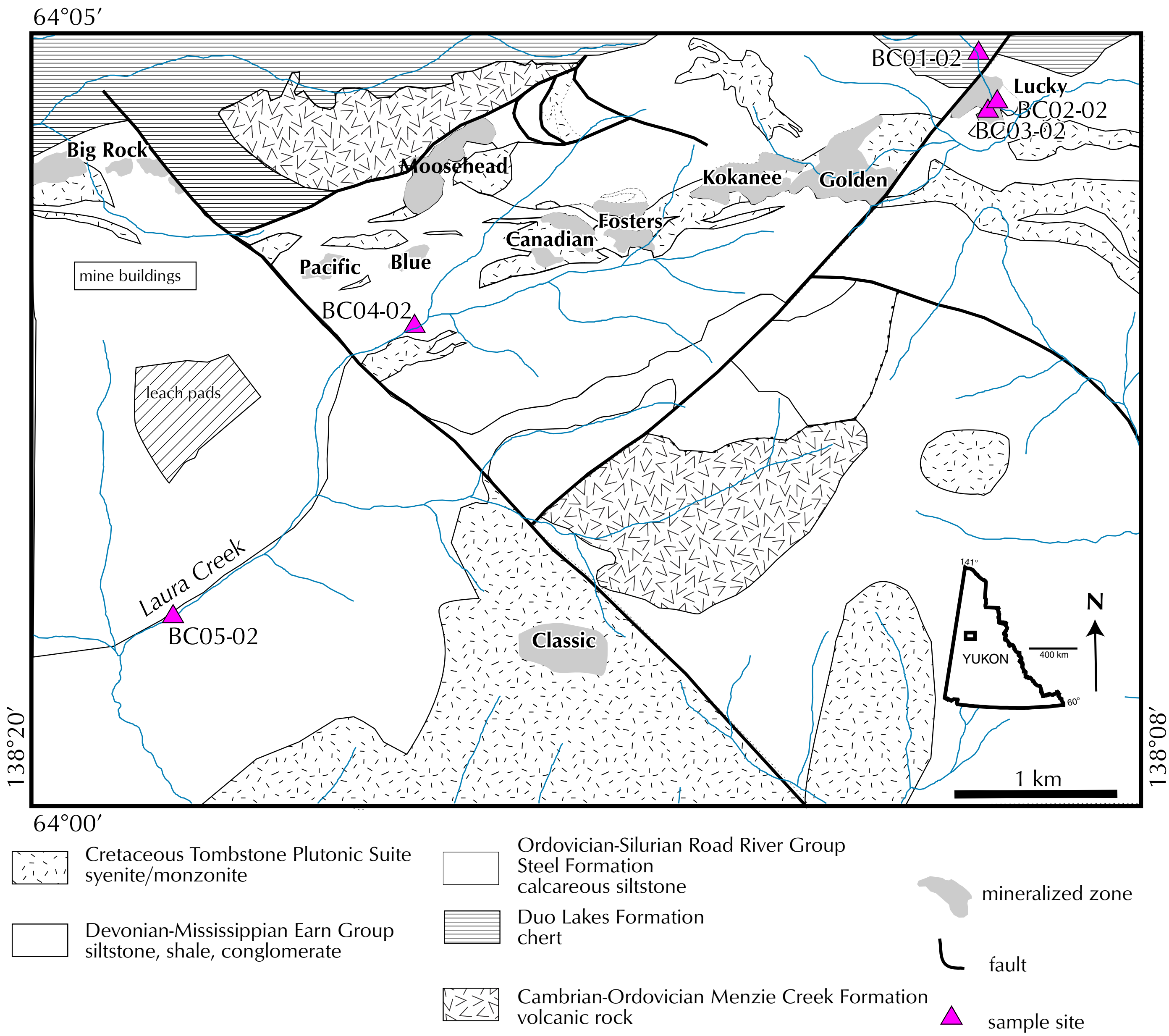

Figure 1. *Location map of the study area showing sampling locations, stream traces, and local geology at the Brewery Creek mine, central Yukon. Modified from Lindsay et al., 2000.*

stage stibnite are present in trace amounts. In hypogene ores, gold occurs as a refractory phase in arsenian pyrite. However, since this area was not glaciated during the most recent ice advance, oxidation locally extends to depths of 100 m below surface. Consequently, the near-surface sulphide minerals have been converted to goethite and scorodite, and gold has been liberated, thus making the ores appropriate for heap leaching (Diment, 1996; Diment and Craig, 1999). Mining of the oxide ores occurred from 1995 to 2002, and recently ceased during a time of low gold prices. The current deposit landscape is a series of open pits, haul roads and trenches.

SAMPLING LOCATION, TECHNIQUE AND ANALYTICAL METHODS

Two seeps and three streams were sampled to define the post-mining water chemistry above and below mined-out ore zones. Sampling locations were carefully chosen so as to best determine changes in water chemistry from just upstream of a mineralized zone (i.e., above the Lucky pit) to within a mineralized zone (i.e., immediately below the Lucky pit and below the Blue Zone), and significantly downstream from the mineralized zones (e.g., downstream of the heap leach facility and pumping facility; Table 1, Fig. 1). Field parameters, including temperature (°C), pH, dissolved oxygen (DO), and specific electrical conductance (SEC), were taken on-site using a hand-held Fisher Accumet™ all-in-one meter with the appropriate probe submerged directly into the flowing water (Fig. 2). Samples of the water were collected using a portable peristaltic pump and flexible, non-reactive, 0.635-cm-diameter tubing. For the filtered samples, a 0.45-micron nitrocellulose canister filter was attached to the delivery end of the tubing. The collected samples include: 1) a 125 ml, filtered (0.45 mm), acidified (pH~2, nitric acid) sample for inductively coupled plasma-mass spectrometry (ICP-MS), and inductively coupled

Figure 2. *Authors sampling at location BC05-02 next to the pump house. In the foreground, pH, DO and SEC measurements are being taken. In the background, the samples are being collected.*

Table 1*. Field number and location description of the sampling sites for this study.*

Field no.	Location description
BC01-02	north-trending tributary above Lucky pit, 1 m wide, maximum depth 20 cm
BC02-02	southeast below Lucky pit, junction of two tributaries, same tributary as BC01-02 but below Lucky pit
BC03-02	southeast below Lucky pit second tributary draining from Lucky pit
BC04-02	Laura Creek below Blue Zone, but not draining pit, below old exploration camp
BC05-02	Lower Laura Creek, below pumphouse, near Earn Group shale outcrop

plasma-atomic emission spectrometry (ICP-AES) analyses; 2) a 125 ml unfiltered, acidified (pH ~2) sample for ICP-MS and ICP-AES analyses; and 3) a 250 ml, unfiltered-unacidified sample for ion chromatography (IC) and alkalinity analyses. The filtered acidified sample was preserved with concentrated nitric acid after filtration, to avoid dissolving suspended particulate matter >0.45 μm in diameter.

Major, minor and trace element analyses included ICP-MS (Lamothe et al., 2002), ICP-AES (Briggs et al., 2002) and IC (Theodorakos, 2002) methods and were performed at the U.S. Geological Survey in Denver, CO, U.S.A. (Table 2). Quality control samples included field blanks, field duplicates, analytical blanks, and analytical blinds, as well as a number of certified water quality standards (Taggart, 2002).

STREAM CHEMISTRY OUTSIDE THE ORE ZONE

Sample BC01-02 was collected from a tributary upstream of the Lucky pit and presumably above any of the mineralized zones. Analysis of this sample was intended to define the background concentrations of dissolved species in natural waters of the area that had not interacted with the hydrothermal mineralization. The water from this background site had a pH of 7.9, was strongly oxidized (DO=8.1), had a relatively high total dissolved load (SEC=403), and was Ca and HCO_3^- dominated. It had a characteristic major element/anion composition of Ca>Mg>Na≥K and $HCO_3^- > SO_4^{2-} > NO_3^- > Cl^- \geq F^-$ (Table 2). Dissolved and total concentrations, respectively, were 53 and 58 mg/L Ca and 20 and

Table 2. *Field number, location (latitude/longitude in decimal degrees[1]), field parameters, and selected analyses of the five water samples taken for this study.*

Field no.	BC01-02		BC02-02		BC03-02		BC04-02		BC05-02	
Date	07/19/02		07/19/02		07/19/02		07/19/02		07/19/02	
Latitude	64.066667		64.05		64.05		64.033333		64.016667	
Longitude	-138.1667		-138.167		-138.167		-138.25		-138.283	
T (°C)	2.7		4.8		2.6		4.8		5.4	
pH	7.9		8.2		7.6		8		8.2	
DO (mg/L)	8.1		10.9		10.2		11.5		11.9	
SEC (μS/cm)	403		450		686		478		420	
FILTRATION	filtered	unfiltered	filtered	unfiltered	filtered	unfiltered	filtered	unfiltered	filtered	unfiltered
Concentration (mg/L)	**dissolved**	**total**	**dissolved**	**total**	**dissolved**	**total**	**dissolved**	**total**	**dissolved**	**total**
Ca	53	58	61	65	84	62	38	49	56	61
Mg	20	21	22	24	36	27	14	17	20	22
Na	0.94	0.72	0.89	1.1	1.2	0.91	0.95	1.2	2.3	2.7
K	0.65	0.61	0.74	0.97	1.2	0.94	0.98	1.4	1.2	1.3
Fe	0.03	0.03	<0.02	0.18	<0.02	0.025	0.051	9.6	0.1	0.21
SiO_2	6.8	6.6	6.6	7.3	6.0	3.9	4.5	18.0	9.0	8.8
HCO_3^-	181		192		182		169		156	
SO_4^{2-}	63		81		200		85		90	
NO_3^-	2.1		2.4		9.3		0.6		0.5	
PO_4	< 0.01		0.06		< 0.01		0.12		0.09	
Cl^-	0.2		0.3		0.2		0.5		0.3	
F^-	0.2		0.2		0.3		0.2		0.2	
(μg/L)										
Al	3.2	17	2.3	56	1.5	9.7	16	3800	28	49
As	2	2	18	26	10	8.2	3	47	3	3
Ba	61	63	79	106	46	39	52	456	63	74
Bi	< 0.05	< 0.005	< 0.05	< 0.005	< 0.05	0.007	0.1	< 0.005	< 0.05	< 0.005
Cd	< 0.02	< 0.02	0.02	0.06	0.03	0.02	0.09	2.2	0.04	0.04
Co	0.08	0.06	0.05	0.12	0.07	0.06	0.18	7.1	0.18	0.22
Cr	1.3	< 1	5.9	< 1	< 1	< 1	4.7	7.1	6.3	< 1
Cu	< 0.5	0.54	0.71	1.1	< 0.5	< 0.5	1.5	17	1.5	1.8
Li	2.4	2.9	1.4	2.5	2.9	4.1	4	10	8	11
Mn	21	23	0.6	8.1	0.8	2.2	40	880	27	31
Mo	0.45	0.66	3.3	3.1	0.77	0.79	1.3	0.86	2.3	2.8
Ni	1.6	1.2	1.1	1.9	2.9	2	2.4	26	2.8	3
Pb	< 0.05	< 0.05	< 0.05	0.7	< 0.05	0.2	0.1	8.9	< 0.05	< 0.05
Sb	0.31	0.47	18	21	19	12	16	17	9.2	9.9
Se	4.1	3.3	3	2.3	6.8	3.6	1.9	2.5	1.8	1.7
Sr	210	240	258	338	402	357	192	302	256	319
Ti	0.6	0.9	0.6	2.1	1.7	1.6	0.5	25	0.9	2.4
U	0.55	0.53	1.2	1.2	2.3	1.6	1.35	2.4	1.7	1.7
V	0.5	0.2	1.9	0.4	0.2	< 0.1	1.5	22	2.2	0.6
W	0.24	0.09	0.2	0.1	0.38	0.22	0.08	0.05	0.2	0.07
Zn	0.6	0.6	0.6	2.2	2	1	24	128	2	3.1

[1]GRS 1886, NAD 27

DO=dissolved oxygen

SEC=specific electrical conductance

21 mg/L Mg; the concentrations of anions were 181 mg/L HCO_3^- and 63 mg/L SO_4^{2-} (Table 2).

Trace elements characteristic of epizonal gold deposits (e.g., Brewery Creek) that are of environmental and exploration interest include arsenic, copper, mercury, lead, antimony and zinc. Mercury concentrations were not determined during this preliminary study because an additional sample, with special preservation requirements, would have been necessary. However, the dissolved concentrations of arsenic, copper, nickel, lead, antimony and zinc were determined as 2 μg/L, <0.5 μg/L, 1.6 μg/L, <0.05 μg/L, 0.31 μg/L and 0.6 μg/L, respectively. Total concentrations of these elements were only slightly higher by, on average, <10%. Minor elements of interest, including aluminum, iron and manganese were determined because they may represent sources and sinks of trace metals associated with the mineralization in the form of colloidal oxides and hydroxides ($AlOH_3$, FeOOH, MnOOH). These have the potential to sorb or release trace metals into the environment with changes in the pH and oxidation/reduction potential of the ground and surface water. The background dissolved concentrations of aluminum, iron and manganese were 3.2 μg/L, 0.03 mg/L and 21 μg/L, respectively, and the total concentrations were the same or slightly higher at 17 μg/L, 0.03 mg/L and 23 μg/L respectively (Table 2).

SEEP AND STREAM CHEMISTRY WITHIN THE ORE ZONE

Two samples were collected from flow emanating from the bottom of the Lucky pit. Sample BC02-02 was taken along the same stream as sample BC01-02, about 300 m downstream from the background sample site, beyond where the stream re-emerged from beneath excavated pit rocks. Sample BC03-02 was taken from a small seep less than a metre away from BC02-02, which was flowing from eroded and mined overburden along one of the side walls of the main stream.

Significant changes occur in the water chemistry over the short distance between sites BC01-02 and BC02-02. Most notable are an increase in the dissolved and total concentrations of arsenic and antimony. Prior to entering the mineralized zone of the Lucky pit, the stream water was observed to have dissolved and total arsenic concentrations below detection limits (< 3 μg/L) and dissolved and total antimony concentrations of < 1 μg/L (Table 2). However, after interaction with mineralized regolith removed from the Lucky pit, and presumably mineralized rock within the Lucky pit itself, the stream water showed an increase in both dissolved (As_{diss}) and total arsenic (and As_T) and antimony (Sb_{diss} and Sb_T) concentrations. As_{diss} increased to 18 μg/L and As_T increased to 26 μg/L, with Sb_{diss} and Sb_T in sample BC02-02 increasing to 18 and 21 μg/L, respectively. Dissolved iron and aluminum concentrations remained at background levels, but the total iron and aluminum concentrations increased to 0.18 mg/L and 56 μg/L respectively. Surprisingly, the dissolved and total manganese concentrations decreased significantly (Mn_{diss}=0.6 μg/L and Mn_T=8.1 μg/L) after the waters had interacted with the mineralized rock. In contrast, the major element/anion abundances, pH, DO, and SEC remained relatively unchanged, differing by <10% from the upstream background values.

Sample BC03-02 also showed elevated trace element concentrations (As_{diss}=10 μg/L, As_T=8.2 μg/L and Sb_{diss}=19 μg/L, Sb_T=12 μg/L). Dissolved and total aluminum and iron concentrations are low and similar to those of BC01-02. Dissolved and total manganese concentrations are similar to those of BC02-02 (Table 2). However, the pH (7.6) is significantly lower than all other samples, the SEC (686 μS/cm) is the highest measured during the study, and the dominant anion is SO_4^{2-} (200 mg/L), rather than HCO_3^-. These differences reflect the smaller discharge from the seep below the pit that has interacted extensively with the mineralized material in the channel walls.

Sample BC04-02 collected in Laura Creek, and taken below the Blue Zone, also shows evidence of interactions with mineralized rock as indicated by elevated arsenic and antimony concentrations (As_{diss}=3 μg/L, As_T=47 μg/L and Sb_{diss}=16 μg/L, Sb_T=17 μg/L). In addition to the arsenic and antimony, sample BC04-02 also shows increased copper, nickel, lead and zinc concentrations (Cu_{diss}=1.5 μg/L, Cu_T=17 μg/L; Ni_{diss}=2.4μg/L, Ni_T=26 μg/L; Pb_{diss}=0.1 μg/L, Pb_T=8.9 μg/L; and Zn_{diss}=24 μg/L, Zn_T=128 μg/L) suggesting, not only interaction with arsenic- and antimony-bearing sulphide and oxide minerals, but also minor base metal sulphide minerals that are sometimes recognized in the ore zones. Furthermore, both total and dissolved aluminum, iron and manganese (Al_{diss}=16 μg/L, Al_T=3800 μg/L; Fe_{diss}=0.051 mg/L, Fe_T=9.6 mg/L; Mn_{diss}=40 μg/L, Mn_T=880 μg/L) concentrations are the highest among all samples in this study.

Given the relatively high DO concentration of all the water samples, the most probable mechanisms controlling the mobility of arsenic and antimony is the oxidation of the primary sulphide minerals (i.e., arsenopyrite and stibnite), or the dissolution of their secondary weathering products (i.e., scorodite and stibiconite). Studies have shown that at neutral to alkaline pH, the oxidation of arsenopyrite can lead to substantial dissolved arsenic concentrations (> 1 mg/L; Craw et al., 2003). The amount of arsenic entering into solution is limited by the formation of iron-oxide coatings on the arsenopyrite grains and thus the amount of arsenic actually released can be orders of magnitude less than predicted by equilibrium values (<0.1 mg/L; Smedley and Kinniburgh, 2002; Craw et al., 2003). Furthermore, given that the ore bodies may be oxidized to depths of several tens, if not up to 100 m depth, it is likely that the dissolution of scorodite, which is not stable at high pH is the source of the arsenic in the groundwater (Krause and Ettle, 1988; Vink, 1996). During both oxidation of arsenopyrite and dissolution of scorodite, acidity is produced. However, as supported by the pH measurements (Table 2), there appears to be ample buffering capacity within the Brewery Creek deposit. Mapping and Portable Infrared Mineral Analyser (PIMA) studies by Viceroy Resources recognized an ankeritic alteration halo to the mineralized rock which has contributed to this buffering. Similarly, the oxidation of stibnite, or dissolution of stibiconite, is the most likely source for the elevated dissolved antimony concentrations (Filella et al., 2002).

STREAM CHEMISTRY DOWNSTREAM OF THE ORE ZONE

Sample BC05-02 was taken from lower Laura Creek, near the location of the pump house, downstream of the heap leach facility (Figs. 1 and 2) and 2 km downstream from the recognized mineralized rock and site BC04-02. This site is interpreted to include the surface water that has flowed through the bulk of the ore zones to the north and possibly through non-mineralized bedrock on the southern side of the deposit, and is consequently diluted within the larger Laura Creek (Fig 1). Arsenic concentrations have been diluted from elevated levels at BC04-02 to near detection limits (3 μg/L) in the surface waters at site BC05-02. Total and dissolved copper, lead, nickel and zinc concentrations are also only slightly enriched or at background levels. The major elements and anions, pH, DO, and SEC are all similar to the observed values at site BC01-02. In contrast, dissolved and total antimony have stayed relatively high (Sb_{diss}=9.2 μg/L and Sb_T=9.9 μg/L). The total and dissolved aluminum, iron and manganese concentrations are still elevated compared to those at BC01-02, although diluted to only about 50% of their concentrations in the mineralized zones (samples BC02-02, BC03-02 and BC04-02, Table 2).

The increase in the mineralized zone, and subsequent downstream decrease in concentrations of aluminum, iron and manganese, play an important role in the sequestration of most trace metals (arsenic, copper, zinc). This is due to the formation of iron, aluminum and manganese hydroxides which, in oxidizing conditions, create colloids that adsorb the trace metals and precipitate out of the water column (Driehaus et al., 1995; Manning and Goldberg, 1997; Raven et al., 1998; Smedley and Kinniburgh, 2002). The persistence of elevated dissolved antimony in waters away from the mineralized zone can likely be explained by the fact that antimony can form potentially non-reactive anionic species ($Sb(OH)^{6-}$) and remain in solution (Vink, 1996; Filella et al., 2002). In contrast, arsenic concentrations decrease rapidly downstream because iron, manganese, and possibly aluminum hydroxides adsorbed/absorbed the arsenic onto/into their structure and precipitated out of solution.

COMPARISON TO OTHER TGP EPIZONAL DEPOSITS

A comparison of the arsenic and antimony concentrations in surface and subsurface waters from Brewery Creek with similar style epizonal deposits at the True North and Donlin Creek deposits, although in different stages of development, shows that the arsenic-antimony hydrogeochemical signature characterizes the waters draining all of these systems (Table 3; Mueller et al., in press). The arsenic concentrations in water within the mineralized zones, regardless of stage of development, average 29 μg/L for all three deposits, and the total antimony concentration in the same areas average 9.3 μg/L (Table 3). Outside of the deposit, both arsenic and antimony concentrations drop off to normal background concentrations of 2.7 and 0.204 μg/L respectively at Donlin Creek, and 2.5 and 5.1 μg/L at Brewery Creek (Table 3).

Table 3. *Comparison of the minimum, maximum, and average total arsenic and antimony concentrations within and outside of the Brewery Creek (post-development), True North (in development), and Donlin Creek (pre-development) epizonal gold deposits.*

		Concentration within mineralized zone (μg/L)[1]				Concentration outside of mineralized zone (μg/L)[2]			
Deposit	**Element**	minimum	maximum	average	n	minimum	maximum	average	n
Donlin Creek	As	<3	274	33	15	<1	4.7	2.7	13
	Sb	<0.1	4.5	1.5		<0.1	0.35	0.204	
*True North[3]	As	17	42	26	6				
	Sb	2.5	20	9.5					
Brewery Creek	As	8.2	47	27	3	2	3	2.5	2
	Sb	12	21	17		0.47	9.9	5.1	
Donlin Creek, True North, Brewery Creek	As			29	24			2.6	15
	Sb			9.3				2.7	

[1]samples taken within resource area or mapped mineralization
[2]samples take outside of known mineralized area
[3]all streams sampled in the vicinity of True North emanate from the mineralized area, therefore there is no outside information available
*True North data is part of a larger unpublished dataset

CONCLUSIONS AND FUTURE WORK

Preliminary reconnaissance studies of the current background hydrogeochemistry of the post-mining environment at the Brewery Creek mine reveal:

- The natural streams and seeps outside of known mineralization and within the mineralized area are naturally alkaline (pH 7.6-8.2) $Ca\text{-}HCO_3^-$ to $Ca\text{-}SO_4^{2-}$ type waters;
- Elevated arsenic, copper, antimony and zinc concentrations are the result of either oxidation of primary sulphide minerals, or the dissolution of secondary oxidation products, with no net acidification, likely due to buffering by host rocks;
- The production of aluminum, iron and manganese hydroxides during oxidation or dissolution of primary sulphide minerals or secondary minerals may sequester the trace metals arsenic, copper and zinc, effectively reducing their mobility;
- Antimony appears to remain in solution, despite the presence of possible sorbents (Al-, Fe-, Mn- hydroxides) most likely as a consequence of the high pH and oxidizing conditions of the surface water;
- The post-mining hydrogeochemical signatures at Brewery Creek are similar to both undeveloped Donlin Creek and the developing True North deposits in Alaska, showing that low-level concentrations of As, Sb and other metals are naturally typical of waters draining these epizonal deposits, regardless of whether they are developed or not.

At the time of writing, sulphur isotope analyses on aqueous sulphate are currently being performed in order to determine whether a distinct sulphur isotope signature for the gold-bearing sulphide minerals can be detected, in the hope that this will provide another exploration tool with which to prospect for additional epizonal deposits in the Tintina Gold Province. Further study of trace element arsenic, antimony and mercury (As, Sb, and Hg) mobility in the surface environments at these deposits will contribute to the development of a geoenvironmental model useful for the exploration and development of these deposits in the future.

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Geology and structural setting of the Regal Ridge emerald property, Finlayson Lake district, southeastern Yukon

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ABSTRACT

Emerald at the Regal Ridge property in the Finlayson Lake district of southeastern Yukon is hosted within mid-Paleozoic mafic metavolcanic and metaplutonic rocks. These rocks overlie the shallowly dipping western edge of a 112 Ma quartz monzonite body, and aplite dykes associated with the intrusion locally contain beryl. Beryl-bearing aplites chemically differ from non-mineralized intrusions by having lower potassium and fluorine, and higher beryllium contents. The main host rocks for the mineralization are high-calcium boninites (high-magnesium basalt to andesite) with anomalously high chromium contents. Beryl occurs either within quartz-tourmaline veins or in highly altered schist zones adjacent to the veins. Several generations of syn- to late-tectonic quartz veins are present at Regal Ridge, and emerald appears to be mainly associated with the latest vein set, especially near the intersection between these and older veins. All of the quartz veining is thought to be related to progressive Cretaceous deformation and the relatively late emplacement of the quartz monzonite intrusions.

RÉSUMÉ

L'émeraude dans la propriété de Regal Ridge du disctrict de Finlayson Lake dans le sud-est du Yukon est encaissée dans des roches métavolcaniques et métaplutoniques mafiques du Paléozoïque moyen. Ces roches reposent sur un massif de monzonite quartzique de 112 Ma à faible pendage vers l'ouest, et les dykes d'aplite associés à l'intrusion renferment ici et là du béryl. Les aplites à béryl diffèrent par leur composition chimique des intrusions non minéralisées : elles ont une teneur plus faible en potassium et en fluor mais plus élevée en béryllium. Les principales roches encaissantes pour la minéralisation sont des boninites à haute teneur en calcium (basalte à andésite à haute teneur en magnésium) dont les teneurs en chrome sont atypiquement élevées. Le béryl est présent soit dans des filons de quartz-tourmaline ou dans les zones schisteuses altérées jouxtant les filons. Plusieurs générations de filons de quartz syntectoniques à tarditectoniques sont présents dans la propriété de Regal Ridge et l'émeraude semble principalement associée aux filons les plus tardifs, en particulier près de l'intersection entre ces filons et les plus anciens. Tous les filons de quartz serait liés à une déformation progressive au Crétacé et à la mise en place relativement tardive d'intrusions de monzonite quartzique.

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INTRODUCTION

The Regal Ridge property is 100% owned by True North Gems, Inc. It is located in the Finlayson Lake district of southeastern Yukon within the Pelly Mountains. The property consists of 93 quartz mining claims covering a total of 18 km^2, centred at 61°16.6' north latitude, 133°5.5' west latitude on NTS map sheet 105G/7 (Fig. 1).

This paper reports on new field work by the authors during 2003. Our three-week program focussed on producing a detailed (1:2500 scale) geological map of the

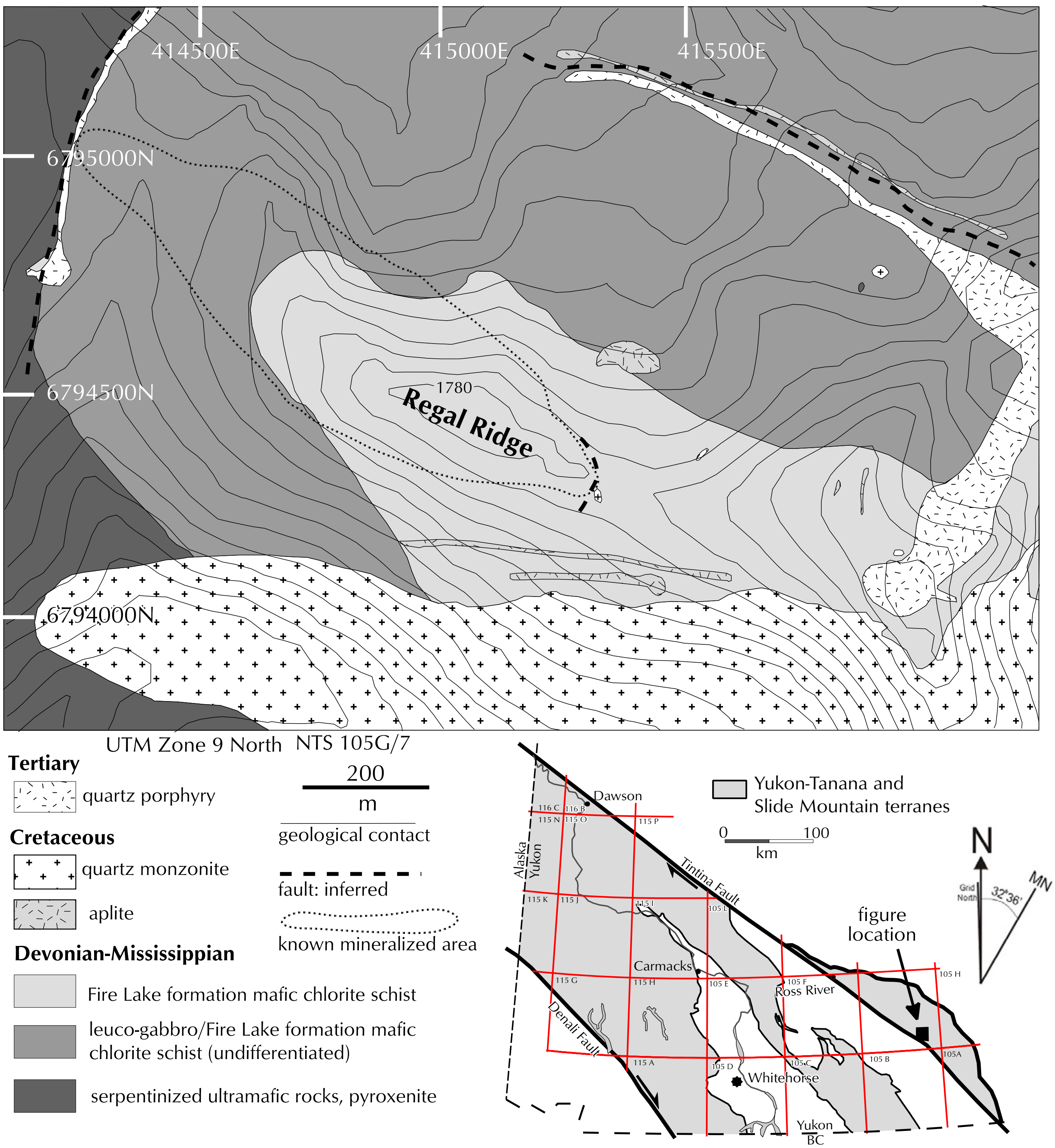

__Figure 1.__ Geological map of the Regal Ridge property. Location map modified from Murphy, this volume. Contour interval = 20 m.

Regal Ridge property. We also carried out structural studies to better understand the structural evolution of the area and possible structural controls on the localization of emerald mineralization.

PROPERTY EXPLORATION HISTORY

Chevron Canada first explored the area from 1978 to 1980, carrying out a regional stream sediment sampling and prospecting program on the Howdee claims, 1 km southwest of the Regal Ridge property (Yukon MINFILE 2002, 105G 147, Deklerk, 2002).

With the discovery of the Kudz Ze Kayah volcanogenic massive sulphide (VMS) deposit in the early 1990s, the Finlayson Lake district saw renewed exploration interest. Expatriate Resources carried out exploration targeting VMS mineralization on the Goal claims (claims now including Regal Ridge) in 1995 and 1996, with a program involving geological mapping, prospecting, soil sampling and hand trenching.

While prospecting for Expatriate Resources in September, 1998, geologist W. Wengynowski discovered a showing of green beryl and emerald on Expatriate's GoalNet property (Goal claims). Detailed work on the property began in July, 1999; by late August, numerous green beryl- and emerald-bearing float trains and six main sources had been discovered in a 900 by 400 m area on both sides of the ridge (Groat et al., 2002).

In mid-2001, True North Gems, Inc. entered into an option agreement with Expatriate Resources Ltd. to acquire a 50% interest in the property. True North carried out an evaluation program in 2001, trench mapping and sampling over the property. In March of 2002, True North purchased Expatriate's remaining 50% interest in the Regal Ridge property. Later that year they carried out more extensive fieldwork, consisting of a small drilling program which resulted in the discovery of new mineralized zones. A small processing mill was also constructed.

Results of reconnaissance investigations of the geology and emerald occurrences of Regal Ridge carried out by the authors during the 2002 field season were summarized in Neufeld et al. (2003).

REGIONAL GEOLOGY

The Regal Ridge area is located within Yukon-Tanana Terrane (Fig. 1). Rocks in this area are composed of mainly pre-Late Devonian quartz-rich metaclastic rocks and carbonates and Late Devonian and Mississippian meta-volcanic and -plutonic rocks which are inferred to have formed in continental magmatic arc (Mortensen and Jilson, 1985; Mortensen, 1992; Murphy, 1998; Murphy and Piercey, 2000) and back-arc settings (Piercey et al., 2000a,b). The oldest rocks are in the pre-Late Devonian to earliest Mississippian Grass Lakes succession. The Fire Lake unit, a mafic meta-volcanic unit composed mainly of chloritic phyllite (Murphy et al., 2002), is the second-oldest unit within the Grass Lakes succession. The Kudz Ze Kayah unit in the footwall of the Money Creek thrust stratigraphically overlies the Fire Lake unit; and the Wolverine succession unconformably overlies the Kudz Ze Kayah unit (Piercey et al., 2001). The rocks were thrust onto the North American miogeocline between Late Triassic and earliest Cretaceous time.

All rocks are intruded by several ca. 112 Ma quartz-monzonite to granite intrusions of the Cassiar-Anvil suite. In the Finlayson Lake district these Cretaceous intrusions form a 25-km-long northerly trend, with the Regal Ridge property located at the approximate mid-point. The intrusions are late- to post-kinematic with respect to the main Cretaceous deformation, which in this area was orogen-parallel, with a northwest rather than northeast transport direction (D. Murphy, pers. comm., 2003).

The Tintina Fault lies 14 km southwest of the Regal Ridge property, and possibly related faults run through the Finlayson Lake district.

PROPERTY GEOLOGY

The main host rock for the emerald-bearing veins at Regal Ridge is green-grey chlorite-plagioclase schist that locally contains biotite and actinolite porphyroblasts. This schist forms part of the Upper Devonian Fire Lake mafic metavolcanic unit (Fig. 1; unit DF of Murphy et al., 2002). At Regal Ridge, this rock is invariably foliated and lineated, and in some areas has a waxy phyllitic texture. Despite the pervasive deformation that the unit has experienced, some quartz amygdules are still locally recognizable. Piercey et al. (1999) have shown that unit DF regionally consists of rocks with geochemical signatures ranging from boninites (high-magnesium andesite to basalt) through island arc tholeites, calc-alkaline and non-arc volcanic rocks. Geochemical analyses of the Regal Ridge mafic schist all fall in the range of high-Ca boninites (high-magnesium basalt to andesite; Fig. 2). The mafic schists on Regal Ridge have anomalously high chromium contents

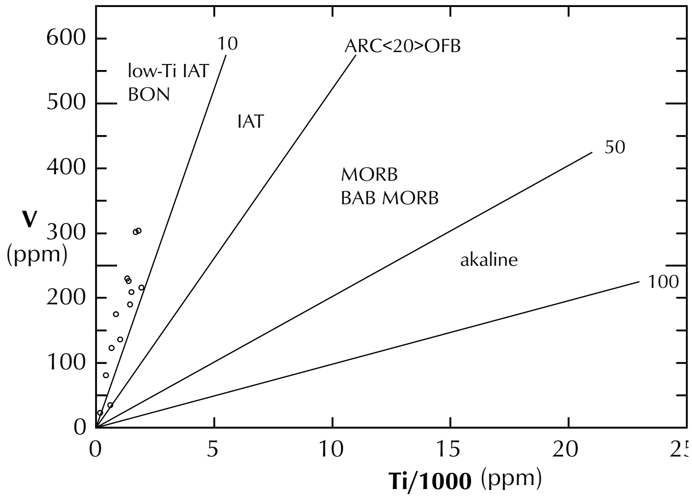

Figure 2. *Vanadium versus titanium/1000 diagram of mafic chlorite schist at Regal Ridge. The schist plots as low-titanium boninite, a high-magnesium andesite-basalt. Modified from Shervais (1982). Abbreviations: BON – boninite; IAT – island arc tholeite; MORB – mid-ocean-ridge basalt; BAB – back-arc basin; ARC – arc basalt; OFB – ocean floor basalt.*

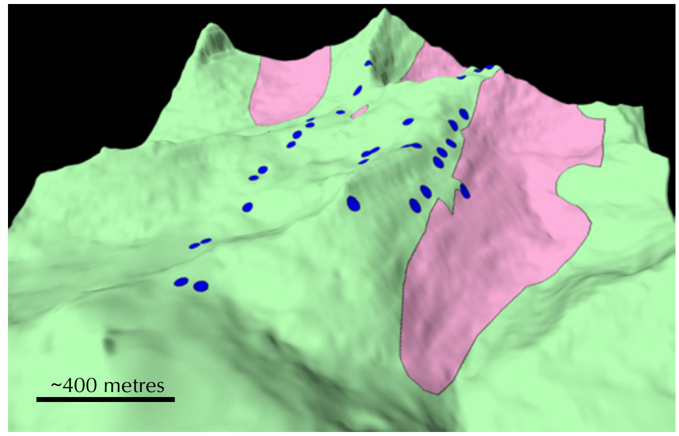

Figure 3. *Three-dimensional map looking to the east over the Regal Ridge property, showing the quartz monzonite intrusion (the darker grey) and location of aplite dykes (black circles). The mineralized area sits on the ridge, above and between protruding 'fingers' of the quartz monzonite's western edge.*

(average 960 ppm Cr), and these local host rocks are likely the source of chromium necessary for the emerald chromophore.

A biotite-actinolite-plagioclase leuco-gabbro unit (correlated with unit Dmi of Murphy et al. 2002) is closely interfingered with the mafic schist and could not be mapped separately at the scale of our mapping (Fig. 1). In hand sample, the leuco-gabbro is distinctly mottled green and white in colour, with millimetre-scale actinolite and plagioclase crystals causing the mottled texture. It is a more competent rock than the chlorite schist and is generally less altered by quartz veining.

The irregular contacts between the two units likely reflect primary interlayering (the leuco-gabbro forming synvolcanic feeder dykes and/or sills to the Fire Lake unit volcanic rocks) which has been further complicated by subsequent transposition of the original contacts.

Brown-weathering, dark green to black, variably serpentinized ultramafic rocks occur in the western and northern parts of the map area (Fig. 1). Murphy et al. (2002) suggest that the ultramafic bodies represent intrusive sills that fed the overlying Fire Lake volcanic rocks (DF) via gabbroic dykes (Dmi). Alteration of the ultramafic rocks where they are cross-cut by younger aplitic dykes and sills is highly variable, and much less extensive than that seen in the mafic schist or leuco-gabbro units. This suggests there was a more limited interaction between the host rock and the felsic magma and associated fluids. This unit has not yet been found to host emerald-bearing quartz veins.

The pluton proximal to the Regal Ridge emerald occurrence is part of the Anvil Plutonic Suite (Mortensen et al., 2000), a 112-100 Ma suite of felsic intrusions which regionally are associated with numerous tungsten, molybdenum, gold and bismuth occurrences. The 112 Ma two-mica (biotite>muscovite) quartz monzonite extends to the east of Regal Ridge, as well as far to the north and south. It is weakly foliated to unfoliated, with shallowly dipping contacts. Regal Ridge is situated above the shallowly dipping western margin of the intrusion (Fig. 3). Mapping during the 2003 field season confirmed that the mafic host rocks for emerald mineralization at Regal Ridge are underlain by Cretaceous quartz monzonite at a relatively shallow depth (approximately 800 metres) and the emerald occurrence is considerably closer to a granite body than was previously inferred by Groat et al. (2002).

Numerous aplite dykes from 40 cm to 10 m in width are present on the property. These bodies are variably strained, ranging from massive and essentially undeformed, to strongly deformed in places. The extent of hydrothermal alteration surrounding the dykes is also highly variable.

STRUCTURAL SETTING

The Fire Lake mafic metavolcanic formation was initially deformed in the early Mississippian, at ca. 360 Ma, shortly after the unit was deposited (Murphy and Piercey, 2000). This early deformation resulted in contraction and folding, and the formation of foliation-parallel, centimetre-scale, non-mineralized quartz veins. Most of this mid-Paleozoic deformation was overprinted by deformation during Cretaceous time.

In the Early Cretaceous, rocks at Regal Ridge were subjected to non-coaxial, simple shearing as a result of major contraction related to northwest-verging, Cordillera-wide orogen-parallel deformation (D. Murphy, pers. comm., 2003). Foliation related to this deformation is generally west-northwest striking in the Regal Ridge area and dips shallowly to the north. Quartz veins were formed and deformed during the progressive movement of the shear system. This resulted in considerable variability in the amount of deformation of individual veins or portions of veins depending on their orientation within the shear system and the time when they were introduced to the system. The oldest veins in the system are typically isoclinally folded and boudinaged, whereas the youngest veins are generally planar or slightly folded. Emplacement of the large quartz monzonite body to the southeast, and subsequent intrusion of aplite dykes, appears to have coincided with a re-orientation of the shear system and the development of a new generation of veins within the system. This is shown by the presence of at least two directions of lineations that are thought to have developed within the shear system and two directions of boudinage exhibited by the most strongly deformed veins. Brittle-ductile shearing outlasted intrusion of the granite and aplite bodies, since strong ductile shear zones are present within some of the aplite dykes.

Most of the quartz veining observed at Regal Ridge is thought to be related to progressive Cretaceous deformation and the relatively late-tectonic emplacement of the quartz monzonite intrusions.

Late-stage, brittle deformation, in the form of thrust and strike-slip faults and rusty-weathering alteration zones, cross-cuts much of the earlier deformation observed on the property. This deformation could be associated with regional deformation related to movement along the Tintina Fault and emplacement of Eocene dykes and sills. These dykes and brittle faults appear to follow the same zones of weakness which were exploited by the aplite bodies.

MINERALIZATION AND DISCUSSION

Twelve mineralized zones have been found thus far at Regal Ridge, within a 900- by 450-m area.

Quartz veins are abundant throughout the property, and by far the majority of them appear to be related to Cretaceous deformation. Early veins are typically relatively thin, foliation-parallel, relatively sulphide-rich, and contain no tourmaline. All of the other quartz veins, including those that contain beryl and emerald, are associated with at least some amount of tourmaline, either within the veins themselves or in the immediate vein selvages. The younger veins are at least 10 cm wide, except where they have been boudinaged. The degree of alteration surrounding the veins varies from almost no evident alteration, to metre-wide horizons of soft, rusty-weathering, jarosite-rich schist. This rustiness is likely due to weathering of finely disseminated sulphide minerals (especially pyrrhotite) that is commonly present in the alteration envelopes on the veins. Emerald is found associated with veins of several different orientations. Mineralization appears to be particularly well developed in the area of intersection between the youngest generation of veins and older, more deformed veins. Emeralds occur along the margins of quartz veins in highly altered schist, as well as within the quartz veins themselves. The mineralizing event is therefore interpreted to have occurred over a considerable period of time, but was mainly syn- to late-tectonic, coinciding with the waning stages of quartz monzonite intrusion. Crack-seal textures are present locally within some of the quartz veins, with tourmaline filling the cracks. Late ductile deformation has also affected some of the emerald-bearing veins, as evidenced by the presence of fractures healed by emerald and micro-boudinage of tourmaline grains within vein quartz.

Most aplites are spatially associated with abundant quartz veins which either cut the aplite bodies themselves or the schists immediately adjacent to the aplites. Some of these veins locally contain emerald. At least two of the aplite dykes locally contain beryl or emerald, which confirms the authors' hypothesis that there is a continuum from the

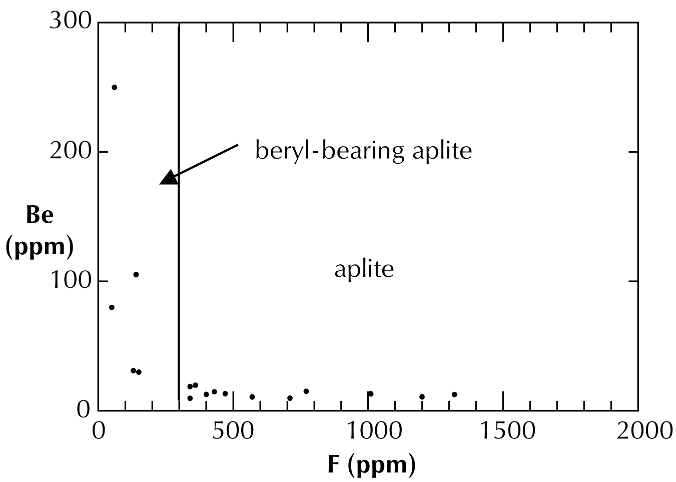

Figure 4. Beryllium versus fluorine diagram for all Regal Ridge aplite dykes. Beryl- and emerald-bearing aplite dykes have much lower fluorine contents than aplite dykes that do not contain beryl.

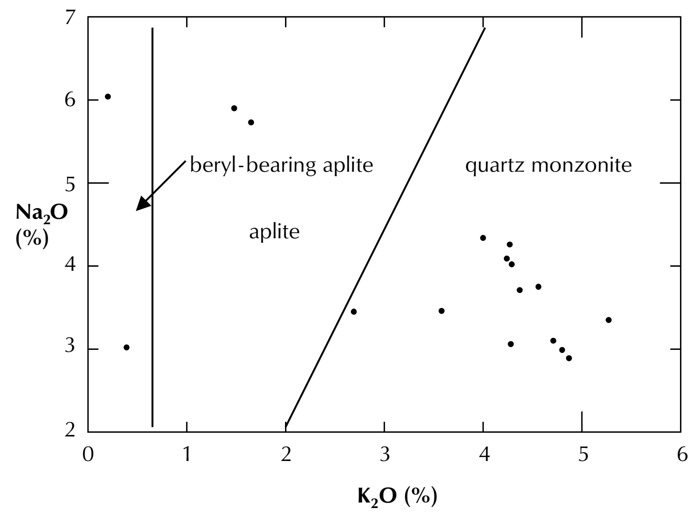

Figure 5. Sodium- versus potassium-oxide diagram for all Regal Ridge intrusive rocks. The potassium content of beryl- and emerald-bearing aplite dykes is lower than that of non-mineralized aplite dykes. The main intrusive body has the highest potassium content.

quartz monzonite intrusion through aplite dykes to beryl-bearing quartz veins (Neufeld et al., 2003).

Beryl-bearing aplite dykes chemically differ from non-mineralized intrusions (both aplite dykes and the main quartz monzonite body) by having lower potassium and fluorine and higher beryllium contents (Figures 4 and 5). This may provide a useful geochemical method for identifying intrusive phases elsewhere in the region that have a higher potential for being associated with emerald mineralization. The low fluorine values are surprising, however, since we hypothesize that the beryllium was transported within intrusion-derived fluids as a fluorine complex. Since an effort was made to avoid actual beryl mineralization when sampling (in order to avoid a nugget-effect chemical anomaly), it is possible that fluorine that is contained as fluorite inclusions within beryl grains was also missed. This hypothesis assumes that fluorine is intimately related to beryllium in the beryl-forming process, and only separates at the site of beryl crystallization, leaving the remainder of the intrusion relatively depleted in fluorine. However, this could alternately indicate that beryllium was transported also as a hydroxy and/or chloride complex, although there is little evidence for the latter.

CONCLUSIONS

This most recent work has resulted in a number of important findings, as listed below:

1. The discovery of emerald and beryl mineralization in the aplite dykes is more evidence for a genetic link between the quartz monzonite pluton and the emerald-bearing quartz veins.
2. The granite underlies the deposit at an estimated depth of 800 m, with depth increasing to the west-northwest.
3. The timing of deformation relative to mineralization is now understood. In particular, mineralization was syn- to late-tectonic, coinciding with the waning stages of quartz monzonite emplacement.

ACKNOWLEDGEMENTS

This work results from field work that was funded by the National Sciences and Engineering Research Council (NSERC), True North Gems, Inc., and the Yukon Geological Survey (YGS). The authors thank Don Murphy (YGS) for visiting the property for a few days and invaluably contributing to the understanding of the structural setting of the mineralization. We also thank Josh Neufeld for his assistance in the field.

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Early Jurassic porphyry(?) copper (-gold) deposits at Minto and Williams Creek, Carmacks Copper Belt, western Yukon

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ABSTRACT

The Minto and Williams Creek copper (-gold) deposits in western Yukon are hosted by variably deformed Early Jurassic (198-197 Ma; U-Pb) plutonic rocks and to a lesser extent strongly metamorphosed supracrustal rocks. These rocks are pendants and schlieren within slightly younger (197 Ma; U-Pb), intermediate-composition intrusive phases of the Granite Batholith. Chalcopyrite and bornite are disseminated and also occur as stringers in these rocks. Alteration muscovite associated with late quartz-feldspar-epidote veins gives a 182 Ma Ar-Ar age. Geobarometry on post-mineral intrusive phases in the area indicate that they were emplaced at a depth of >9 km. Hornblende geochemical studies of plutonic and meta-plutonic host rocks at Minto and Williams Creek indicate that they formed in a continental magmatic arc setting. Cu/Au ratios and field observations indicate that supergene mobility of copper was more extensive at Williams Creek than at Minto. Our results indicate that the two deposits represent variations on typical copper (-gold) porphyry deposits.

RÉSUMÉ

Les gisements de Cu (-Au) de Minto et de Williams Creek dans l'ouest du Yukon sont encaissés dans des roches plutoniques (198-197 Ma; U-Pb) du Jurassique précoce variablement déformées et dans une moindre mesure dans des roches supracrustales fortement métamorphisées. Ces roches constituent des enclaves dans des phases intrusives de composition intermédiaire légèrement plus jeunes (197 Ma; U-Pb), du Batholite de Granite. La chalcopyrite et la bornite sont disséminées et forment également des filonnets dans ces roches. La muscovite d'altération associée aux filons tardifs de quartz-feldspath-épidote donne un âge de 182 Ma selon la méthode Ar-Ar. L'analyse géobarométrique de phases intrusives postérieures à la minéralisation indique que leur mise en place a eu lieu à plus de 9 km de profondeur. Des études géochimiques de la hornblende contenue dans les roches plutoniques et méta-plutoniques encaissantes aux gisements de Minto et de Williams Creek indiquent qu'elles se sont formées dans un arc magmatique continental. Les rapports Cu/Au et les observations sur le terrain indiquent que la mobilité supergène de Cu a été plus étendue au gisement de Williams Creek qu'à celui de Minto. Selon les résultats que nous avons obtenus, les deux gisements représentent des variations de gîtes porphyriques de Cu(-Au) typiques.

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INTRODUCTION

The north-northwest-trending, informally named 'Carmacks Copper Belt', in west-central Yukon (Fig. 1) contains the Minto deposit (Yukon MINFILE 2002, 115I 021 and 022, Deklerk, 2002) and the Williams Creek (Carmacks Copper) deposit (Yukon MINFILE 2002, 115I 008, Deklerk, 2002), which is located approximately 50 km to the southeast of the Minto deposit. Several other copper (± gold) occurrences, some of which have been drilled (e.g., the Stu; Yukon MINFILE 2002, 115I 011, Deklerk, 2002), are also present in the area between these two deposits. The Minto deposit was discovered in 1971 and contains approximately 9 million tonnes of ore with an average grade of 1.73% Cu, 0.48 g/t Au and 7.5 g/t Ag (Deklerk, 2002). The Williams Creek (Carmacks Copper) deposit contains published reserves of approximately 15.5 million tonnes at 1.01% Cu (Deklerk, 2002). The nature and origin of the two deposits are poorly known because both deposits are deformed, metamorphosed, deeply weathered, variably oxidized by meteoric waters, and poorly exposed. Original lithological and contact relations are generally only exposed in exploration trenches, road cuts and drill core. Previous workers have assigned these deposits to various different deposit types, including metamorphosed volcanogenic massive sulphide deposits, metamorphosed redbed copper deposits and deformed copper-gold porphyries (e.g., Pearson, 1977; Sinclair, 1977; Pearson and Clark, 1979). Exploration for additional mineralized zones of the Minto or Williams Creek type in the region has been hampered by the lack of genetic or exploration models for the deposits. The purpose of the current project is to gain a better understanding of the nature of copper (-gold) deposits and the main host rock units in the Minto and Williams Creek deposit areas. This information will form the basis for new genetic and exploration models for copper (-gold) deposits in the Carmacks Copper Belt. During the 2002 and 2003 field seasons, the authors examined and sampled surface exposures of the Minto Main Zone, host rocks for the mineralized rock zones exposed in new cuts in the vicinity of the camp and along the access road at Minto, and exposures of the No. 1 and No. 12 zones at Williams Creek, as well as core from

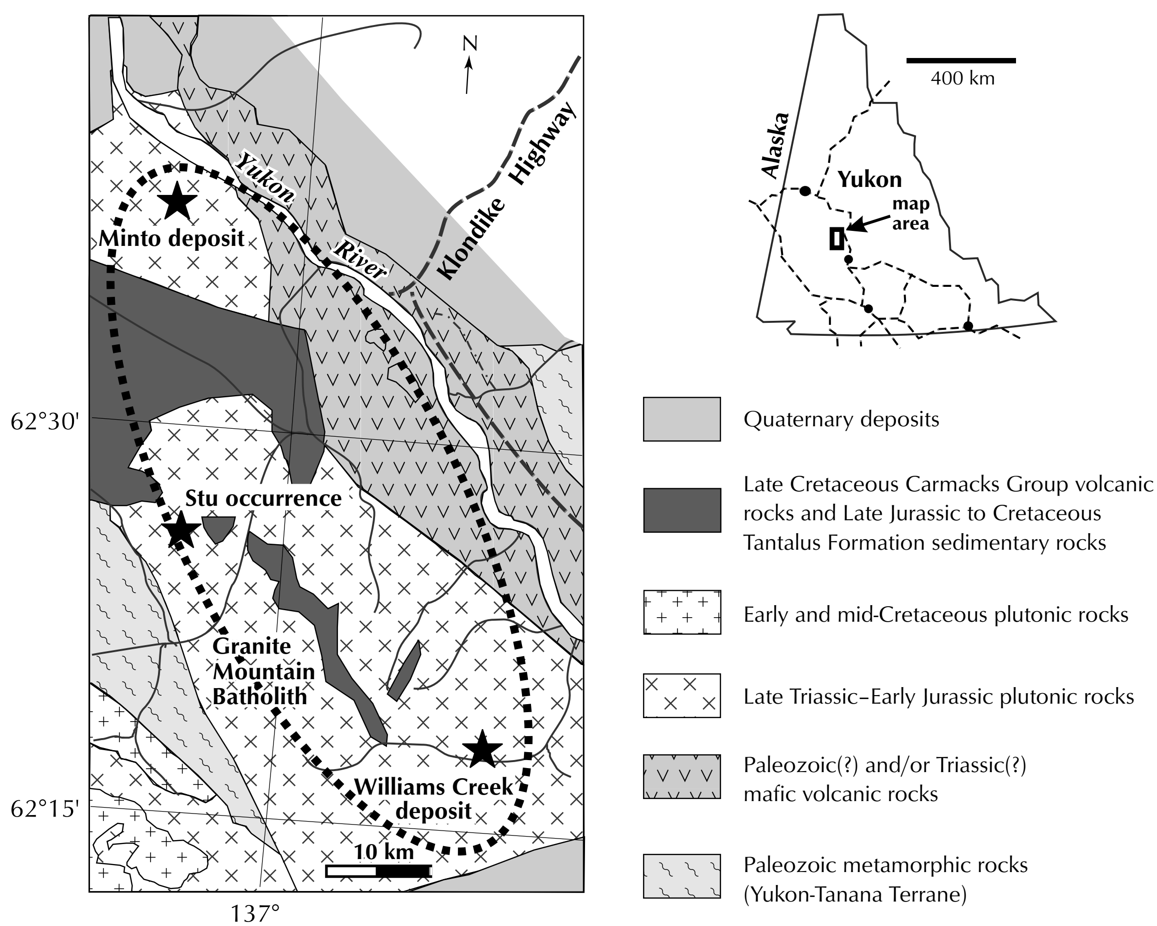


Figure 1. *Map showing the location and regional geological setting of the Minto and Williams Creek deposits and the Stu occurrence (Yukon MINFILE occurrences, Deklerk, 2002; geology simplified from Gordey and Makepeace, 1999). The Carmacks Copper Belt is outlined by the heavy dashed line.*

several drill holes at Minto and Williams Creek and the Stu prospect. This work included documenting the nature of contact relationships between rock units, and detailed sampling for petrographic, geochemical and geochronological studies. Magnetic susceptibility measurements were also taken on representative samples of the main lithological units to help constrain interpretations of ground and airborne magnetic surveys.

PREVIOUS WORK

The Williams Creek deposit was discovered by J.G. Abbott in 1970 (Abbott, 1971), who recognized that the copper was contained mainly within lenses of gneissic and amphibolitic rock (interpreted to be metasedimentary in origin) that were surrounded by unmineralized intrusive rocks. Abbott (1971) noted some similarities between the Williams Creek deposit and typical porphyry copper deposits. Sinclair (1977) carried out geological mapping in the vicinity of the Minto deposit, as well as reconnaissance-level geochemical studies of intrusive rocks in the area. Pearson (1977; see also Pearson and Clark, 1979) completed a Master of Science thesis focused on the Minto deposit, which included petrographic, mineralogical and geochemical studies, as well as a limited amount of sulphur isotope work on the sulphide minerals at Minto. A 1:250 000-scale geological map of the Carmacks map sheet was published by Tempelman-Kluit (1984). The detailed geology of the Minto and Williams Creek deposits is described in numerous unpublished mineral assessment reports prepared by various company geologists. A low-level airborne magnetic and radiometric survey was flown over the entire Minto-Williams Creek area by the Geological Survey of Canada and the Yukon Geology Program in 2001 (Shives et al., 2002). No geological interpretation of this new geophysical data set has yet been published.

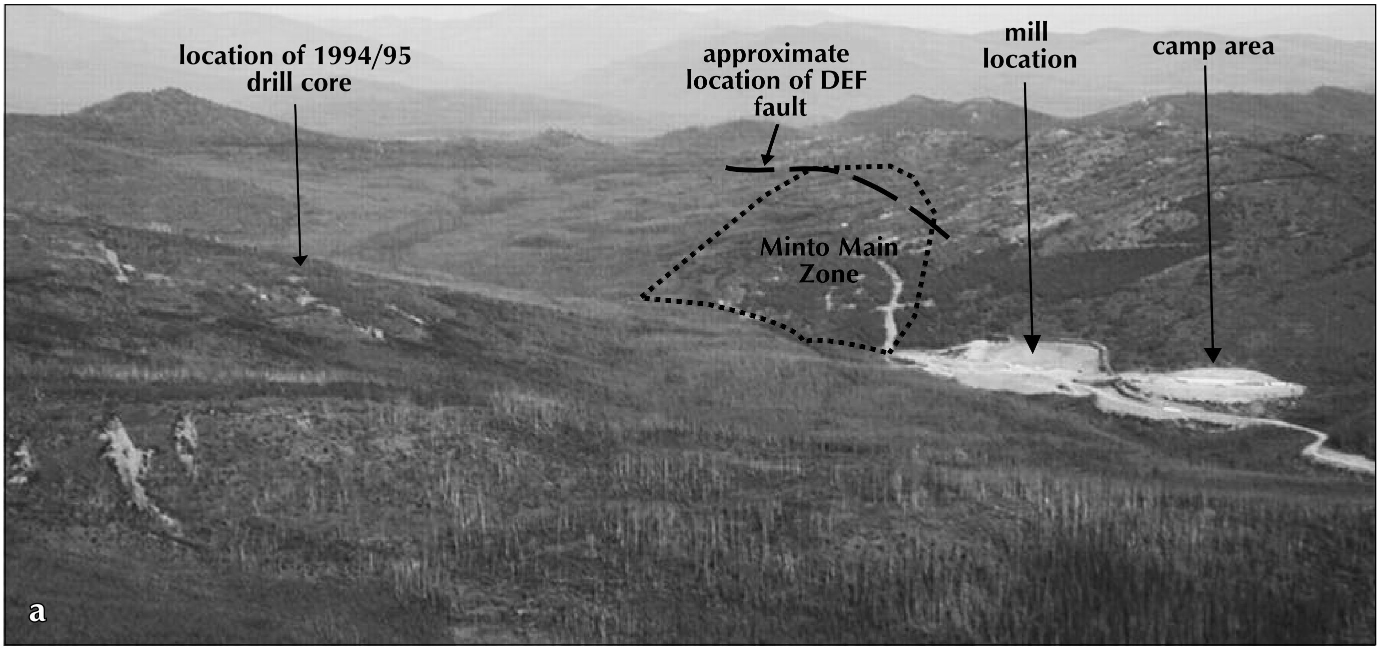
REGIONAL SETTING

Three main lithological assemblages underlie the Minto-Williams Creek area. Intermediate to felsic intrusive and meta-intrusive rocks of the early Mesozoic Granite Batholith underlie much of the area and are interpreted to be intrusive to the Yukon-Tanana Terrane (Fig. 1; Gordey and Makepeace, 1999). The batholithic rocks are in fault and/or intrusive contact with an unnamed package of altered mafic volcanic rocks to the northeast, and are unconformably overlain by sedimentary rocks and volcanic flow rocks of the Late Cretaceous Tantalus Formation and Late Cretaceous Carmacks Group, respectively. Copper and gold at Minto and Williams Creek are hosted by deformed and metamorphosed rafts and pendants of older intrusive rock units and supracrustal rocks contained within the Granite Batholith. Regional structure is poorly understood because outcrop is very sparse (<1% exposure; Fig. 2), and the area is unglaciated and deeply weathered. In addition, there is a lack of detailed geological mapping in this area. However, some significant steep faults have been recognized in the area (e.g., the DEF fault at Minto; see later discussion).

GEOLOGY OF THE CARMACKS COPPER BELT

Much of the Minto-Williams Creek area is underlain by intrusive and meta-intrusive rocks. Stained slabs and thin section petrography together with field observations were used to differentiate between different intrusive phases in the area. Sample modes have been calculated for representative stained slabs using digital image analysis methods, as described by Duncan (1999). Based on modal analysis, ten distinct intrusive phases were identified in the Minto and Williams Creek area (Mortensen and Tafti, 2003). Compositions range from granodiorite to quartz monzodiorite to diorite. Quartz diorite and diorite are more common at Williams Creek than at Minto. These rocks are equigranular to porphyritic, and massive to moderately foliated. The porphyritic phases contain phenocrysts of K-(potassium) feldspar, plagioclase and/or quartz. In some instances the K-feldspar phenocrysts range up to 3 cm long. Post-mineralization granitic pegmatite and aplite dykes are widespread in the area, especially at Minto.

Microscopic studies of the intrusive rocks indicate that biotite occurs as the main mafic mineral in all phases. Hornblende is present in dioritic and quartz dioritic intrusive rocks and locally in the granodioritic phases. Euhedral to subhedral epidote and allanite are present in some of the unfoliated intrusive phases (Fig. 3). Much of this epidote is clearly part of the original mineral assemblage of the rock and is therefore considered to be 'magmatic' epidote (see later discussion). Quartz, K-feldspar and plagioclase (oligoclase) are present in all intrusive phases. Plagioclase is subhedral and very locally displays growth zoning. Zircon, titanite and apatite are the main accessory minerals, and are present in all of the intrusive phases. Euhedral garnet (almandine) occurs locally in some of the intrusive phases (especially the



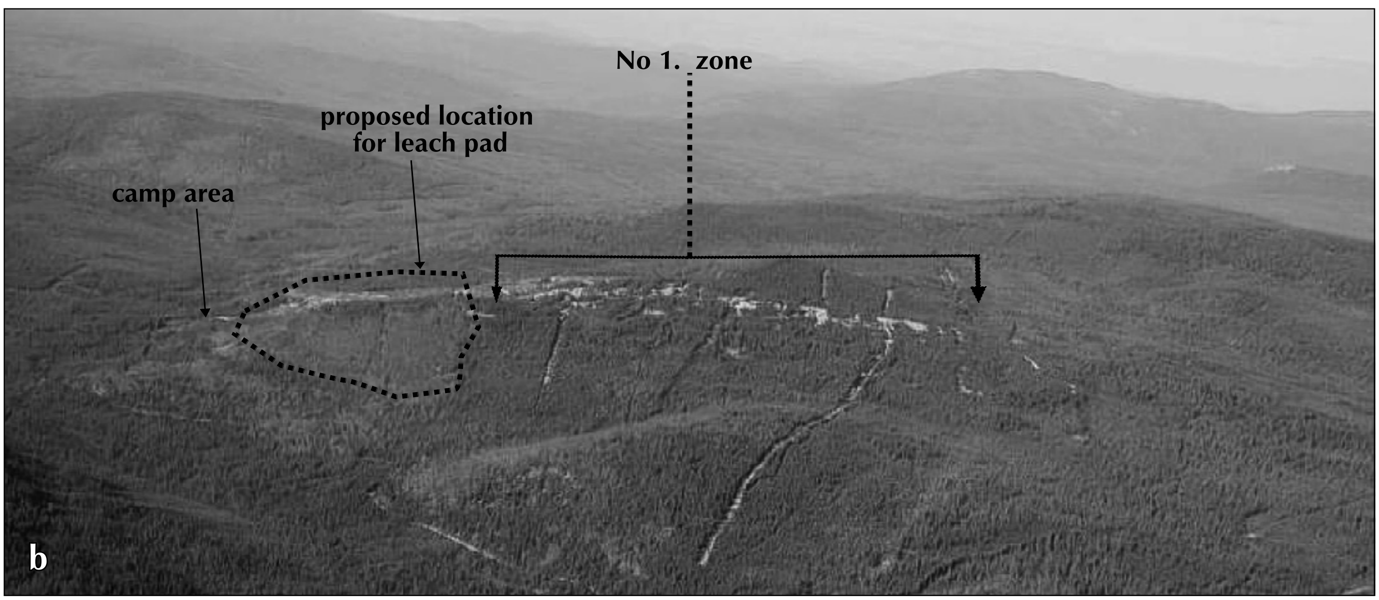


Figure 2. (a) *Aerial view of the Minto deposit area (looking northwest) showing the approximate location of the DEF fault and the Main Zone.* ***(b)*** *Aerial view of the Williams Creek deposit (looking west) showing the No. 1 zone and the proposed location for leach pad.*

foliated granodiorite at Minto) and ranges up to 0.7 cm in diameter. The main opaque mineral is magnetite and locally ilmenite. Biotite and hornblende have locally been partially altered to chlorite and secondary epidote. This alteration is more extensive in the more strongly foliated rocks. Some late calcite veinlets are also present.

The immediate host rocks for copper- and gold-mineralized rock can be divided into three types: 1) biotite-rich gneiss and quartzofeldspathic gneiss (main ore hosts at Minto and Williams Creek); 2)'siliceous ore' at Minto and rarely at Williams Creek; and 3) fine-grained 'amphibolite' and biotite schist at Williams Creek. The petrography of the host rocks is discussed in more detail in a later section.

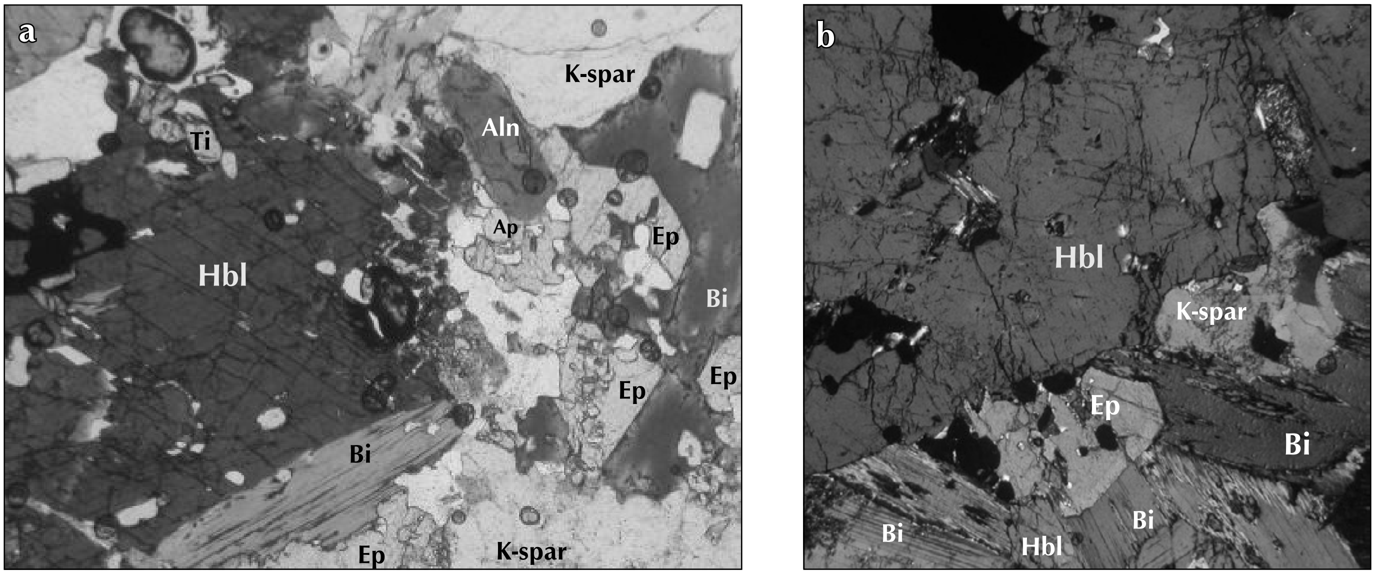


Figure 3. *Photomicrographs of massive K-feldspar-phyric granodiorite at Minto.* ***(a)*** *Sub-euhedral grains of epidote (Ep) and allanite (Aln) are present; plane-polarized image, field of view is 3 mm.* ***(b)*** *Subhedral epidote (Ep) showing zoning; cross-polarized image, field of view is 2 mm. Bi = biotite; Ap = apatite; K-spar = potassium feldspar; Hbl = hornblende; Ti = titanite.*

CONTACT RELATIONSHIPS AND STRUCTURAL GEOLOGY

The structural evolution of the Minto and Williams Creek areas, and the nature and origin of the foliation(s) within the various rock units are critical for understanding the genesis of the two deposits. Alignment of K-feldspar phenocrysts in the porphyritic granodiorite of the Granite Batholith is ascribed to magmatic flow. It is likely that some alignment of mafic minerals and mineral aggregates, and potentially the formation of mafic schlieren observed locally within the batholith, may have also occurred during emplacement of the intrusion. However, petrographic studies of the intrusive rocks show that they have been affected by at least two distinct phases of foliation development. Feldspar phenocrysts (mainly plagioclase) in the main phase of porphyritic diorite and quartz diorite at Williams Creek are typically strongly recrystallized in both the massive and foliated phases. Many of the moderately to strongly foliated phases show features of strong recrystallization and strain in quartz and plagioclase grains, which indicate tectonic deformation and metamorphism at biotite grade (300-400°C). Field relationships and drill core intercepts show that this foliation is cut by massive to slightly foliated intrusive phases (Fig. 4) and by several generations of aplitic dykes. Ductile deformation has also affected some of the late dykes that cut the massive intrusive rocks (Fig. 5). The foliation in orthogneiss units is parallel to the foliation of amphibolite/biotite-schist wall rocks at Williams Creek, which indicates they were deformed together (Fig. 6). There are numerous cases of small-scale, ptygmatically

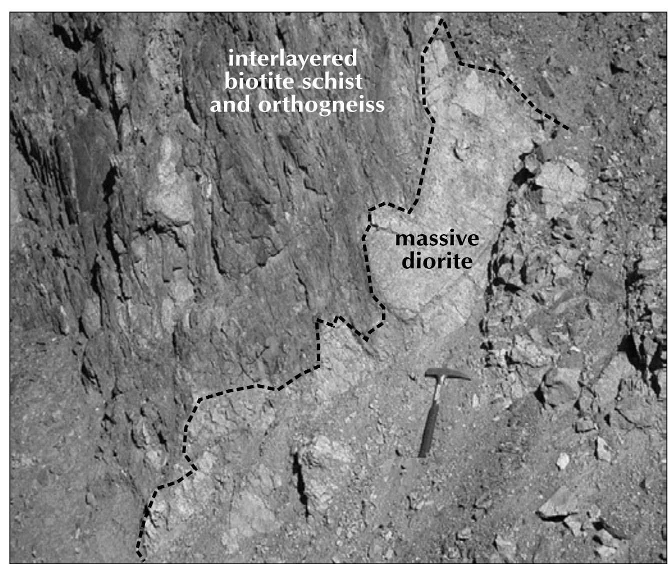


Figure 4. *Sharp contact between interlayered biotite schist and orthogneiss, and massive, post-mineralization diorite in the hanging wall of the No. 1 zone at Williams Creek (bulk sampling trench 91-20).*

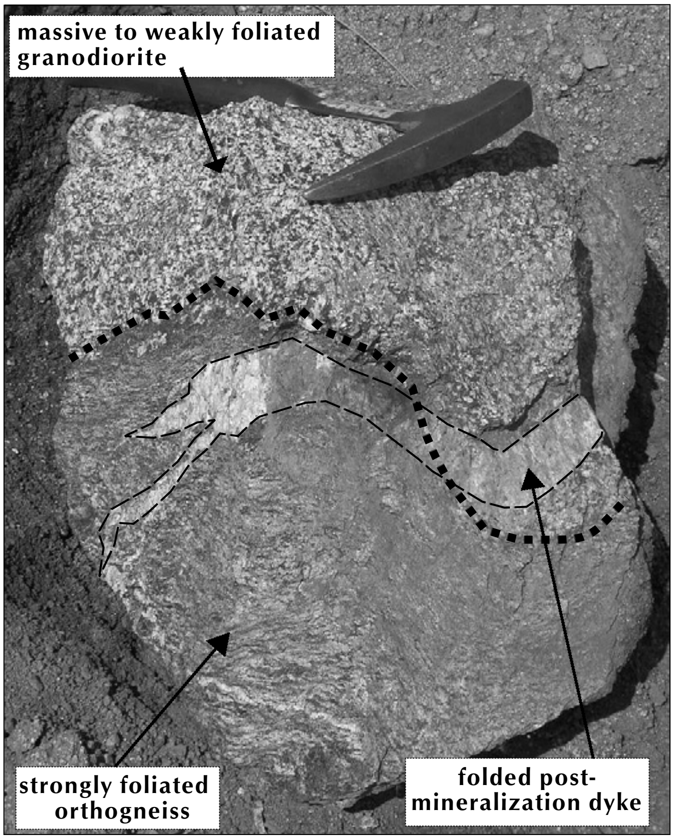


__Figure 5.__ Contact between a well foliated orthogneiss and a massive K-feldspar-phyric granodiorite at Minto. The small dyke cuts the main body of granodiorite and cuts across the foliation of the orthogneiss. The contact between the massive granodiorite and the orthogneiss, as well as the small dyke and the foliation in the orthogneiss, are folded into gentle open folds.

__Figure 7.__ Slab of strongly deformed, mineralized orthogneiss with ptygmatically folded aplitic dyke.

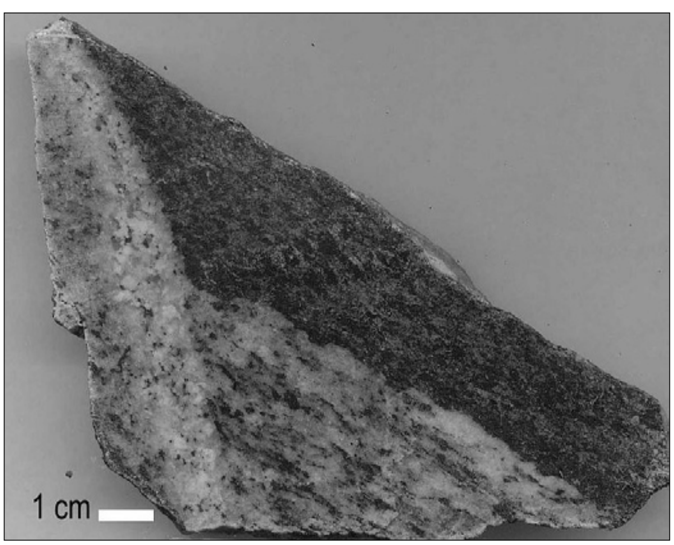


__Figure 6.__ Interlayered biotite schist and orthogneiss that are cut by a granodiorite dyke. Foliation in both the schist and orthogneiss is parallel, indicating that they were deformed at the same time.

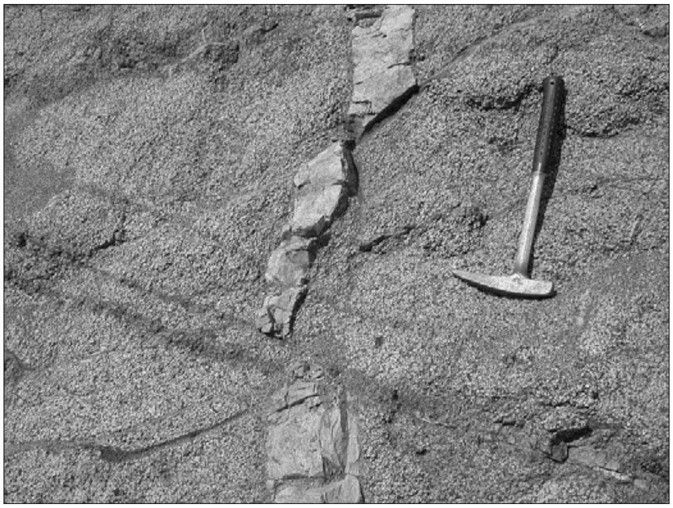


Figure 8. *Small-scale conjugate fault sets displacing a late aplite dyke at Minto.*

folded aplite/pegmatite dykes within strongly deformed orthogneisses (Fig. 7).

Late, post mineralization, brittle faults at several different orientations have been identified in the area, including the east-west-trending DEF fault that forms the northern boundary of the Main Zone at Minto (Fig. 2a). In some instances (e.g., Fig. 8), the brittle faults form conjugate sets. These young brittle faults have facilitated deep circulation of surface water and oxidation of the hypogene sulphide minerals and their host rocks, including the pervasive hematization noted throughout parts of the Minto deposit. In addition, substantial block rotation has occurred at Minto, at least locally. This is evidenced by the tilting of younger sedimentary units (probably Late Jurassic to Cretaceous Tantalus Formation) south of the Main Zone at Minto by up to 60° (bedding/core angles as low as 30° in vertical drill hole 99-01). Such late fault block rotation may in part account for the anomalously shallow dips of the dominant foliation in gneissic host rocks in the Minto Main Zone. The difference between the mainly subhorizontal dip of foliation at Minto and the much steeper (up to vertical) dips at Williams Creek may also be due to large-scale block rotation.

GEOCHRONOLOGY

Preliminary uranium-lead (U-Pb) zircon ages of 194 ± 1 Ma and 192 Ma were reported by Mortensen and Tafti (2003) for a mineralized and strongly foliated granodiorite from Minto and massive porphyritic quartz diorite of the Granite Batholith at Williams Creek, respectively. A detailed U-Pb and Ar-Ar (argon) dating study of the two deposits and their host rocks is now underway. The recent work has demonstrated that the intrusive rocks in this area have very complex U-Pb systematics, with multiple ages of zircon inheritance and significant post-crystallization lead-loss. We have obtained U-Pb zircon and/or titanite ages for the following samples:

- fine-grained granitic orthogneiss at Williams Creek (197.3 ± 1.5 Ma; zircon);
- K-feldspar-phyric granodiorite at Williams Creek (197.3 ± 1.5 Ma; zircon);
- plagioclase-phyric diorite at Williams Creek (197.3 ± 1.5 Ma; zircon);
- mineralized garnetiferous orthogneiss at Minto (197 ± 2 Ma; zircon);
- K-feldspar-phyric granodiorite at Minto (192 ± 2 Ma; titanite);
- post-mineralization granitic dyke at Minto (195 ± 1 Ma; zircon).

Although field relationships clearly show that the massive phases of the Granite Batholith are younger than the foliated and mineralized intrusive phases, they are actually very similar in age.

Two samples of coarse muscovite from selvages, developed adjacent to late quartz-feldspar-epidote veins at Minto that are associated with strong bleaching and K-feldspar alteration, gave Ar-Ar plateau ages of 182 ± 1 Ma. These veins are observed to cross-cut pegmatite and aplite dykes that locally contain miarolitic cavities and must therefore have been emplaced at relatively shallow levels. We therefore interpret the Ar-Ar ages to date the latest hydrothermal event that affected the Minto area.

GEOBAROMETRY AND GEOTHERMOMETRY

The aluminum-in-hornblende geobarometer of Anderson and Smith (1995) was used in combination with the amphibole-plagioclase thermometer of Blundy and Holland (1990) to determine the depth and temperature of emplacement of some of the intrusive phases in the study area. McCausland et al. (2002) previously reported surprisingly great depths of emplacement of intrusive rocks in the Williams Creek area based on aluminum-in-hornblende geobarometry. Our results show that the latest intrusive phases in the Minto and Williams Creek area formed at depths of more than 9 km. The presence of euhedral to subhedral epidote that is interpreted to be magmatic in origin in some of these samples is consistent with a pressure during crystallization of at least 6 kbar (corresponding to depths of ~18-20 km; e.g., Zen and Hammarstrom, 1984).

Crystallization temperatures for several of the intrusive phases were calculated using amphibole-plagioclase thermometry. The resulting temperature estimates of 720°C to 840°C are surprisingly low for intrusive rocks with granodioritic to dioritic compositions. Model temperatures for intrusive rocks from throughout the Minto and Williams Creek area were also calculated using zircon saturation geothermometry (Watson and Harrison, 1983). This method yields similar and in some cases even lower magmatic temperatures than those obtained from the amphibole-plagioclase equilibria. The significance of these consistently low temperature estimates is uncertain at this point.

GEOCHEMISTRY

Major, trace and rare-earth element compositions have been determined for more than 40 samples of mainly unmineralized, foliated and unfoliated intrusive rocks, and 5 samples of amphibolite and biotite schist in the Minto and Williams Creek area. They indicate that most intrusive rock units are subalkaline, and weakly to moderately peraluminous. Concentrations of immobile trace, high field-strength and rare-earth elements are most consistent with generation in a continental magmatic arc. Calculated ferric/ferrous ratios for the samples are between 0.17 to 0.67, which indicate that these are moderately oxidized magmatic rocks. Mineralized rock units are compositionally very similar to the unmineralized phases but appear to be slightly enriched in K and some trace elements. Summary geochemical plots for these samples are shown in Figure 9.

Our results from the Minto and Williams Creek area indicate that intrusive rocks in this area are geochemically very similar to other Late Triassic and Early Jurassic intrusive rocks elsewhere in the Yukon-Tanana Terrane in Yukon and eastern Alaska as described by Mortensen et al. (2000).

COPPER-GOLD DEPOSITS AT MINTO AND WILLIAMS CREEK

Results of the fieldwork and petrographic studies confirm that the main host rocks for both the Minto and Williams Creek deposits are variably deformed plutonic rocks. The Minto deposit is mainly hosted within foliated biotite and quartzofeldspathic orthogneiss ('quartzofeldspathic ore'), with a lesser amount of copper- and gold-mineralized rock contained within a banded, relatively quartz- rich rock ('siliceous ore'). The mineralized zones are enclosed by massive to very weakly foliated granodiorite of the Granite Batholith. The main host for the Williams Creek deposit is orthogneiss of dioritic to quartz dioritic composition, and to a lesser extent supracrustal rocks (amphibolite and biotite schist). In surface exposures at Williams Creek (e.g., the bulk sample trenches within the main No. 1 zone), copper is present in both orthogneisses and supracrustal rocks; however, nearly all of the contained copper appears to be as secondary copper-oxide minerals along fracture surfaces, and there is little evidence that significant amounts of hypogene copper sulphide minerals were ever present in these rocks. As at Minto, the mineralized zones and their deformed and metamorphosed host rocks at Williams Creek are enclosed by massive quartz diorite and granodiorite of the Granite Batholith (Fig 4).

Petrographic and field studies of 'quartzofeldspathic ore' and biotite-rich gneiss show that these rock types are strongly deformed and metamorphosed intrusive rocks (orthogneiss), and the excess amount of biotite appears to represent secondary (hydrothermal) biotite associated with strong hypogene potassic alteration.

'Siliceous ore', which is well developed at Minto and locally present at Williams Creek, is typically thinly banded on a scale of millimetres to 1 cm, with layers consisting mainly of quartz (± K-feldspar) and lesser amounts of magnetite, as well as disseminated bornite and chalcopyrite. These characteristics suggest derivation from a very different protolith than the quartzofeldspathic or biotite-gneiss units. These quartz-rich bands could have been derived from siliceous layers in a thinly bedded supracrustal sequence, or could in part represent completely transposed sets of quartz veins, or both.

Geochemistry and petrography of fine-grained 'amphibolite' at Williams Creek (actually mainly biotite schist) indicate that these rocks had a supracrustal protolith, most likely an intermediate or mafic volcanic rock, or epiclastic rock of this composition. The presence

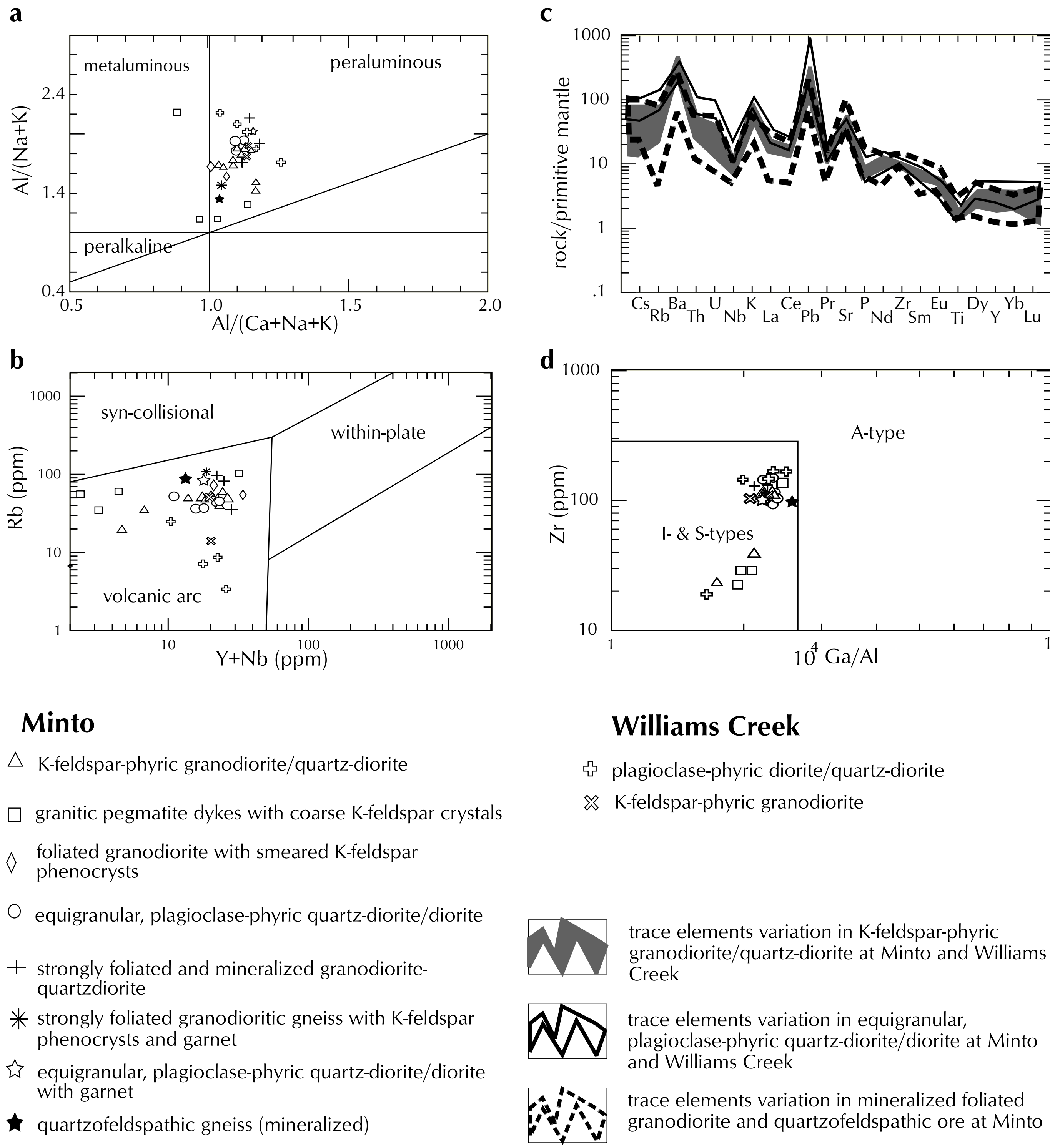


***Figure 9. (a)** Shand's index plot (after Maniar and Piccoli, 1989) depicting the dominantly peraluminous nature of the Early Jurassic intrusions at Minto and Williams Creek deposits. **(b)** Rb versus Y+Nb discrimination diagram indicating a volcanic arc setting for the intrusions at Minto and Williams Creek (Pearce et al., 1984). **(c)** Primitive-mantle-normalized multi-element plots for different intrusive phases (from Sun and McDonough, 1989). **(d)** Zr versus Ga 10^4/Al discrimination plot for I-, S- and A-type granites (from Whalen et al., 1987).*

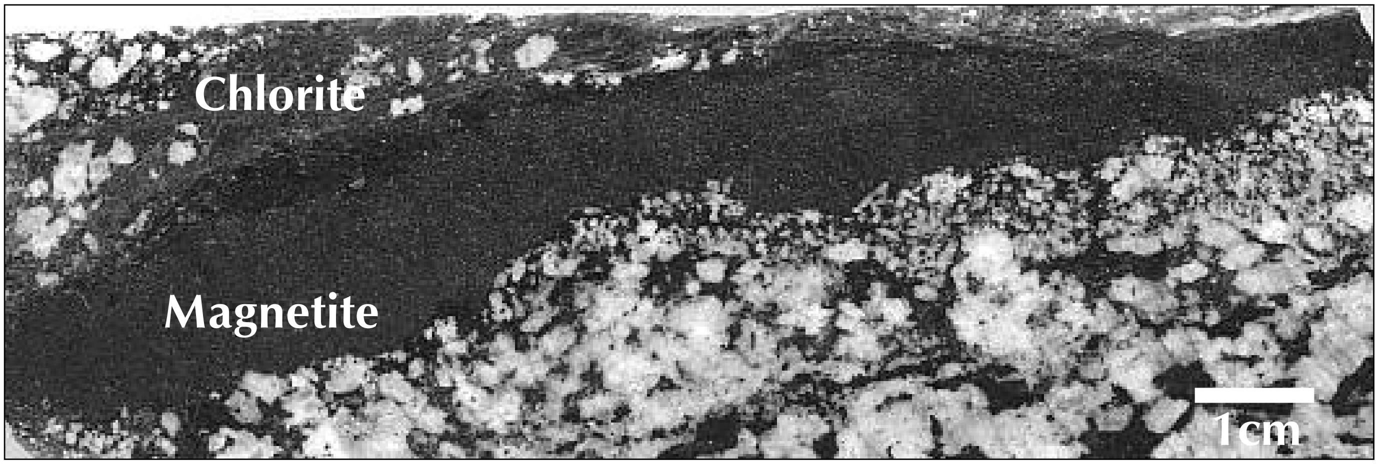


Figure 10. *A 2.5-cm-thick vein of magnetite within weakly foliated quartz diorite at the Williams Creek deposit.*

of banded 'siliceous ore' interlayered with the amphibolite in some drill intercepts at Williams Creek may support the sedimentary origin suggested above for the 'siliceous ore'. Observed field relationships indicate that these supracrustal units were wall rocks to early intrusive phases and that the intrusive rocks and their wall rocks were mineralized during a single hydrothermal event.

Chalcopyrite, bornite and very minor pyrite are the main hypogene sulphide minerals observed at Minto and Williams Creek. These minerals are disseminated in host rocks and locally occur as narrow, discontinuous, foliaform stringers. In some instances chalcopyrite and/or bornite form bands or blobs up to 2 to 3 cm long. Mineralization occurred prior to the ductile deformation that has affected the host units. With the exception of rare, fine grains of chalcopyrite and/or bornite that appear in some of the late dykes (attributed to late remobilization of the sulphide minerals), copper sulphide minerals are always hosted by strongly deformed rock units. In biotite-rich rocks (particularly 'biotite gneiss ore'), sulphide minerals are closely associated with the biotite. Magnetite is present in all the mineralized rocks in varying amounts and locally comprises as much as 25% of the rock. Magnetite veins up to 2 cm wide are locally associated with massive bornite veins of similar dimensions (Fig. 10).

Petrography and SEM (scanning electron microprobe) studies of mineralized rock samples show that chalcopyrite and bornite are intimately intergrown. Supergene alteration of these hypogene minerals produced secondary copper sulphide minerals such as covellite and chalcocite along rims and fractures, and locally as whole grain replacements. Native copper is also very locally present as narrow veinlets in oxidized zones.

Pyrite is rare in both deposits, and where present is associated with chalcopyrite. In rare instances pseudomorphs of calcite and/or siderite after hypogene pyrite are observed. Anhedral to subhedral magnetite and hematite occur together with the hematite commonly appearing to replace the magnetite. Gold is present both in native form and alloyed with silver (electrum). Silver is also present very locally as silver telluride (hessite). These gold and silver minerals are commonly contained within bornite and rarely form isolated grains. SEM studies show that electrum forms grains up to 150 microns in diameter (Fig. 11). It is uncertain at this time why high-fineness gold coexists with electrum within a single grain; however, it

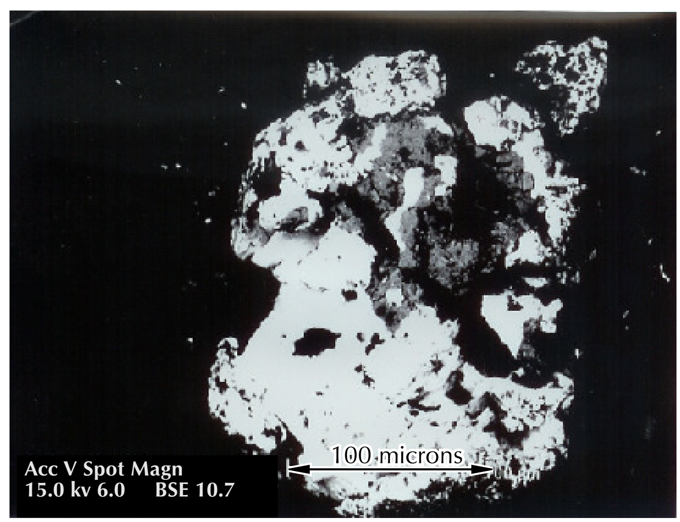


Figure 11. *Scanning electron microscope (SEM) image of an electrum/gold grain mounted on epoxy (black) recovered from a heavy mineral concentrate from 'siliceous ore' at Minto. White portions are gold with relatively high fineness, and the medium grey portions are electrum.*

may indicate that some of the primary electrum has had silver leached out during supergene processes. Molybdenite is very rare; where present it occurs as euhedral hexagonal grains in garnetiferous 'quartzo-feldspathic ore'.

The mineralogy of the 'siliceous ore' is slightly different than that of other mineralized rocks. A significant amount of gold, zinc sulphide (wurzite) and barite occurs in some samples of the 'siliceous ore'.

Pyrrhotite is locally disseminated in some sections of the fine-grained, garnetiferous amphibolite and biotite schist at Williams Creek. The origin of this sulphide mineralization is uncertain; it may represent syngenetic (volcanogenic?) sulphide minerals that were present in the mafic rocks prior to intrusion of the Early Jurassic magmas.

The very limited exposure in the Minto and Williams Creek area makes it difficult to confidently differentiate between the effects of hypogene alteration and later supergene effects. Earthy, and locally specular hematite is commonly observed to replace magnetite; it also stains feldspars along late fractures and fills late fractures. The hematization is commonly accompanied by bleaching of the wall rocks. It appears to be entirely late in the alteration history, and is likely completely unrelated to the mineralizing process. Epidote is commonly associated with hematite on late fractures but also occurs as an earlier, disseminated style of alteration, typically associated with mafic minerals. Chlorite is widespread throughout the Minto and Williams Creek areas. Some chlorite is spatially associated with late faults and breccia zones, where it has pervasively altered the breccia matrix and fragments. However, chlorite also replaces bent and kinked biotite grains that are considered to be part of the hypogene alteration. Clay alteration is pervasive in all of the oxidized zones, especially in the vicinity of late faults and fractures. Biotite in massive intrusive phases is mainly igneous in origin; however, locally secondary biotite is seen replacing primary hornblende in some of the altered but undeformed intrusive phases. In the strongly foliated gneissic zones, biotite has been recrystallized along with the sulphide minerals, and primary textural information relating to its origin is not preserved. However, it appears likely that both primary igneous biotite and a substantial component of hydrothermal (hypogene) biotite were originally present in the rocks, and both were completely recrystallized during the ductile deformation. Relatively coarse-grained sericite is only rarely developed as an alteration phase at Minto and has not yet been observed at Williams Creek. At Minto, sericite is observed both as an alteration envelope around a late epidote-filled vein that cuts massive granodiorite, and also as a narrow envelope surrounding a late aplite and pegmatite dyke. Pervasive, very fine-grained sericite alteration is also locally observed in some of the strongly foliated intrusive rocks.

Although strongly overprinted by supergene effects, we conclude that strong potassic alteration, consisting of development of secondary biotite after primary mafic minerals, and probably minor introduction of secondary K-feldspar, was well developed during formation of the hypogene copper-gold mineralization. Propylitic alteration (chlorite, carbonate and epidote) may have been developed during the hypogene processes; however, this would be largely obscured by subsequent deformation and supergene processes. The general scarcity of widespread pyrite and sericite suggests that hypogene argillic and sericitic alteration may not have been widely developed.

A GENETIC MODEL FOR MINERALIZATION AT MINTO AND WILLIAMS CREEK

As discussed above, hypogene minerology at Minto and Williams Creek consists of chalcopyrite, bornite and magnetite, with only minor amounts of pyrite and very minor molybdenite. Very small amounts of quartz were introduced during hypogene processes, with the possible exception of quartz stockwork that may now be represented by 'siliceous ore' (see previous discussion). Associated hypogene alteration is characterized by abundant secondary biotite and lesser amounts of secondary K-feldspar. These ore and alteration assemblages closely resemble those associated with early stages of mineralization in typical copper (-gold) porphyry deposits (e.g., Einaudi et al., 2003) as well as some iron-oxide-copper-gold-type (IOCG) deposits. Post-ore, very localized quartz veins display alteration envelopes consisting of epidote, minor calcite and rare sericite. A critical consideration in evaluating the resource potential and economics of metal extraction for the two deposits is the nature and extent of supergene modification that has affected them. Supergene effects are characterized by the presence of abundant secondary copper oxide and less abundant secondary copper sulphide minerals, especially at Williams Creek, and by the local presence of abundant hematite and clay (mainly in the vicinity of late steep faults). Within the main No. 1 zone at Williams Creek, as exposed in the bulk sample trenches, nearly all of the contained copper appears to occur in the form of

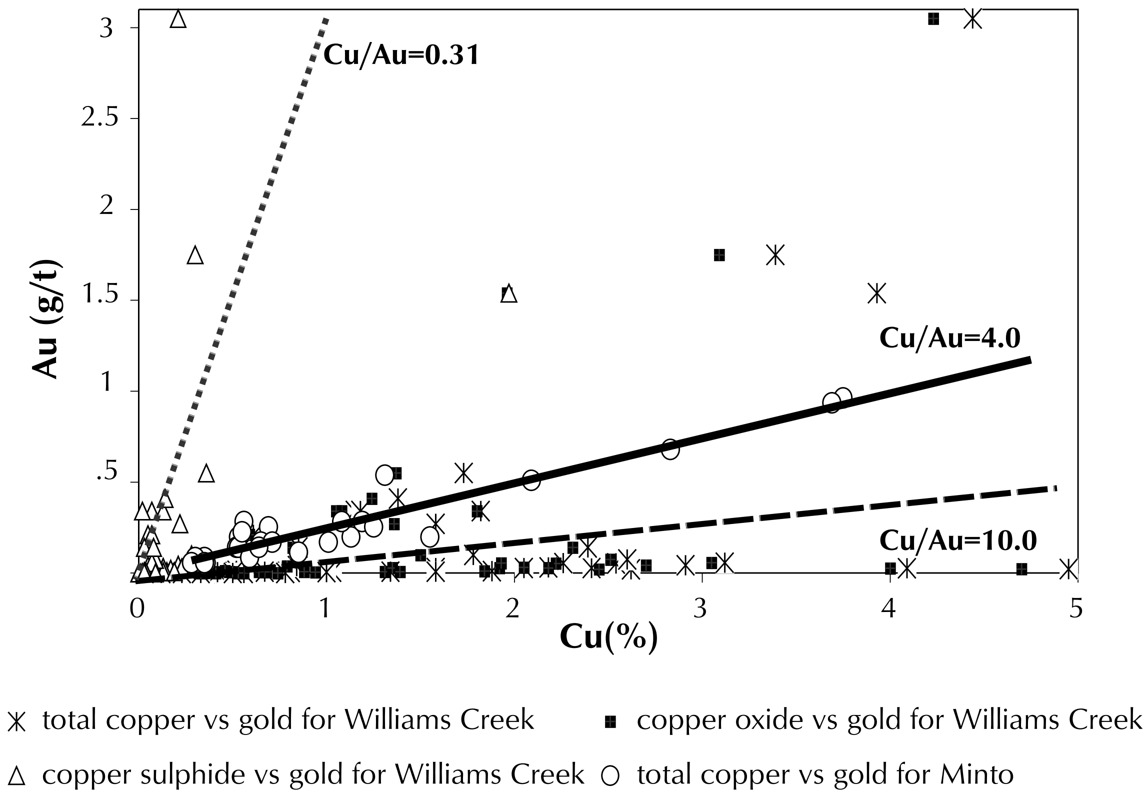


Figure 12. *Gold versus copper plot for the Minto and Williams Creek (No. 1 zone) mineralization. Data from Williams Creek are from three 1981 drill intersections. See text for discussion.*

secondary copper oxide minerals (especially malachite and azurite) coating fracture surfaces, and there is little evidence that significant amounts of hypogene copper sulphide minerals were ever present in the rocks. A plot of total Cu (%) versus Au (g/T) for the two deposits (Fig. 12) shows a slightly lower total Cu/Au ratio for Minto than Williams Creek (~4 at Minto versus ~10 at Williams Creek); however, both ratios are well within the range of typical values for alkaline porphyry copper deposits of British Columbia (Cu/Au = 0.3-15; McMillan et al., 1995). A plot of oxide Cu versus Au for the No. 1 zone at Williams Creek, however, suggests that much of the copper present is in the form of oxide minerals. This data, together with the observation that most of the copper in the No. 1 zone, at least at shallow levels, appears to have been introduced into the host rocks by supergene processes, suggests that the No. 1 zone has experienced strong supergene enrichment. A plot of Cu (as sulphide mineral) versus Au for the No. 1 zone at Williams Creek (Fig. 12) results in a much lower Cu/Au ratio (~0.31), which is unusually low for a typical hypogene porphyry copper deposit. It therefore remains uncertain how much of the copper contained in the Williams Creek deposit represents hypogene grade versus supergene enrichment, and therefore what the true hypogene Cu/Au ratio of the deposit was.

DISCUSSION

Sulphide minerals at Minto and Williams Creek occur mainly disseminated or as foliaform stringers within moderately to strongly deformed intrusive rocks, and to a lesser extent in foliated supracrustal rocks. Sulphide minerals in the deformed intrusive rocks clearly pre-date most if not all of the ductile strain recorded by their host rocks. The sharp contact between unmineralized, massive quartz diorite of the Granite Batholith, which is dated at ~197 Ma at Williams Creek, and the foliated and mineralized rocks demonstrates that the mineralization is older than the Granite Batholith. These observations provide evidence for four distinct events that occurred within a very short time interval in the Minto and Williams Creek area: 1) intrusion of early plutonic rocks into (probably) already deformed supracrustal rocks of the Yukon-Tanana Terrane at 198-197 Ma; 2) mineralization and alteration of these intrusive phases and their wall rocks; 3) ductile deformation of the mineralized rock units; and 4) intrusion of the main, massive, post-mineral phases of the Granite Batholith at ~197 Ma. The very tight age-brackets on these events suggest that they essentially represent a continuum.

Lead isotopic analyses of sulphide minerals and igneous feldspars from Minto and Williams Creek (this study) and sulphur isotopic studies by Pearson (1977) indicate magmatic sources (δ^{34}S ‰ values between –3 and +1) for the metals and sulphur contained in the deposits. The nature of the hypogene mineralization and alteration observed is consistent with the early stages of a typical porphyry system. The lack of evidence for a significant quartz stockwork in either of the deposits is reminiscent of the alkalic copper-gold porphyry deposits in British Columbia (e.g., McMillan et al., 1995), which are very similar in age to the Minto and Williams Creek deposits (Mortensen et al., 1995). The mineralized units were almost immediately intruded by post-mineral phases of the Granite Batholith, and petrographic evidence (presence of abundant magmatic epidote) and aluminum-in-hornblende geobarometry indicates that these post-mineral intrusions were emplaced at depths much greater than those that would permit formation of a porphyry-type deposit (note that Rusk et al. (2002) report a depth of formation of up to 8.5 km for the Butte porphyry-copper deposit in Montana). We suggest that a hydrothermal system had begun to develop a typical porphyry deposit but was shut off when the whole system was buried to depths of >9 km. Therefore, the late stages of hypogene mineralization and alteration that are typically associated with porphyry deposits (phyllic and argillic alteration and widespread introduction of pyrite) could not develop. Late pegmatite and aplite dykes, dated at ~194-196 Ma at Minto, cross-cut the Granite Batholith and locally contain miarolitic cavities, indicating that they were emplaced at a relatively shallow level in the crust; this provides evidence for a regional uplift event following the burial event at ~197 Ma. Sericite and epidote alteration that is associated with these dykes is dated at ~182 Ma (Ar-Ar muscovite), and indicates that hydrothermal fluid circulation had resumed by that time.

We conclude that the Minto and Williams Creek deposits formed during a major period of 'vertical tectonics' that affected this region. Regional scale uplift from mid-crustal depths to very shallow crustal levels at ~186 Ma was demonstrated by field and U-Pb dating studies of the Aishihik Batholith and Long Lake plutonic suite intrusions approximately 70 km to the southwest of our study area (Johnston et al., 1996). There is also evidence for regional-scale crustal thickening throughout large portions of the Yukon-Tanana Terrane in western Yukon and eastern Alaska between ~195 and 185 Ma (e.g., Mortensen, 1990, 1992), which could coincide with the burial of the mineralizing systems at Minto and Williams Creek. The crustal thickening, burial and subsequent uplift of the region must have occurred within an active continental arc setting, since the geochemistry of all intrusive phases emplaced during this interval indicates a strong arc affinity.

A relatively simple, 'arrested porphyry' model for the formation of the Minto and Williams Creek deposits has therefore emerged from our studies. However, many questions are still outstanding. For example, the importance of locally abundant disseminated pyrrhotite (at Williams Creek) and wurtzite (at Minto) of possible syngenetic origin in the amphibolite and biotite schist remains uncertain. Could this mineralization have provided a critical local source of some of the sulphur required for the formation of the hypogene copper ores? This and other problems are still being investigated. Some important exploration implications arise from the study. In particular, the mineral deposits at Minto and Williams Creek have been shown to be temporally and genetically associated with ~198 Ma magmatism. Although Late Triassic to Early Jurassic intrusive rocks are widespread throughout the Yukon-Tanana Terrane in Yukon and eastern Alaska (Mortensen et al., 2000), most of these intrusions appear to be either older (218-202 Ma) or younger (192-185 Ma) than the main mineralized intrusive phases at Minto and Williams Creek. Furthermore, formation of a porphyry deposit requires relatively shallow-level intrusions, and many of the Triassic and Jurassic intrusions contain epidote that is thought to be magmatic in origin, indicating emplacement of the magmas at too great a depth to permit the formation of a porphyry-type deposit. Identification of relatively shallow, ~198 Ma intrusions in western Yukon should therefore be a first-order criteria for exploring other deposits of this type in the region.

Recognition of the extent of supergene enrichment that has affected the Williams Creek deposit in particular has implications for the original dimensions and grade of the deposit. Although we have only been able to examine a small portion of the Williams Creek deposit, our observations suggest that much of the copper contained in the No. 1 zone is in the form of secondary oxide-mineral enrichment, and is not simply hypogene ore that has been oxidized in place.

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