MINERAL INDUSTRY

Yukon mining and exploration overview, 1999

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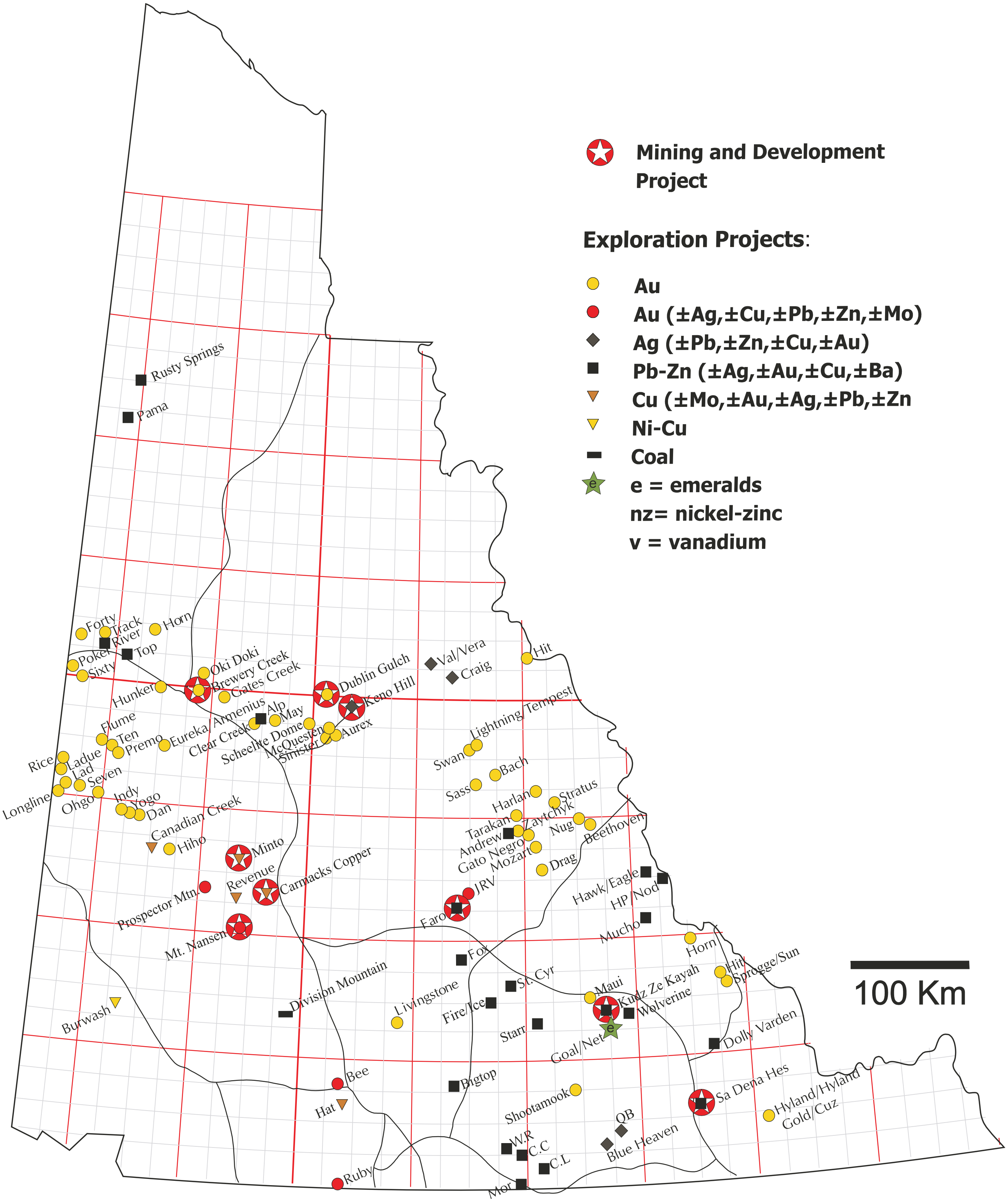

Figure 1. *Location of active Yukon mines, development and exploration projects in 1998. Not all projects are shown on the map.*

YUKON MINING AND EXPLORATION OVERVIEW, 1999

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Yukon Geology Program

Burke, M., 2000. Yukon mining and exploration overview 1999. *In:* Yukon Exploration and Geology 1999, D.S. Emond and L.H. Weston (eds.), Exploration and Geological Services Division, Yukon, Indian and Northern Affairs Canada, p. 2-32.

RÉSUMÉ

L'or a dominé la scène de l'exploration en 1999 (Fig. 1); plus de 75 % des 9,5 millions de dollars (environ) qui ont été dépensés pour l'exploration au Yukon ont été dirigés vers la recherche du précieux métal jaune (Fig. 2). La plupart des cibles se situent dans la ceinture aurifère de Tintina, une série arquée d'indices et de gisements aurifères associés au plutonisme, au Yukon et en Alaska. Le Yukon a subi une forte activité plutonique au Crétacé moyen et la ceinture aurifère de Tintina comprend plusieurs séries intrusives du Crétacé moyen. Plusieurs projets reliés aux Séries intrusives de Tombstone et de Tungsten faisaient l'objet de programmes de forage en 1999, dont les projets Scheelite Dome, Clear Creek, Dragon Lake et Hit. Depuis plusieurs années, les Séries de Tombstone et de Tungsten ont été la cible de programmes d'exploration à la recherche d'or associé aux intrusifs et plusieurs régions offrent des cibles de forage et de nouvelles découvertes. La ceinture intrusive de Dawson Range, dans le centre-ouest du Yukon, a été intensément jalonnée sur la foi de travaux de recherche et de reconnaissance basés sur un modèle POGO (un gisement d'or associé au plutonisme en Alaska). La plupart des projets situés dans la ceinture de Dawson Range ont été soumis à une première phase d'exploration cette année et les résultats positifs générés pourraient aboutir à des projets plus avancés et à des découvertes. Le projet Longline dans la ceinture de Dawson Range est le projet le plus avancé dans cette ceinture intrusive; le succès des forages continuera à faire avancer le projet et servira de point d'ancrage pour augmenter les activités d'exploration dans la région.

L'exploration à la recherche de métaux communs a été orientée vers toute une gamme de types de gisements. L'exploration à la recherche de gisements de sulfures massifs volcanogènes continue dans le district de Finlayson Lake et dans les roches équivalentes du terrane de Yukon-Tanana, dans le sud du Yukon et dans la région de Dawson. En outre, on a examiné le district d'Ag-Pb de Rancheria à la recherche de gisements de veines d'argent à haute teneur et de gisements de remplacement des carbonates; la région de Howard's Pass à la recherche de gisements sédimentaires-exhalatifs (Sedex); ainsi que les régions de Kathleen Lakes et de Rusty Springs à la recherche de gisements de type Mississippi Valley et de type remplacement. Curieusement, il y a eu très peu d'exploration pour les cibles de Cu-Ni-EGP dans le sud-ouest du Yukon; pourtant cette région avait produit certaines des valeurs en EGP des plus spectaculaires au Canada ces dernières années. Les valeurs obtenues sur la propriété Klu d'Inco ltée en 1997 atteignaient jusqu'à 3,1 % de nickel, 10,4 % de cuivre, 0,19 % de cobalt, 75,8 g/t de platine, 20,6 g/t de palladium et 7,0 g/t d'or dans des échantillons choisis. L'exploration pour les métaux communs a été principalement axée sur l'affinage des cibles de forages dans les propriétés existantes. On prévoit plusieurs programmes de forage pour l'année 2000.

La mine d'or Brewery Creek de Viceroy Resources, produisant par lixiviation en tas à l'est de Dawson, était l'unique producteur à temps plein au Yukon en 1999. On avait extrait 1 890 000 tonnes de minerai au cours des trois premiers trimestres. La production d'or,

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jusqu'à la fin septembre, se chiffrait à 34 682 onces (107 600 grammes) à un coût de production réel de 289 $ US/oz. On prévoit que la production annuelle atteindra 55 000 onces (1 700 000 grammes) à un coût de production réel de 250 $ US/oz. Les travaux de mise en valeur à la mine Brewery Creek comprennent un agrandissement de 80 000 mètres carrés du remblai de lixiviation et le prolongement de la route de service jusqu'à la zone Lucky. Les dépenses en travaux préparatoires à la mine Brewery Creek se sont chiffrées à 6,1 millions de dollars en 1999 ce qui constitue presque la totalité des investissements de 6,5 millions de dollars qui ont été dépensés au Yukon en 1999 pour la mise en valeur de mines. Au début de 1999, les réserves de Brewery Creek étaient de 11,8 millions de tonnes titrant 1,13 g/t.

La mine d'or-argent Mt Nansen de BYG Natural Resources a fermé en février. La production jusqu'à la fin de février a atteint 15 500 tonnes titrant 7,5 g/t d'or et 50 g/t d'argent ce qui représente 3738 onces (116 200 grammes) d'or et 24 917 onces (775 000 grammes) d'argent.

Il y a eu de nouveaux travaux d'aménagement au projet minier de cuivre-or-argent Minto de Minto Explorations ltée. Un court programme de construction a été complété à la fin de septembre. On a déménagé jusqu'au site Minto deux broyeurs appartenant à la société, qui étaient temporairement entreposés. Toutes les composantes des broyeurs ont été nettoyées, passées au jet de sable et repeintes et on a assemblé les deux broyeurs. De plus, on a complété des travaux routiers et préparatoires qui permettront de continuer la construction au cours de l'hiver qui vient. Ce projet a régulièrement progressé pendant une période de faibles prix du cuivre pour en arriver au stade de prochaine mine du Yukon. Les réserves géologiques en place du gisement se chiffrent à 8 818 000 tonnes titrant 1,73 % de cuivre, 0,48 g/t d'or et 7,5 g/t d'argent, la teneur de coupure du minerai se situe à 0,50 % de cuivre. La quantité de minerai qui sera extraite selon le plan actuel de la mine se chiffre à 6 510 000 t titrant 2,13 % de cuivre, 0,62 g/t d'or et 9,3 g/t d'argent, le coefficient de recouvrement est de 4,9/1. Pendant la durée d'exploitation prévue de la mine, le coût de production réel moyen sera de 0,46 $ US/lb, après les crédits pour l'or et l'argent, et en tenant compte de tous les coûts attribuables au transport ainsi que des tarifs de fonderie et d'affinage. On prévoit commencer la production vers la fin de 2000.

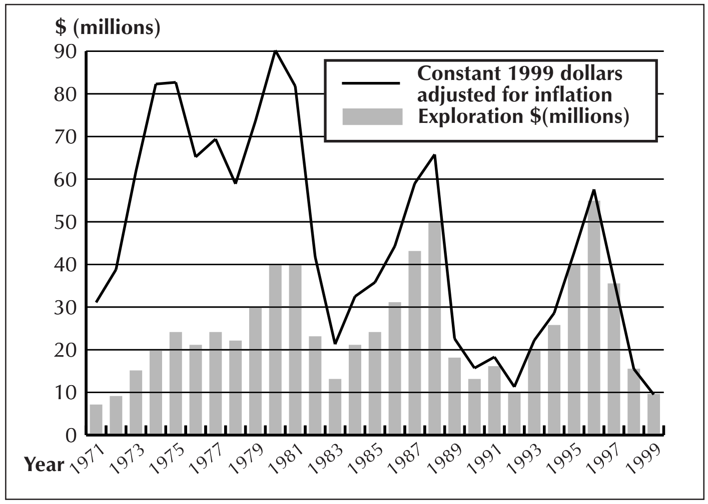

Figure 2. *Yukon exploration expenditures: 1971-1999.*

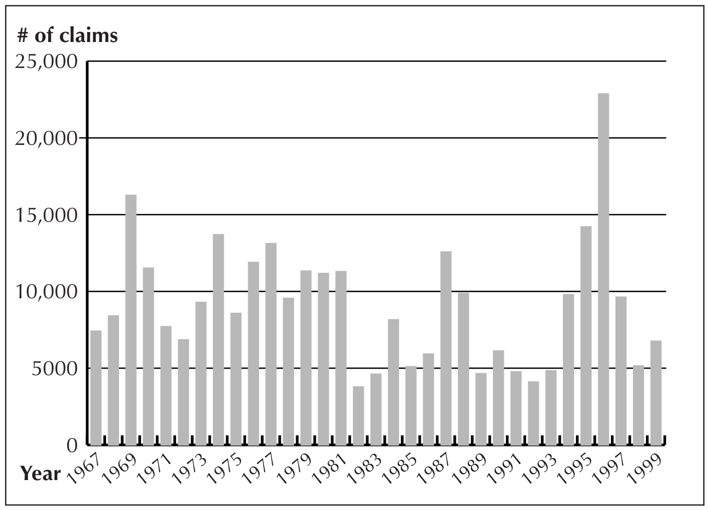

Figure 3. *Quartz claims staked: 1967-1999 (to end of October).*

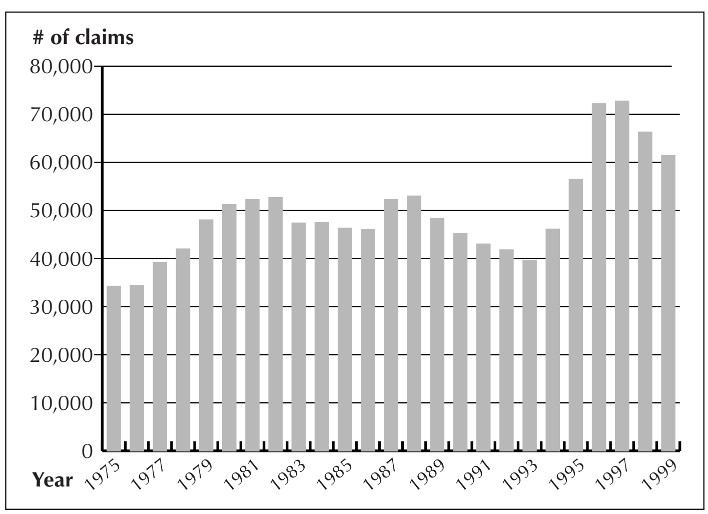

Figure 4. *Quartz claims in good standing: 1975-1999 (to end of October).*

INTRODUCTION

Gold dominated the exploration scene in 1999 (Fig. 1); over 75% of the approximately $9.5 million spent on Yukon exploration was directed towards the search for the precious yellow metal (Fig. 2). Most targets are within the Tintina gold belt, an arcuate sequence of intrusive-related gold occurrences and deposits in Yukon and Alaska. The Yukon experienced extensive plutonism in the mid-Cretaceous, and the Tintina gold belt encompasses several of these mid-Cretaceous intrusive suites. Several projects, such as Scheelite Dome, Clear Creek, Dragon Lake and Hit which are related to the Tombstone and Tungsten intrusive suites, had drill programs in 1999. The Tombstone and Tungsten suite have received several years of exploration for intrusive-related gold targets, and several areas are generating drill targets and new discoveries. The Dawson Range intrusive belt in west-central Yukon experienced a large amount of claim staking on targets generated by research and reconnaissance using a POGO model (Alaskan intrusive-related gold deposit). Most projects in the Dawson Range were subjected to first pass exploration this year, and positive results generated could lead to more advanced projects and discoveries. The Longline project within the Dawson Range is the most advanced project in this intrusive belt; positive drill results will continue to advance this project and anchor expanded exploration in this area.

Base metal exploration focussed on a variety of deposit types. Exploration continued in the Finlayson Lake district, and equivalent Yukon-Tanana Terrane rocks in southern Yukon and the Dawson area, for volcanogenic massive sulphide deposits. In addition, the Rancheria Ag-Pb district was investigated for high grade silver vein and carbonate replacement deposits, the Howard’s Pass area for sedimentary-exhalative (Sedex) deposits, and the Kathleen Lakes and Rusty Springs areas for Mississippi Valley-type and replacement deposits. Surprisingly, only a small amount of exploration was conducted in southwestern Yukon on Cu-Ni-PGE targets; this area has in recent years produced some of Canada’s most spectacular PGE numbers. Results reported in 1997 from Inco Ltd.’s Klu property returned values from grab samples of up to 3.1% nickel, 10.4% copper, 0.19% cobalt, 75.8 g/t platinum, 20.6 g/t palladium and 7.0 g/t gold. Most exploration for base metals was directed at refining drill targets on existing properties and several drill programs are anticipated in 2000.

The number of quartz claims staked to the end of October, 1999 was 7258 (Fig. 3), an increase over 1998 figures. The bulk of new claims were staked on targets in the Tintina gold belt. Claims in good standing had dropped to 61,407 (Fig. 4) in the same period, a decrease of approximately 5000 claims from 1998 levels.

MINING AND DEVELOPMENT

Viceroy Resources Ltd.’s **Brewery Creek gold mine** (Yukon Minfile, 1997, 116B 160) was the Yukon’s only full-time producer in 1999. Production to the end of September, 1999 from the heap leach gold mine, located east of Dawson City, was 34,682 ounces (107,600 grams) at a cash cost of US$289 per ounce. Brewery Creek is host to a range of intrusive-related gold deposits including the intrusive-hosted Classic Zone (10.9 Mt of 0.52 g/t Au), to more distal deposits hosted in sills and sedimentary rocks outside the thermal aureole of the pluton (Lindsay et al., this volume). It is these more distal deposits which are currently the producing ore bodies. Production to the end of 1999 is estimated at 55,000 ounces (1,700,000 grams) of gold at a cash operating cost of US$250 per ounce. Earlier forecasts projected production of 74,000 ounces (2,300,000 grams) but longer leach cycles for sediment-hosted ore, and lower recoveries have resulted in a shortfall. Minesite development at Brewery Creek included expansion of the heap leach pad by 80,000 square metres and extension of the haul road to the Lucky Zone. Development costs at Brewery Creek were $6.2 million, which was the bulk of the $6.5 million spent on mine development in the Yukon in 1999. Reserves at Brewery Creek were 11.8 million tonnes grading 1.13 g/t at the beginning of 1999, based on a gold price of US$375 per ounce. Ore mined to the end of the third quarter was 1,890,000 tonnes (Fig. 5).

Figure 5. *Mining at Brewery Creek occurred in the Golden open pit seen in the photo, and in the Kokanee and Lower Fosters pit in 1999. Photo by H. Copeland*

Viceroy also conducted extensive exploration on the mine site in an effort to upgrade resources into the reserve category. Reverse circulation drilling was conducted mainly in the Bohemian and Schooner zones, with lesser drilling in the North Slope and Classic zones. Trenching was also conducted in the Classic and Schooner zones.

Late February saw the closure of the **Mt. Nansen gold-silver mine** (Yukon Minfile, 1997, 115I 064, 065; Stroshein, 1999) of BYG Natural Resources. Production to the end of February was 15,500 tonnes at a grade of 7.5 g/t gold and 50 g/t silver, or 3738 ounces (116,200 grams) of gold and 24,917 ounces (775,000 grams) silver.

New mine development occurred at the **Minto copper-gold-silver project** (Yukon Minfile, 1997, 115I 21, 22) of Minto Explorations Ltd. A short construction program was completed at the end of September. Two grinding mills owned by the company were moved from a temporary storage area to the property (Fig. 6). All mill components were cleaned, sandblasted and painted, and the two mills were assembled. In addition, some roadwork and preparations to allow construction to continue through the coming winter were also completed. The project

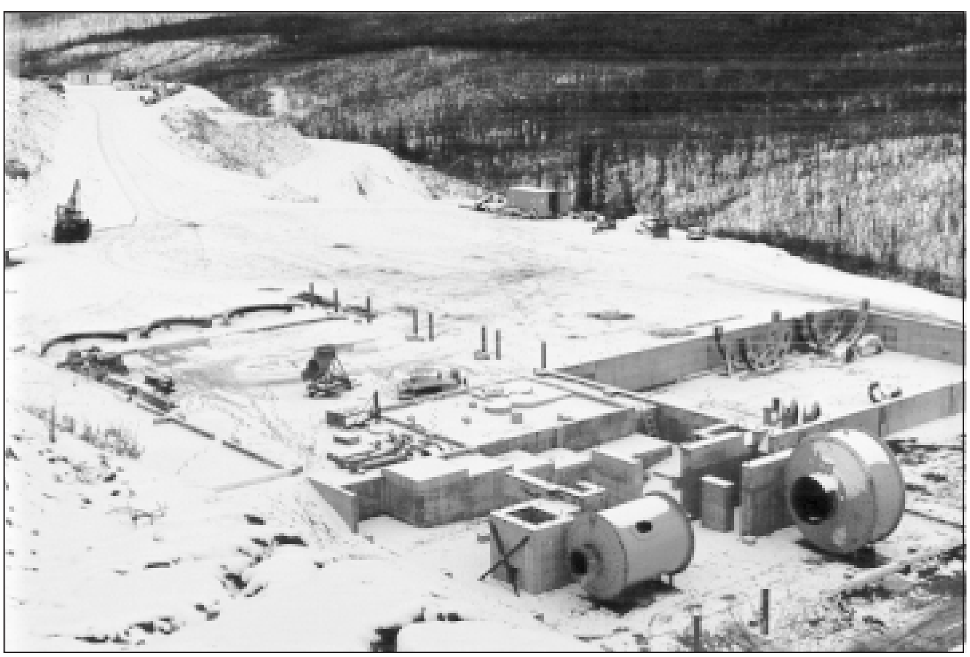

Figure 6. *Assembly of the semi-autogenous grinding (SAG) and ball mills were completed in the fall of 1999 at the Minto project. The completed mills are ready for installation on the mill foundation. Photo by Minto Explorations Limited*

has made steady progress despite a period of depressed copper prices. It is hoped that the Minto property may develop into the Yukon's next mine. The *in-situ* geological reserve for the deposit is 8,818,000 t with grades of 1.73% copper, 0.48 g/t gold and 7.5 g/t silver above a cut-off grade of 0.50% copper. The ore that will be mined as per the current mine design is 6,510,000 t with grades of 2.13% copper, 0.62 g/t gold and 9.3 g/t silver with an overall stripping ratio of 4.9:1.0. The average cash operating cost per pound of copper produced is US$0.46 over the estimated mine life, including all freight, and smelting and refining charges, and after gold and silver credits. The project is fully permitted and production is currently anticipated for late in 2000.

GOLD EXPLORATION

Gold exploration was the main focus of companies working in the Yukon in 1999. Intrusive-related gold deposits of the Tintina gold belt were the main targets sought. Deposit styles in this relatively young exploration play include intrusion-hosted, proximal (in contact) zones, or within the thermal aureole, as well as in distal settings beyond the horfels zone (Hart et al., in press). Exploration in recent years has shifted from intrusion-hosted targets to encompass a wider range of prospects in the proximal and distal settings. The high potential for discoveries in this belt is emphasized by the recognition of the multiple styles of deposit types, combined with the expansion of the belt to include most of the mid-Cretaceous plutonic suites in the Yukon. These factors, combined with overall low exploration expenditures in recent years, illustrate that the Tintina gold belt in the Yukon is under-explored.

Shawn Ryan of Canadian United Minerals Incorporated, a locally based private exploration company, made a significant discovery of high-grade gold skarn in 1997. The discovery on the **HORN** claims (NTS 116B/07) covers part of a roof pendant of sedimentary rocks of Devonian to Jurassic age enclosed by quartz monzonite of the Tombstone Plutonic Suite. Pyroxene and pyrrhotite skarns containing gold, silver, copper, lead, zinc, arsenic and bismuth are developed in Permian Takhandit Formation limestone. In 1999, Canadian United performed Kubota trenching, geological mapping, prospecting and AX-size core drilling (Fig. 7) on the discovery. Channel sampling in the walls of Trench 99-01 returned values of 58.9 and 85.44 g/t Au over widths of 5.94 metres and 4.45 metres, respectively. The

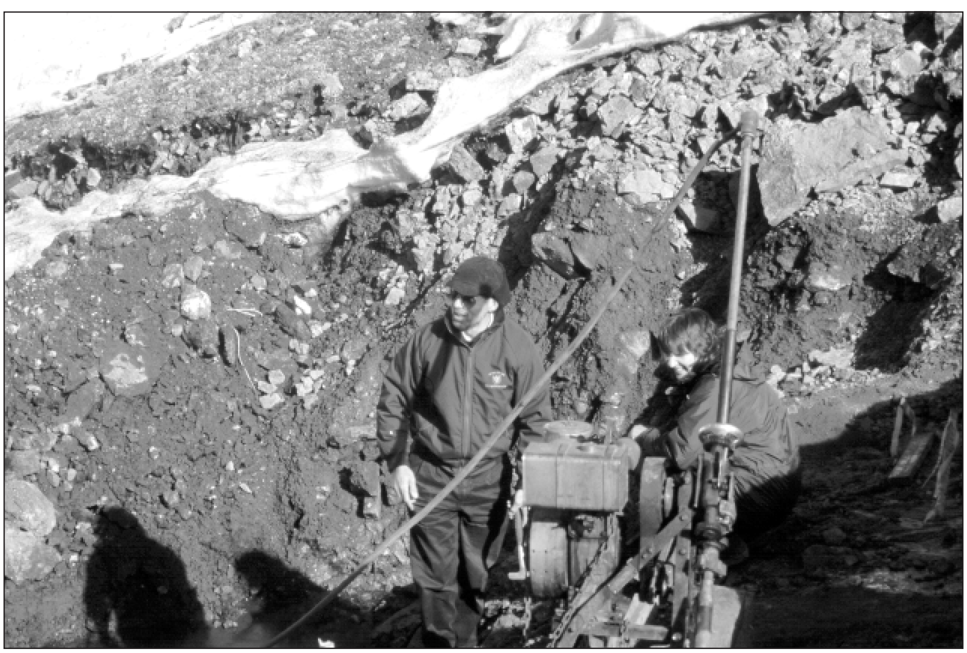

Figure 7. *An X-ray drill capable of drilling AX core is pictured in trench 99-01 on the Horn property. Photo by J. Duke*

Figure 8. Discordant quartz-sulphide vein in quartz sericite schist from the Scheelite Dome property.

channel samples were on opposite walls of the trench, approximately 10 metres apart. Ten holes were drilled from the floor of the 99-01 trench, with seven holes intersecting significant mineralization. Hole 99-04 returned 11.03 metres of 21.6 g/t Au, and 99-11 returned 5.30 metres of 180.8 g/t Au (Tenney, 1999). Dave Tenney, an independent consulting geologist, has proposed an exploration program based on a model derived from the Little Chief copper skarn deposit in the Whitehorse Copper Belt. Further drilling will be required to define the extent of this new discovery and other high-grade showings on the property.

Copper Ridge Exploration conducted a 13-hole, 1357-metre diamond drilling program, structural analysis, ground magnetics, geochemical sampling, and mapping and prospecting on the large **Scheelite Dome** property (Yukon Minfile, 1997, 115P 033). Drilling was directed at several targets within a large 6 by 2 kilometre, >100 ppb gold-in-soil anomaly, which is underlain by Neoproterozoic to Lower Cambrian Hyland Group metasedimentary rocks adjacent to the Scheelite Dome granitic intrusion of the Tombstone suite. Mineralization on the property consists of structurally controlled, metasedimentary-rock-hosted, quartz-sulphide veins, skarn, and replacement occurrences (Hulstein et al., 1999; Fig. 8). Fort Knox-type, intrusive-hosted low sulphide veins occur in the Scheelite Dome intrusion. Work to date has concentrated on the mineralization hosted in metasedimentary rocks. The 1999 drilling was successful in continuing to delineate widespread gold mineralization on the property. Structural interpretation, followed by ground-based magnetometer surveys and diamond drilling, was successful at demonstrating the importance of northwest-striking veins. Holes 99-23 and 99-24 were drilled to test a newly interpreted northwest structure; these holes had the two best results from the 1999 program, yielding 3.7 g/t Au over 4.6 metres and 2.5 g/t Au over 5.9 metres, respectively. Drill intersections were characterized by correlation with key pathfinder elements including bismuth, arsenic and antimony. Drill interesections also correlate well with areas of strong alteration, fracturing and shearing, and the presence of a large quantity of discordant quartz veining.

Redstar Resources conducted a late season, 2-hole diamond drilling program (Fig. 9) totalling 219.2 metres on the **Clear Creek** (Yukon Minfile, 1997, 115P 012, 023) property. The two

Figure 9. Diamond drill on the Clear Creek property of Redstar Resources in October, 1999. Photo by M. Stammers

holes targeted the Bear Paw breccia zone, a quartz breccia zone cutting metasedimentary and intrusive rocks. The breccia is dominantly clast-supported, with fragments consisting of quartz monzonite and minor quartz biotite schist and hornfels. Intervening sections of quartz monzonite are highly silicified, have limonitic fractures, and contain minor disseminated and fracture-controlled pyrrhotite and arsenopyrite. The zone is defined by a large 1300 by 1100 metre gold-arsenic-bismuth geochemical anomaly, which coincides with a magnetic-low geophysical anomaly. Surface sampling of limited exposures returned values up to 9.24 g/t Au from sulphide-rich float samples. Drill hole BP99-01 returned three separate intersections, including: 1) 7.25 m grading 2.17 g/t Au within a section of mainly quartz breccia; 2) 26.70 metres grading 2.00 g/t Au (including 10.5 metres at 3.35 g/t Au) within quartz monzonite; and 3) 0.50 metres grading 3.02 g/t Au from a quartz-sulphide vein within a larger section of quartz breccia. Gold grades from the 26.70 metre intersection are evenly distributed, with the highest assay within a zone of 5.4 g/t over 1.5 metres. Drill hole BP99-02, located 250 metres from BP99-01, intersected 0.44 metres of 10.21 g/t Au from a quartz-sulphide vein and 1.68 metres of 3.32 g/t Au within quartz breccia. This discovery of a new style of intrusive-related gold mineralization at Clear Creek illustrates the potential for new discoveries, even in areas with a long exploration history.

International Kodiak Resources continued to evaluate the large 68,000 hectare **Oki Doki** (Yukon Minfile, 1997, 116BA 013, 033) property that adjoins the Brewery Creek mine. The property covers intrusive-related gold targets within Selwyn Basin stratigraphy that is intruded by the Tombstone Plutonic Suite. The 1999 program followed up on anomalous stream and soil geochemical anomalies generated by previous work. Grid and contour soil sampling, prospecting, geological mapping, blast- and hand-trenching were performed in three main areas (Areas 1, 5 and 3). A quartz monzonite plug that contains areas of sheeted veins underlies Area 1, northeast of Brewery Creek near Mike Lake. East-trending shears with silicic, argillic, sericitic and carbonate alteration, and quartz-sulphide veining were also investigated. Chip sampling of sheeted veining (Fig. 10) returned an average value of 340 ppb Au over 40 metres with a peak value of 584 ppb Au. Quartz sulphide veining within the shears assayed up to 1.23 g/t Au, 66.1 g/t Ag, 16,755 ppb As, 6492 ppb Sb, 97 ppm Bi, 2198 ppb Hg and 5434 ppm Zn over 0.60 metres. Area 5, east of Brewery Creek, covers a small monzonite intrusive, where gold values up to 480 ppb have been obtained from hornfelsed sedimentary rocks containing finely disseminated arsenopyrite. Hand trenching in Area 3 revealed Earn Group and Road River Group lithologies with anomalous silver, vanadium, selenium, chromium, barium and phosphorous indicative of "Nick" style Sedex mineralization. Silver values averaged 5500 ppb over the entire 100-metre-length of the hand trench (Penner et al., 1999).

__Figure 10.__ Don Penner and Marco Vanwermeskerken (back) examine a zone of sheeted quartz veins in quartz monzonite on the Oki Doki property.

Expatriate Resources performed a small program of geochemical sampling, mapping and prospecting on the **Aurex** (Yukon Minfile, 1997, 105M 060) property, adjacent to their wholly-owned **Sinister** property. Expatriate Resources optioned the Aurex property from YKR International. The property is underlain by Hyland Group metasedimentary rocks in the immediate hanging wall of the regional-scale Robert Service Thrust. Values up to 8.8 g/t Au have been obtained from arsenopyrite-pyrrhotite-bearing skarn exposed on the Aurex property. Shallow air-track drilling by YKR International between 1992 and 1994 outlined three zones containing widespread gold mineralization with highly anomalous arsenic, antimony and tungsten. The best intersection within these holes averaged 7.9 g/t Au over 6.1 metres. Late in the year, Expatriate entered into a joint venture agreement on the Aurex-Sinister with Newmont Mining Corporation.

NovaGold Resources Inc. conducted a small program of auger soil sampling to test ground and airborne magnetic anomalies on the **McQuesten** (Yukon Minfile, 1997, 105M 029) property optioned from Eagle Plains Resources. The property adjoins the Aurex-Sinister ground to the north and covers similar geology. Previous work has identified two major zones: the West and East zones. The West Zone covers a Cretaceous quartz monzonite dyke, which variably crosscuts reactive and non-reactive stratigraphy. Reverse circulation drilling in 1997, north of the dykes, drilled through intersections within calcareous sedimentary rocks with abundant gouge zones. Intersections returned values of 1.77 g/t Au over 35.3 metres and 3.23 g/t Au over 21.3 metres. Trenching in 1998, 500 metres to the east, across an extension of the dyke hosted by calcareous rocks, returned a value of 5.18 g/t Au over 10 metres. This intersection is part of a larger intersection of 2.05 g/t Au over 36 metres. The East Zone, located roughly 600 metres east-southeast of the West Zone, consists of thick mineralized horizons in calcareous sedimentary rocks. Gold is associated with zones of structural disturbance visible only in trench excavation and drill core. Trench results from an east-trending trench illustrate the lateral extent of mineralization and include: 0.33 g/t Au over 148 metres; 1.59 g/t Au over 14 metres, open to the east; and 0.82 g/t Au over 98 metres. The McQuesten and Aurex-Sinister properties represent the potential for an emerging gold camp. Moreover, the McQuesten and Aurex-Sinister properties are located adjacent to the prolific Keno Hill silver-lead-zinc district, which has produced over 200 million ounces of silver.

Eagle Plains Resources conducted geochemical sampling, mapping and prospecting on several intrusive-related gold targets related to the Tombstone suite. The properties included the **May** (Yukon Minfile, 1997, 115P 056) in the Mayo area, **Nug** (Yukon Minfile, 1997, 105O 048) near McMillan Pass, **Dragon Lake** (Fig. 11; Yukon Minfile, 1997, 105J 007), and

Figure 11. *Ken Galambos, Mineral Development Geologist with the Yukon Government, examines core on the Dragon Lake property of Eagle Plains Resources Ltd.*

Hit (Fig. 12; NTS 105P/5). The programs at Dragon Lake and Hit were followed up with helicopter-supported diamond drilling. Mineralization at Dragon Lake consists of widespread oxidized skarn mineralization hosted in Neoproterozoic to Lower Cambrian Hyland Group calcereous sedimentary rocks adjacent to a small quartz monzonite plug. Four holes totalling 288 metres were drilled, with each hole intersecting hornfels to calc-silicate rocks, to garnet-actinolite skarn with minor pyrrhotite, pyrite, chalcopyrite. The highest value returned from drilling was in a skarn interval which assayed 3.66 g/t Au over 1.2 metres. An outcrop of oxidized grey limestone near the contact of a small Tombstone suite granitic plug on the Hit property was tested with two diamond drill holes. Samples from outcrop on surface assayed 7.85 g/t Au over 7.0 metres, while drilling intersected calc-silicate skarn mineralization which assayed 2.56 g/t Au over 0.9 metres.

NovaGold Resources Inc. explored several properties with geochemical sampling, mapping and prospecting in the eastern portion of the Tombstone belt. These included the **Lightning/ Tempest, Sass, Bach, Tarakan, Stratus, Zaytchyk, Gato Negro, Mozart, Beethoven and Harlan** properties. NovaGold acquired 100% of the properties early in 1999 from Viceroy Resources. Viceroy staked most of the properties in 1997 and 1998 as a result of a large regional exploration program aimed at intrusive-related gold targets in Selwyn Basin. Most of these properties cover new prospects. The Harlan property is a new discovery located approximately 150 kilometres north-northeast of Ross River. The geology of the property is described in detail by Schulze in this volume. Two zones have been described on the property: the Vortex and West Porphyry zones. The Vortex Zone consists of a thick sequence of heavily argillically altered and silicified Earn Group chert-pebble conglomerate with quartz veining and interstitial replacement quartz-arsenopyrite mineralization. Contour soil sampling has outlined a 600 by 400 metre area of greater than 1000 ppb Au. Select

Figure 12. *Chuck Downey examines the surface showing on the Hit property, consisting of limonitic weathering grey siliceous limestone.*

grab sampling of quartz-arsenopyrite talus within the zone returned up to 4.64 g/t Au. Exploration in 1999 also identified a breccia underlying part of the Vortex Zone (Fig. 13). Samples of the breccia returned values to 6.5 g/t Au. The West Porphyry Zone occurs approximately 2.5 kilometres west of the Vortex Zone. The West Porphyry Zone consists of a swarm of altered quartz monzonite dykes intruding mainly Road River Group sedimentary rocks. Chip sampling of various dykes has returned values up to 0.86 g/t Au over 20.8 metres and 1.08 g/t Au over 1.5 metres. The Vortex Zone represents a significant new discovery as the host conglomerates have previously been thought to have low mineral potential. NovaGold plans to aggressively explore this new discovery in 2000.

Prospector International Resources Inc. conducted an airborne magnetics survey on their **Swan** (Yukon Minfile, 1997, 105O 024) property which adjoins NovaGolds' Lightning/ Tempest property.

Hudson Bay Exploration explored the **Hit** property in southeastern Yukon with geochemical sampling, mapping, prospecting, airborne geophysics, as well as a 4-hole, 642-metre diamond drilling program (Fig. 14). The property is one of a group of properties that define a northwesterly trend including NovaGold's Sun/Sprogge, Rimfire's Fer (described by Jones and Caufield in this volume), and Phelps Dodge's Hy property. The properties are in general underlain by Neoproterozoic to Lower Cambrian Hyland Group clastic rocks. The closest mapped intrusive rocks are at the Tuna occurrence (Yukon Minfile, 1997, 105H 082), approximately five kilometres to the south, and several monzonitic to granitic dykes on the Sun/Sprogge property to the southeast. Hudson Bay has not released any results from this year's program.

NovaGold conducted a minor program of mapping and sampling on the **Sun/Sprogge** (Yukon Minfile, 1997, 105H 034) property. Three main mineralized zones occur on the property. The Ridge Zone consists of a wide west-northwest-trending, moderately north-northeast-dipping coarse clastic member comprised of quartz-pebble conglomerate and sandstone, with lesser fault-bounded phyllite. The entire unit has undergone variable argillic alteration of feldspathic members, silicification and quartz veining, and limonitic staining after fine disseminated sulphides. Narrow auriferous quartz-arsenopyrite veins occur throughout this

Figure 13. *Quartz breccia with argillite and clay-altered intrusive fragments from the Harlan property of NovaGold Resources Inc.*

zone, but comprise only a small percentage of the rock mass. This is unlikely to totally account for the large surrounding gold anomalies within talus fines. Gold values up to 1130 ppb Au were obtained from limited soil development directly along the ridgeline within limonitic 'grits,' returning 0.33 g/t Au from rock chip sampling. In 1999, NovaGold Resources recognized the presence of fine north-northeast-trending, fracture-controlled, strongly limonitic mineralization. Selective sampling returned values up to 536 ppb Au; north-northeast-trending fractures may host the bulk of gold mineralization across the zone. NovaGold also obtained a value of 6.79 g/t Au from a grab sample of silicified vuggy breccia float with clasts of sedimentary rock. This sample was collected from talus along the northern flank of the Ridge Zone.

The Main Skarn/Confluence Zone area is the second major exploration target. The Main Skarn has recently been identified as a gently east-southeast-dipping zone of retrograde skarn roughly five metres thick, underlain by strongly brecciated phyllite, and associated with abundant proximal skarn 'pods.' Surface chip sampling, oblique to true width, returned 2.38 g/t Au over 22.5 metres, extending into a monzonitic dyke along the west margin. Mineralization consists of locally nearly massive pyrite and pyrrhotite, with up to 3% chalcopyrite and minor arsenopyrite veins. The Confluence Zone is a zone at least 500 metres in length of chalcedony and arsenopyrite veining within silicified and argillically altered, limonitic coarse clastic sedimentary rocks. Abundant anomalous values to 8.19 g/t Au over 0.1 m and 0.525 g/t Au over 5.0 metres were returned from 1998 sampling, as well

Figure 14. *Mike Buchanan (right) and Anna Fonseca (left) of Hudson Bay Exploration examine core on the Hit property.*

as a value of 4.24 g/t Au over 4.5 metres from 1997 sampling. Exploration by NovaGold in 1999 resulted in the discovery of fairly abundant rubble of strongly mineralized skarn and arsenical breccia returning values of 2.00 g/t Au within the Confluence Zone.

The third target is a broad gold-in-soil anomaly with values of up to 875 ppb Au. Gold values are greatest along the south flank of the Ridge Zone and proximal to similar altered coarse clastic members to the west; mineralization may be associated with the extension of the Ridge Zone coarse clastic unit. Anomalous values appear to occur along lower, often discreet elevations, suggesting partial structural control. (Schulze, pers. comm., 1999).

Expatriate Resources conducted a small geological program on the **Hyland** (Yukon Minfile, 1997, 95D 011) property approximately 70 kilometres northeast of Watson Lake in southeastern Yukon. The property is underlain by Neoproterozoic to Lower Cambrian Hyland Group metasedimentary rocks. Structural interpretation, the presence of narrow intrusive dykes, geophysics and a gold-bismuth-arsenic soil geochemical signature suggest the property overlies a buried intrusive. The Hyland property surrounds the Hyland Gold property, now 100% owned by Cash Resources, and the Cuz property of Nordac Resources. Previous work on Hyland Gold, including rotary percussion drill holes, has produced significant results, including intersections of 3.0 g/t Au over 16.7 metres, and 1.1 g/t Au over 142 metres.

Several properties were staked in west-central Yukon in the early part of 1999. Properties were staked based on regional compilations done over the winter. These compilations utilized exploration concepts generated by the POGO discovery in Alaska (8.98 million tonnes grading 17.8 g/t Au). The bulk of the claims were staked in the northern extent of the mid-Cretaceous Dawson Range intrusive belt. The area has had a long history of placer gold production, but no major hard rock source of the gold has ever been discovered.

Figure 15. *Geologist Sara Gougeon examines core at the Longline property of Barramundi Gold. Photo by S. Sears*

Barramundi Gold continued to work on their **Longline** (Yukon Minfile, 1997, 115N 024) property, which is the most advanced property in the northern portion of the Dawson Range. The company carried out two phases of diamond drilling (Fig. 15), 53 kilometres of Gradient Induced Polarization, 25 kilometres of Real Section Induced Polarization surveys, geochemical surveys, prospecting and sampling. The property is underlain by granodiorite of the Klotassin Batholith, which is host to several high-grade quartz-sulphide vein occurrences. The first phase of drilling was directed at outlining a small reserve on the V2 vein, which could then be bulk sampled. The vein was tested with 22 holes totalling 550 metres. Assays up to 386.6 g/t Au over 0.66 metres were obtained from the drilling. The drilling was difficult with variable core recovery, and the results reflect the strong nugget effect that is evident from surface sampling. A second phase of drilling was conducted after a financing arrangement and joint venture agreement with Newmont Exploration. This phase of drilling targeted coincident gold-arsenic-geochemical and geophysical (gradient I.P.) anomalies, which had never been previously tested. Twelve holes totaling 2100 metres were drilled. High-grade quartz veining, similar to veining cutting the granodiorite on surface, was intersected at depth with values up to 45.7 g/t Au over 0.20 metres. Several drill holes intersected altered granodiorite, consisting of locally intense sericite and silica alteration with disseminated arsenopyrite and pyrite. The alteration zones assay as high as 3.19 g/t Au over 27 centimetres and 2.23 g/t Au over 1.00 metre. These zones generally range between 0.10 and 0.30 g/t Au over widths of 10 to 20 centimetres; these zones average 1-2 per metre over several metres cored width. An average of 20 alteration zones occur per hole, with 52 found in hole LL99-10.

Troymin Resources Ltd. conducted an exploration program consisting of stream sediment sampling, ridge-and-spur soil sampling, rock sampling and mapping on its newly staked **Moosehorn Property** adjacent to the Longline property. The property covers 294 LAD claims in the Moosehorn Range mountains, 80 kilometres north of Beaver Creek. The stream sediment sampling program identified three areas of anomalous metal zonation: 1) the northwest part of the property is Bi-rich; 2) the central part of the property is Au, Ag and As-rich; and 3) the south-central part of the property is Sb-rich. Anomalous Zn, W and Hg values are irregularly distributed throughout the property. Gold values in stream sediments range from less than detection (< 0.2 ppb) to 701.6 ppb, with 5 samples greater than 100 ppb. The ridge-and-spur soil sampling program returned values up to 364 ppb Au, with 4 samples > 100 ppb. Three areas of coincident, anomalous Au, Ag, As, Sb, Bi, Pb and Zn were identified, two of which are greater than 400 metres long. Rock samples from the property returned values up to 432 ppb Au, 0.4% Pb, 1.2% Zn, 10.2 g/t Ag and 0.45% As (S. Casselman, pers. comm., 1999).

Kennecott Canada conducted geochemical surveys, geological mapping, prospecting, minor trenching and airborne geophysical surveys on the Sixty and Poker Creek properties in the Sixty Mile Creek, Glacier Creek and Miller Creek areas. No results from the program were released.

Nordac and Expatriate Resouces formed the Eureka Joint Venture to explore the Eureka-Armenius, Forty and Track properties in west-central Yukon. The properties are all within historic placer gold mining areas. The properties were explored with geochemical sampling, mapping, prospecting and hand trenching. The **Track** (Yukon Minfile, 1997, 116C 137) property, about 50 kilometres northwest of Dawson City, hosts tungsten-bearing skarns developed in metasedimentary rocks along the north side of a Cretaceous intrusion. Prospecting in a heavily vegetated area near one of the skarn showings located float specimens that returned anomalous gold, bismuth and tungsten values. The best specimen yielded 3.59 g/t Au, 1655 ppb bismuth and 810 ppm tungsten.

The **Eureka/Armenius** (Yukon Minfile, 1997, 115N 057) properties adjoin one another and collectively total 386 claims covering 8000 hectares. They are located in the southern part of the Klondike Goldfields and are easily accessible by an extensive network of roads serving local placer miners. Creeks draining the property have produced more than 140,000 ounces (4.3 million grams) of placer gold. The claims are underlain by metasedimentary and metavolcanic rocks of the Devonian to Mississippian Nasina Assemblage of the Yukon-Tanana Terrane. The best bedrock exposures are in a few bulldozer trenches excavated by a previous owner. Sampling on the floor of one of these trenches returned a weighted average of 0.33 g/t Au across a 6.5-metre-wide limonitic fracture zone. Prospecting along access roads and in soil profiles on the banks of trenches discovered abundant previously unbroken and unreported boulders of limonite breccia. Samples of the breccia assayed in the range of 0.85 to 15.00 g/t Au. A regional-scale thrust was mapped and sampled in a placer miner's cut and one of seven samples taken assayed 75.38 g/t Au. Before the crew could return to the area, placer mining had progressed upstream and the sampled area had been reburied. Subsequent sampling of another bedrock exposure adjacent to an area that was being actively placer mined and was producing gold, returned low values. Results from this target suggest the gold is erratically distributed within strongly fractured rocks developed along the thrust fault.

Teck Exploration performed a program of geological mapping, prospecting, and soil and stream sediment sampling on the **Ten Mile** (Yukon Minfile, 1997, 115N 110) Creek property. The claims are underlain by a quartz monzonite intrusive of probable Cretaceous age (Fig. 16) intruding Yukon-Tanana Terrane metamorphic rocks. Phelps Dodge has a large block of **FLUME** claims that adjoin the Teck property and cover similar geology. Phelps Dodge performed a small program of mapping, geochemical sampling and prospecting on the FLUME claims. No results have been released from either program.

Prospector International optioned six properties staked by Prime Properties Syndicate on targets modelled after the POGO deposit in Alaska. The properties include the **HIHO, YOGO, OHGO, PREMO, TKO and LADUE** claims. Prospector International performed stream-sediment geochemistry, reconnaissance soil geochemistry and prospecting on the various targets. The properties produced several areas with anomalous gold, arsenic, antimony and mercury, which warrant follow-up programs.

Figure 16. *Jean Pautler of Teck Exploration examines quartz mineralization hosted in Cretaceous quartz monzonite on the Ten Mile Creek property.*

Other major claim holders in the Dawson Range who have also performed small programs of geochemical sampling and prospecting include Canandian United Minerals Incorporated and Deltango, both private Yukon-based exploration companies.

Pacific Ridge Exploration conducted a 9-hole, 995-metre diamond drilling program on the **JRV** (Yukon Minfile, 1997, 105K 051, 052, 053) property near Faro in central Yukon (Fig. 17). The property hosts silver-gold mineralization within the mid-Cretaceous Anvil Range plutonic suite. Mineralization, discovered as float in High Ace Creek, consists of quartz-sulphide breccia, quartz stockwork and sheeted veins. Grab sampling of this material within the Kulan zone averaged 138 g/t Ag and 1.7 g/t Au. Geochemical sampling and geophysical (Induced Polarization) surveys produced coincident Au-Ag-As-Sb-Pb soil anomalies and IP chargability highs, which were subsequently drilled. Drilling failed to intersect mineralization of the same tenor as that found on surface. The best intersection was in Hole 99-8 with an interval assaying 87.7 g/t Ag and 0.04 g/t Au over 9 metres. Hole 99-3 intersected a 7-metre interval grading 35.2 g/t Ag and 0.10 g/t Au. A new discovery, called the Risby zone, consists of quartz-chalcedony stockwork. Initial sampling by a prospector of 18 mineralized float samples averaged 426.9 g/t Ag and 3.31 g/t Au. Twelve samples were collected during a follow-up traverse that averaged 302.3 g/t Ag and 1.76 g/t Au. A chip sample across 4 metres of exposed quartz-chalcedony vein assayed 384.7 g/t Ag and 2.12 g/t Au.

Yukon Yellow Metal Exploration Ltd. explored the **Shootamook Creek** (Yukon Minfile, 1997, 105B 045) property in south-central Yukon with a program of AX core drilling. A single hole totalling 25.8 metres was drilled, and encountered altered granite with pyrite mineralization; the highest gold value was 39 ppb.

Figure 17. *Wayne Roberts (left), John Brock (right) and Pete Risby (background) discuss the geology of the JRV property.*

Tiberon Minerals explored the **Ruby** (Yukon Minfile, 1997, 105D 090) silver-gold project, 78 kilometres south of Whitehorse, with a program of mapping, prospecting and diamond drilling. The property is located near the centre of the Eocene Bennett Lake Caldera, a circular (23 kilometres in diameter) sequence of flat-lying tuffs and ignimbrites, bounded by a discontinuous ring dyke. The Bennett Lake Caldera occurs within crystalline rocks of the Coast Plutonic Complex. Prospecting discovered four new epithermal quartz-galena-arsenopyrite-silver sulphosalt-pyrite veins called the Brian, Tom, Mike and North. These newly discovered epithermal veins are located in the vicinity of the two main target veins, the Steve and Connie. The veins on the property average approximately 1 metre in width and assay up to 5311 g/t Ag. Drilling consisted of 4 holes totalling 326 metres, targeted at the Connie and Steve veins. The Connie was intersected in 2 holes with values up to 396 g/t Ag, 1.3 g/t Au over 4.7 metres, and 286 g/t Ag over 1.0 metre. The two holes drilled at the Steve vein failed to intersect the mineralized zone. A quartz-carbonate fault breccia with silver-copper-lead-zinc mineralization was discovered late in the season. The zone has a strike length of 250 metres and averages 1-2 metres in width. Channel samples averaged 1.7 metres grading 220 g/t Ag, 1.81% Cu, 1.86% Pb, 0.48% Zn and 1.4 metres grading 361 g/t Ag, 2.71% Cu, 4.7% Pb and 1.06% Zn.

In 1999, Troymin Resources Ltd. conducted an exploration program consisting of mapping, rock sampling and 336 metres of diamond drilling in 2 holes on its **Prospector Mountain** (Yukon Minfile, 1997, 115I 034, 036) property. The property is underlain by mafic to intermediate volcanic rocks of the Late Cretaceous to Early Tertiary Carmacks suite. These have been intruded by slightly younger monzonitic to quartz monzonitic rocks of the Prospector Mountain suite. Two styles of mineralization have been observed on the property: 1) precious-metals-bearing quartz-tourmaline veins; and 2) 'porphyry-type' disseminated pyrite with variable copper and molybdenum contents. The vein mineralization occurs in both the volcanic and intrusive rocks, but tends to be more widespread and have a greater gold content in the volcanic rocks. The veins are generally less than a few metres in width with the occasional vein set up to 10 metres wide. They contain variable amounts of galena, sphalerite, chalcopyrite, gold and silver. Porphyry-type alteration and mineralization were observed in the Prospector Mountain monzonite on the Lightning Grid and consist of two large areas of sub-cropping, disseminated pyrite mineralization with anomalous copper and molybdenum in soils (Casselman, pers. comm., 1999).

The 1999 drill program targeted IP chargeability anomalies with coincident Cu-Mo soil anomalies, and ground/airborne magnetic and radiometric anomalies in the Lightning Grid area. Both holes intersected disseminated pyrite mineralization at the target depth, but no anomalous Cu, Au or Mo values were returned. Troymin interprets the initial drill program as having penetrated the outer pyrite shell of a porphyry system.

BASE METALS EXPLORATION

Base metal exploration investigated a wide range of deposit types and geographic areas of the Yukon. Although the level of exploration was very low with only four small drill programs, a number of new discoveries were made, and several properties were advanced to a drill-ready stage.

CanAustra Resources conducted a 3-hole, 617-metre diamond drilling program on the **Rusty Springs** (Yukon Minfile, 1997, 116K 003) project optioned from Eagle Plains Resources (Fig. 18). The geologic setting, genesis and potential of the Rusty Springs occurrence is described in detail by Charlie Greig in this volume. The 1999 exploration targeted the stratabound silver-lead-zinc-copper-mineralized horizon located at the top of the Devonian Ogilvie Formation dolomite (Fig. 19). Drilling was conducted to the east and south of Orma Hill in an attempt to penetrate the unoxidized mineralized horizon below the water table. Drilling encountered silicified and brecciated mudstones, which are indicative of the underlying mineralization, however the drill was unable to penetrate the siliceous zone in all

Figure 18. *The landing gear collapsed on this Skyvan on the first trip into the Rusty Springs property. No one was injured and, with the aid of a satetllite phone and subsequent arrival of a Twin Otter, the program was only set back a few hours.*

three holes. One hole encountered a 16.6-metre intersection of fine- to medium-grained disseminated sphalerite within the mudstone and in quartz or quartz-carbonate microbreccia which assayed 3000 ppm Zn, suggesting the possibility that sedimentary-exhalative mineralization also exists on the property.

Eagle Plains Resources also staked the **PAMA** claims, which cover the former Bern (Yukon Minfile, 1997, 116K 009) occurrence approximately 40 kilometres south of Rusty Springs. The claims were staked as a result of a regional compilation of the Rusty Springs area. Satellite imagery, a regional-scale airborne magnetic survey, the Rusty Springs geologic model and Yukon Minfile were used to define targets for exploration. The property is host to a two-kilometre-long quartz-carbonate breccia zone containing tetrahedrite,

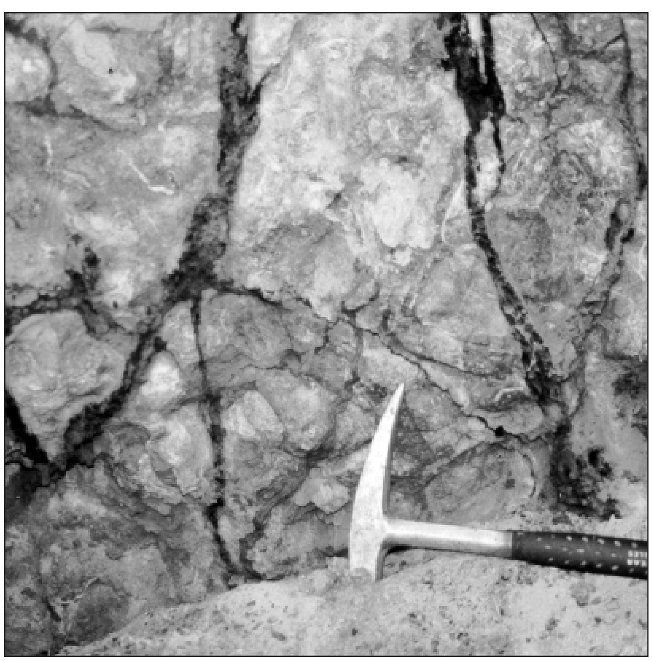

Figure 19. *Heavily oxidized and veined 'Katshat unit' at the top of the Devonian Ogilivie Formation dolomite at Rusty Springs.*

copper oxides, and lead and zinc sulphates hosted in a carbonate unit. Smithsonite-rich samples assayed up to 47.8% Zn.

Manson Creek Resources conducted an 8-hole, 1177-metre drill program (Fig. 20) on the **Kathleen Lake** (Yukon Minfile, 1997, 106C 065, 083, 085, 073) project, approximately 80 kilometres east of Keno Hill. Line cutting, Real Section Induced Polarization surveys, prospecting and sampling were also conducted. Drill holes were targeted on anomalies generated by the geophysical survey in the area of the Val/Vera (Yukon Minfile, 1997, 106D 083, 085) and Craig (Yukon Minfile, 1997, 106D 073) deposits. Replacement, vein and Mississippi Valley-type mineralization hosted in Proterozoic dolomites were the target of the 1999 drilling. The geophysical anomalies were explained in the drilling; unfortunately no economic mineralization was encountered. One hole in the vicinity of the Craig deposit encountered rhythmically bedded pyritic shale and argillite. Up to 30% pyrite occurs as conformable finely disseminated bands. Anomalous values up to 62 ppb Au, 3.0 ppm Ag, 71 ppm Pb and 622 ppm Zn occur in the shale unit.

Figure 20. *Drilling on the Vera property of Manson Creek Resources.*

Expatriate Resources explored the **HP-Nod** (Yukon Minfile, 1997, 105I 012) property in the Howard's Pass district with geochemistry, geological mapping, prospecting and sampling. The HP-Nod claims are adjacent to the Howard's Pass (Yukon Minfile, 1997, 105I 012) sedimentary-exhalative Pb-Zn-Ag deposits which host an indicated geological resource of 113 million tonnes grading 5.4% Zn and 2.1% Pb with approximately 16 g/t Ag. The claims cover extensions to the 'active member' of the Ordivician-Silurian Road River Group, which host the deposits in the district. Soil geochemical sampling by Expatriate returned strongly anomalous values of up to 1% Pb. Geochemistry and drilling by previous operators indicates that the active member extends for 3500 metres on the claims. Expatriate is planning on an 8000-metre drill program to test the active member on the property in 2000.

Nickelodeon and Tanquery Resources also conducted an exploration program of geochemical sampling, mapping and prospecting in the Howard's Pass district on the **Hawk and Eagle** (Yukon Minfile, 1997, 105I 043, 044) claims. These claims are located approximately 15 kilometres to the west of the Howard's Pass deposits.

In the Rancheria silver district in south-central Yukon, Nordac Resources explored the **Blue Heaven** (Yukon Minfile, 1997, 105B 020), **Touchdown** and **Quarterback** (Yukon Minfile, 1997, 105B 098) properties for carbonate replacement and high-grade silver vein deposits. Hand trenching on the Quarterback property uncovered a broad zone of limestone-hosted, galena-sphalerite fracture-filling mineralization containing an average of about 120 g/t Ag. The best individual chip sample returned 519 g/t Ag, 14.2% Pb and 0.6% Zn over 2.0 metres. On the Blue Heaven, an excavator trenching program along high-grade silver veins at the Blue Heaven property was completed. A total of 48 ore bags of galena-rich material was recovered during the exploration (Fig. 21). Complete assay results are not yet available. However, a composite sample of sphalerite-bearing mineralization representing the lower end of the recovered material assayed 2790 g/t Ag, 26.3% Pb and 27.8% Zn. In addition, a specimen of tetrahedrite-bearing galena representing the highest grade mineralization returned 27,561 g/t Ag, 65.3% Pb and 2.2% Zn. Each bag contains between 0.9 and 1.5 tonnes of ore. Carbonate replacement style mineralization also occurs on the property where high-grade veins intersect favourable carbonate stratigraphy.

Volcanogenic massive sulphide (VMS) deposits hosted in Yukon-Tanana Terrane continued to be the focus of exploration in the Finlayson Lake district, Teslin area, and near Dawson City. Recent 1:50 000 scale mapping (Murphy, 1999 and references therein; Hunt, 1999a and in prep.) in the Finlayson Lake district has led to the identification of four horizons which host VMS deposits. In general, VMS deposits are known to occur in clusters; however, in the Finlayson Lake district, only four major deposits have been discovered to date in each of the favourable stratigraphic horizons. This suggests that there is vast potential remaining in this district for the discovery of additional VMS deposits. Coeval stratigraphy in Cassiar Platform, which hosts the recently discovered Wolf VMS deposit, was also the subject of several exploration programs (Gibson et al., 1999; Hunt, 1999b).

In the Finlayson Lake district, Cominco Ltd. released an inferred reserve on a small satellite deposit discovered in 1998 on the **Kudz Ze Kayah** (Yukon Minfile, 1997, 105G 117) property. The deposit hosts reserves of 1.5 Mt grading 6.4% Zn, 3.1% Pb, 0.1% Cu, 90 g/t Ag, 2.0 g/t Au. It is hosted in the same stratigraphic horizon as the ABM deposit and illustrates the potential for additional discoveries in this area. In the spring of 1999, Cominco conducted a small program of geophysics on the Kudz Ze Kayah property.

Expatriate and Atna Resources conducted metallurgical studies for the treatment of selenium in mineralzation from the **Wolverine** (Yukon Minfile, 1997, 105G 072) VMS deposit. The deposit contains reserves of 6,237,000 tonnes grading 12.66% Zn, 1.33% Cu, 1.55% Pb, 370.9 g/t Ag and 1.76 g/t Au. The deposit remains open to the northwest on the property, as well as down dip to the north where it crosses onto claims owned by Cominco. The conversion of zinc sulphide concentrate to a high-grade clean zinc oxide using traditional roasting is preferred from the various on-site metallurgical treatment options considered for zinc processing. This treatment eliminates the selenium, allows slightly higher zinc recoveries to concentrate, and reduces transportation and marketing costs, partially offsetting higher operating costs. The selenium and other contaminants are captured through standard recovery technology. Two on-site treatment options are being evaluated for processing the precious-metal-rich bulk copper-lead concentrate: firstly, bio-leaching of bulk concentrate to recover the precious metals by conventional cyanidation; and secondly, bio-leaching to reduce selenium levels to produce an attractive precious-metal-rich copper concentrate for shipment to smelters. The Wolverine joint venture commissioned AGRA Simons Ltd. to conduct a scoping study on these selections to evaluate the technical viability, capital requirements, and operating costs. Results indicate these two metallurgical processes would produce readily saleable products and are economically attractive. The preferred process options use proven technology and require minimal additional infrastructure cost beyond that required for mine development.

Figure 21. *Excavator with loaded ore bags at the Blue Heaven property of Nordac Resources. Each bag contains between 0.9 and 1.5 tonnes of ore.*

Expatriate holds a large number of claims covering 81,000 hectares in the Finlayson area. The claims cover stratigraphy that is host to all the major deposits in the Finlayson Lake district. In 1999, they conducted a program of geological mapping, geochemical sampling and prospecting on many of the claims. Several of the properties contain attractive drill targets that will be tested when exploration returns to healthier levels.

In the Teslin area, Brett Resources optioned the **MOR** (NTS 105C/1) and **Caribou Creek** (NTS 105C/5) properties from Fairfield Minerals. The two properties are underlain by stratigraphy that has been correlated to the Nasina Assemblage of the Yukon-Tanana Terrane, which hosts VMS deposits in the Finlayson Lake district. Both properties cover previously unstaked targets. Geological mapping and reconnaissance rock sampling at the MOR property have identified felsic volcanic horizons traceable over a strike length of 900 metres. This is within the zone of anomalous, multi-element soil geochemistry and geophysical conductors previously outlined by Fairfield Minerals. Grab samples from mineralized quartz-sericite schist/rhyolite tuff at the Discovery showing have returned assays of up to 8910 ppb Au, 82.2 ppm Ag, 10,500 ppm Cu, 5081 ppm Pb and 5515 ppm Zn. Another occurrence within the same stratigraphy, approximately 450 metres to the east of the Discovery showing, has yielded assays of 570 ppb Au, 9.2 ppm Ag, 411 ppm Cu, 1050 ppm Pb, 714 ppm Zn, 8800 ppm Ba. Further soil geochemical sampling by Brett Resources has outlined significant copper-silver anomalies in other areas of the property. At Caribou Creek, a limited geological mapping program has shown that strongly gossanous horizons hosted within a bimodal (mafic-felsic) volcanic sequence occur in the vicinity of strong soil geochemical anomalies containing values of up to 2675 ppm Cu, 2047 ppm Pb, 1346 ppm Zn, 8.5 ppm Ag and 2320 ppb Au.

Elsewhere in the Teslin area, Fairfield Minerals carried out further reconnaissance exploration. The program consisted of an evaluation of regional base metal and gold geochemical anomalies from an extensive proprietary database.

15053 Yukon Inc. conducted a program of Winkie drilling (Fig. 22) on the **Bigtop** (Yukon Minfile, 1997, 105C 021) VMS target south of Quiet Lake. The drill was successful in revealing flat-lying stratigraphy previously interpreted to be steeply dipping from a Kubota trenching program. Exposure on the property is limited and the new drilling will greatly aid in a re-interpretation of the geology of this prospect.

A three-week program, including prospecting, geophysics and geochemistry, was completed in August on the **Starr** (Yukon Minfile, 1997, 105G 090) base metal property, located 80 kilometres southeast of Ross River. The Starr property is an extensive package of claims that cover 25 kilometres of the same Mississippian volcanic stratigraphy that hosts the Wolf deposit (4.1 Mt grading 6.2% Zn, 1.8% Pb and 84 g/t Ag). Petra Resources has the option to earn a 50% interest in the Starr Property from Pathfinder Resources Ltd. Detailed results will be reported once all analytical results have been received and a comprehensive evaluation of the data has been completed.

Eagle Plains Resources conducted small programs of prospecting, mapping and geochemistry on their **Fire/Ice** (Yukon Minfile, 1997, 105F 071, 073) claims and **St. Cyr** (Yukon Minfile, 1997, 105F 102) properties that cover the same volcanic stratigraphy to the north of the Wolf deposit and Starr claims. Previous work on the claims has identified baritic horizons with base metal mineralization.

Further to the north in this package of volcanic rocks, 15053 Yukon Inc. staked the **FOX** (Yukon Minfile, 1997, 105F 036) claims to cover a previously documented VMS target. Previous work identified float of white siliceous material with banded sphalerite and minor galena that assayed up to 11.5% Zn, 10.2% Pb and 78.9 g/t Ag. A new area of mineralization representing possible feeder-zone mineralization exposed in a talus slope was discovered in 1999 which assayed up to 17.3% Zn and 28 ppm Hg.

H. Coyne and Sons acquired a large package of claims and leases from Hudson Bay Mining and Smelting Co. to add to their current holdings in the **Whitehorse Copper Belt** (Yukon Minfile, 1997, 105D 053). The Copper Belt is host to numerous iron-rich and calc-silicate skarn deposits which have produced over 10 million tonnes of copper ore with an average grade of 1.5% Cu, 0.55 g/t Au and 8.1 g/t Ag. The Coynes commissioned a compilation report by an independent geologist which utilized the voluminous collection of information that Hudson Bay released with the sale of their interest in the Copper Belt. Utilizing this information, the Coynes drilled two holes between the former producing Pueblo and Grafter mines in a largely overburden covered area. Hole Gin-1 intersected 2.5 metres of garnet-

Figure 22. *Steve Traynor, geologist with 15053 Yukon Inc., oversaw the Winkie drilling on the Bigtop VMS property.*

magnetite skarn (Fig. 23) grading 13.8% Cu, 0.29 g/t Au. Trenches on the Hat claims in the Whitehorse landfill site have revealed altered granodiorite which has produced assays up to 1.05% Cu, 180 ppb Au, 8.7 g/t Ag and 0.061% MoS_2 indicating possible porphyry mineralization.

Nordac Resources was the only active company in the Kluane mafic-ultramafic belt. The belt is composed of Triassic mafic-ultramafic intrusive complexes along the eastern margin of Wrangellia in western Yukon. Nordac performed hand trenching on platinum-palladium-nickel-copper showings hosted by gabbro on the margin of an ultramafic sill. The main trenching targets are in areas where sampled float specimens produced assays ranging from 0.13 to 2.20 g/t Pt, 0.34 to 2.17 g/t Pd, 0.36 to 1.02% Ni and 0.24 to 0.49% Cu.

Cash Resources explored the **Mucho** (Yukon Minfile, 1997, 105I 004) property, located about 120 kilometres east of Ross River, with prospecting and soil sampling. The program outlined an extensive system of silver-rich vein, skarn and replacement-type mineralization within a three to five square kilometre area of strongly anomalous silver-lead-zinc soil-geochemical response. Other locally anomalous elements include gold, copper, arsenic, antimony, bismuth and tin. The 1999 program explored previously unrecognized veins, some of which are exposed intermittently within recessive-weathering linears over strike lengths exceeding 1000 kilometres. Where exposed, the veins are up to eight metres wide and are composed of massive quartz bands, gouge zones, and crushed or silica-cemented wallrock. Most vein material is strongly oxidized, but a variety of sulphide minerals, including galena, sphalerite, arsenopyrite, pyrite, tetrahedrite and bismuthinite have been discovered. Specimens of anglesite-coated galena from different veins returned silver assays of 19,480, 10,748 and 5436 grams per tonne. Chip sampling from widely separated outcrops and hand pits also returned encouraging assays. These include: 421 g/t Ag, 6.8% Pb and 0.6% Zn across 130 centimetres; 712 g/t Ag, 1.5% Pb and 2.1% Zn across 30 cm; and 279 g/t Ag, 2.4% Pb and 0.1% Zn across 80 cm.

Gee-Ten Ventures conducted a 5-hole, 439-metre diamond drilling program on the **Dolly Varden** (Yukon Minfile, 1997, 105H 005) property, 128 kilometres north of Watson Lake. Silver-lead-zinc ± copper-tungsten skarn mineralization was targeted in the drilling program.

Figure 23. *Garnet-magnetite-chalcopyrite-bornite skarn from hole Gin-1 drilled by H. Coyne and Sons in the Whitehorse Copper Belt.*

Figure 24. *Ron Berdahl on the upper portion of the kill zone on the Andrew property.*

Local prospectors continued to play an important role in generating new mineral discoveries. Ron Berdahl staked the **Andrew** (Yukon Minfile, 1997, 105K 089) claims in Selwyn Basin which cover an old occurrence described as silver-lead-zinc-copper veins. While investigating the vein showings, Berdahl focussed on an area marked by a large (75 by 150 metre) kill zone (Fig. 24). Hand trenching revealed stratabound lead-zinc mineralization at the contact of quartzites, and overlying maroon and green shale of the Neoproterozoic to Lower Cambrian Hyland Group. A composite grab sample of oxidized surface material at the head of the kill zone returned a value of 17% Zn. The property is an exciting new discovery, which needs to be re-evaluated based on the new style of mineralization discovered by Berdahl.

Figure 25. *Shawn Ryan, 1999 Yukon Prospector of the Year, points out the Zn-Pb-Cu-Ag mineralized horizon on his Alp claims.*

Shawn Ryan also discovered a new zinc occurrence while investigating a gold geochemical anomaly in the Clear Creek area on his **ALP** (Yukon Minfile, 1997, 115P 051) claims. Ryan discovered a stratabound horizon of quartz-sphalerite-chalocpyrite-galena mineralization hosted in Neoproterozoic to Lower Cambrian Hyland Group psammites (Fig. 25). Grab samples from the horizon assayed up to 22% Zn. The property now has potential for significant base metal mineralization, as well as the gold potential highlighted by its proximity to the new discovery made by Redstar Resources on the Clear Creek property.

EMERALD EXPLORATION

Expatriate Resources conducted a field program to define the extent of emerald-bearing host rock, and to evaluate the quality of the emeralds and their extractability on the Goal-Net property in the Finlayson Lake area. Detailed prospecting in the vicinity of the discovery showing has located numerous emerald-bearing float trains in an 800- by 400-metre-area that straddles a ridge top. A Cretaceous granite body occurs approximately 600 metres east of the emerald locality, while a small ultramafic body occurs just to the west. Bedrock consists of interfingered metagabbro and chlorite schist. Hand trenching has exposed four golden-weathering chlorite-phlogopite(?)-tourmaline schist horizons which range from 50 centimetres to 4 metres thick, intersected by gently dipping, subparallel quartz-tourmaline veins. Emeralds occur in the golden-weathering schist horizon and the quartz-tourmaline veins. Where the veins intersect the favourable schist horizons, a higher concentration of emeralds occur. Both the host schists and veins project subhorizontally beneath the ridge at a shallow depth, making the emerald prospect potentially suitable for open pit mining. Washing and hand sorting of about one-half tonne of material from trenches in the first phase of the program yielded about one kilogram of green beryl. The sampling program recovered small gem quality emeralds up to approximately one-quarter carat in size (Fig. 26) with excellent colour and clarity. The sampling program was confined to talus trains. The program was designed to establish geological controls for the emeralds, define the limits of favourable host lithologies (more than three square kilometres at present), identify additional emerald showings, and evaluate the abundance of gem quality stones and potential for larger stones.

Figure 26. *A gem quality emerald is pictured beside a one carat diamond for scale. Photo by North Light Images Ltd.*

COAL EXPLORATION

Usebelli Coal Mine Inc, conducted a spring 1999 exploration program on Cash Resources **Division Mountain** (Yukon Minfile, 1997, 115H 013) coal property. This program successfully discovered coal seams up to 14 metres thick in a previously undrilled area at Corduroy Mountain, 10 kilometres east of Division Mountain. The coal was found in a reverse-circulation drill hole that was one of a fence of holes. Drilling took place across favourable stratigraphy, in a till-covered area, on the west limb of a seven-kilometre-long syncline. Only one additional hole tested the coal-bearing unit along strike, and is located about 200 metres to the north. Both holes intersected a thick sequence of coal-bearing sandstone, with one seam having a true thickness of 14 metres. Preliminary results indicate that the thickness, coal quality and stratigraphic position of the new discovery are very similar to the coal in the Division Mountain area. For a description of the stratigraphy and associated coal quality in the Division Mountain area, see Allen, this volume.

ACKNOWLEDGMENTS

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 1999 field season. The cooperation of companies, in providing information and their hospitality during field tours are gratefully acknowledged. Editing by Diane Emond and Leyla Weston is appreciated.

Companies and individuals exploring in the Yukon and wishing to be included in future reports are encouraged to contact the author by phone at (867) 667-3202 or by e-mail at burkem@inac.gc.ca.

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APPENDIX 1: 1999 EXPLORATION PROJECTS

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 – Pre-feasibility
R – Reconnaissance
T – Trenching
U/GD – Underground Development

PROPERTY	COMPANY	MINING DISTRICT	MINFILE # or (1:50 000 NTS)	WORK TYPE	COMMODITY
Armenius	Expatriate Resources / Nordac	Dawson	115N 057	G,GC,T	Au
Aurex	Expatriate Resources/ YKR International	Mayo	105M 060	G,GC	Au
Bigtop	15053 Yukon Inc.	Whitehorse	105C 021	G,DD	Pb-Zn-Cu-Ag-Au
Blue Heaven	Nordac Resources	Watson Lake	105B 020	G,GC,T	Ag-Pb-Zn-Cu
Brewery Creek	Viceroy Resources	Dawson	116B 160	M,G,GC,RC	Au
Caribou Creek/MOR	Brett/Fairfield Minerals	Watson Lake	(105C/1, 5)	G,GC	Pb-Zn-Ag-Cu
Canadian Creek	Alexis/Wildrose Resources	Whitehorse	115J 036		Cu-Au
Clear Creek	Redstar/Newmont	Mayo	115P 012, 013	DD	Au
Cuz	Nordac Resources	Watson Lake	95D 011	G,GC	Au
Cy/St	Eagle Plains Resources	Watson Lake	105F 102	G,GC	Pb-Zn-Ag
DDL	Nordac Resources	Whitehorse	105E 006	GC,T	Cu-Au
Division Mountain	Cash Resources	Whitehorse	115H 013	G,T,RC	Coal
Dolly Varden	Gee-Ten Ventures	Watson Lake	105H 005	DD	Zn-Pb-Ag-Cu
Drag	Eagle Plains Resources	Mayo	105J 007	G,DD	Au
Eureka	Expatriate/Nordac	Dawson	115N 057	G,GC,T	Au
Fyre Lake	Pacific Ridge	Watson Lake	105G 034	Reclamation	Cu-Co-Au
Gates Creek	Viceroy/Tr'ondëk Hwëch'in First Nation	Dawson	(116A/4, 115P/13)	G,GC	Au
Goal-Net	Expatriate Resources	Watson Lake	(105G/7, 8)	G,GC,T,BS	Cu-Co-Au/ emeralds
Harlan	NovaGold Resources	Mayo	(105O/4, 5)	G,GC	Au
Hat	Coyne & Sons	Whitehorse	105D 053	G,GC,T	Cu-Au-Ag
Hawk/Eagle	Nickelodeon/Tanqueray	Watson Lake	105I 043, 044	G,GC	Pb-Zn-Ag
Hit	Hudson Bay	Watson Lake	(105H/9)	G,GC,DD	Au
Hit	Eagle Plains Resources	Mayo	(105P/5)	G,DD	Au
HP/Nod	Expatriate Resources	Watson Lake	105I 012	G,GC,T	Pb-Zn-Ag
Hunker	Klondike Source/ Barramundi Gold Ltd.	Dawson	(115O/14, 15)	G	Au
Hyland	Expatriate Resources	Watson Lake	95D 011	G,GC	Au

Appendix 1: continued

PROPERTY	COMPANY	MINING DISTRICT	MINFILE # or (1:50 000 NTS)	WORK TYPE	COMMODITY
JRV	Pacific Ridge Exploration	Watson Lake	105K 051, 052, 053	G,GC,DD	Au-Ag
Kathleen Lakes	Manson Creek Resources	Mayo	106C 065, 083, 085, 073	G,GC,GP,DD	Ag-Pb-Zn
Keno Hill	United Keno Hill	Mayo	105M 001	D	Ag-Pb-Zn
Kudz Ze Kayah	Cominco Ltd.	Watson Lake	105G 117	GP	Pb-Zn-Cu-Ag-Au
Livingstone	Larry Carlyle/ Max Fuerstner	Whitehorse	105E 001, 042, 049, 054	G,GC,T	Au-Ag
Longline	Barramundi Gold Ltd./ Newmont	Whitehorse	115N 024	G,GC,GP,DD	Au
May	Eagle Plains Resources	Mayo	115P 056	G,GC	Au
Minto	Minto Resources	Whitehorse	115I 021, 022	D,DD	Cu-Ag-Au
Mos	Barker/Risby	Dawson	115N 039, 040	G,GC	Au-Ag
Mount Nansen	BYG Natural Resources	Whitehorse	115I 064, 065	M,G,GC,T,DD	Au-Ag
Nug	Eagle Plains Resources	Mayo	105O 048	G,GC	Au
Ohgo, etc.	Prospector International	Dawson	(115N, O)	G,GC	Au
Oki-Doki	International Kodiak	Dawson	(116B/1, A/4)	G,GC,T,GP	Au
Pama	Eagle Plains Resources	Dawson	116K 009	G,GC,SD	Zn-Pb-Cu-Ag
Prospector Mtn.	Troymin/Almaden Res.	Whitehorse	115I 034, 036	G,GC	Au-Ag
Revenue	ATAC/YKR International	Whitehorse	115I 042	G,GP	Cu-Au-Ag-WO_3-MoS_2
Ruby	Tiberon	Whitehorse	105D 090	G,GC,DD	Ag-Au
Rusty Springs	CanAustra Resources Eagle Plains Resources	Dawson	116K 003	G,GP,DD	Ag-Cu-Pb-Zn
Scheelite Dome	Copper Ridge/Kennecott	Mayo	115P 033	G,GC,GP,DD	Au
Shootamook	Yukon Yellow Metal	Watson Lake	105B 045	DD	Au
Starr	Pathfinder/Petra Resources	Watson Lake	105G 090, etc.	G,GC	Pb-Zn-Ag
Swan	Prospector International	Mayo	105O 024	GP	Au
Tak, etc.	Canadian United Minerals	Dawson	(116B/7, etc.)	G,GC,GP	Au
Track	Expatriate Resources/ Nordac Resources	Dawson	116C 137	G,GC,T	Au
Wash	Nordac Resources	Whitehorse	115G 100	G,GC,T	Ni-Cu-Au-PGE’s

APPENDIX 2: 1999 DRILLING STATISTICS

PROPERTY	COMPANY	DIAMOND DRILL METRES	DIAMOND DRILL # HOLES	RC/PERCUSSION DRILL METRES	RC/PERCUSSION DRILL # HOLES
BEE	Silver Sabre Resources	139	3		
Brewery Creek	Viceroy Resources			2500	21
Clear Creek	Redstar Resources/Newmont	219	2		
Division Mountain	Cash Resources/Usebelli Coal			1874	20
Dolly Varden	Gee-Ten Ventures	439	5		
Dragon Lake	Eagle Plains Resources	288	4		
Hit	Hudson Bay Mining	642	4		
Hit	Eagle Plains Resources	178	2		
JRV	Pacific Ridge Exploration	995	9		
Kathleen Lakes	Manson Creek/Prism Resources	1177	8		
Longline	Barramundi Gold	550	22		
Longline	Newmont/Barramundi Gold Ltd.	2100	12		
Minto	Minto Explorations	936	6		
Prospector Mountain	Troymin/Almaden Resources	336	2		
Rusty Springs	CanAustra Resources/Eagle Plains Resources	617	3		
Scheelite Dome	Copper Ridge Exploration	1357	13		
Ruby	Tiberon Minerals	326	4		
Whitehorse Copper	Coyne and Sons	280	2		
TOTAL		**10,579**		**4374**	

PLACER MINING OVERVIEW, 1999

William LeBarge[1]
Yukon Geology Program

A late season surge in world gold prices, which resulted in higher than average September production, was one of the few bright spots for the Yukon Placer Mining Industry in 1999. A total of 171 mines operated, with approximately 600 people directly employed in the industry. This represents a 6% increase in the number of mines from 1998. The majority of active mining operations (101) were in the Dawson Mining District, followed by Whitehorse (43), Mayo (26) and Watson Lake (1).

Following historical trends, in 1999, over 80% of the Yukon's placer gold was produced in the Dawson District. This area includes the unglaciated drainages of Klondike River, Indian River, west Yukon River (including Fortymile, Sixtymile, Moosehorn) and lower Stewart River. The remaining gold came from glaciated regions including Clear Creek, Mayo, Dawson Range, Kluane and Livingstone.

Placer gold production to the end of October, 1999 totalled 89,141 crude oz. (2,772,597 g), compared to 84,265 crude oz. (2,620,936 g) for the same period in 1998. Based on this trend, total placer gold production for 1999 is projected to be 92,500 crude oz. (2,877,073 g), which is 6% higher than the 87,488 crude oz. (2,721,183 g) produced in 1998. Despite this moderate increase, the actual total dollar value of Yukon placer gold dropped for the third consecutive year due to the continuing fall of world gold prices. The value of 1999 production is $29.7 million, falling $900,000 short of the $30.6 million produced in 1998.

The operating conditions for Mining Land Use regulations were implemented for all placer mining operations in 1999; the 2000 mining season will be the first time operators will be required to have Mining Land Use licenses. Along with the upcoming 2001 review of effluent discharge standards set under the Yukon Placer Authorization, these are some of the many challenges facing the Yukon placer mining industry in the near future.

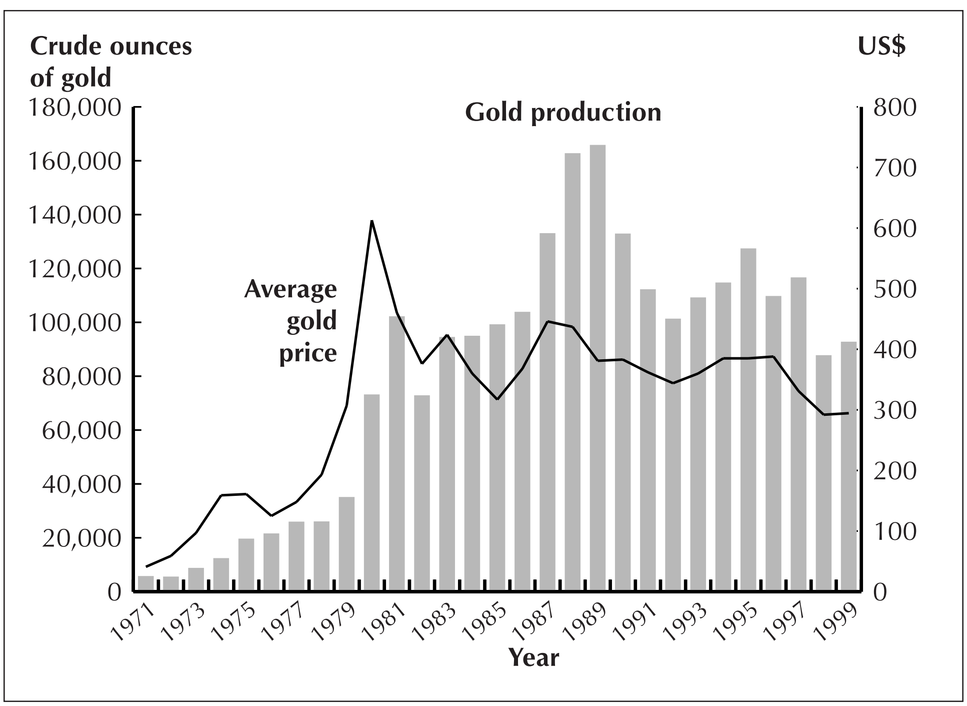

Figure 1. *Yearly gold production figures for the Yukon.*

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RÉSUMÉ

Un des rares événements positifs pour l'industrie d'exploitation des placers du Yukon en 1999 a été la soudaine montée des prix mondiaux de l'or qui a causé une production plus élevée que la moyenne pour le mois de Septembre. Au total, 171 mines ont été exploitées, ce qui a fournit des emplois directs à environ 600 personnes dans l'industrie. Ces chiffres représentent une hausse du nombre des mines en exploitation de 6 % par rapport à 1998. La majorité des exploitations actives se situaient dans le district minier de Dawson (101) suivi par les districts de Whitehorse (43), Mayo (26) et Watson Lake (1).

En 1999, conformément à la tendance historique, plus de 80 % de l'or placérien du Yukon a été produit dans le district de Dawson. Cette région comprend les bassins versants non touchés par la glaciation des rivières Klondike, Indian, ceux de l'ouest du fleuve Yukon (les rivières Fotymile, Sixtymile et Moosehorn) ainsi que le cours inférieur de la rivière Stewart. Le reste de la production aurifère provient des régions qui ont été glaciées ce qui comprend les districts de Clear Creek, Mayo, Dawson Range, Kluane et Livingstone.

À la fin d'octobre 1999, la production d'or a atteignait 89 141 onces brutes (2 772 597 g) comparativement à 84 265 onces brutes (2 620 936 g) pour la même période en 1998. Si on se fie à cette tendance, la production d'or placérien de 1999 sera de 92 500 onces brutes (2 877 073 g), ce qui représente une augmentation de 6% par rapport à la production de 87 488 onces brutes (2 721 183 g) en 1998. Malgré cette modeste hausse, la valeur totale de la production d'or placérien du Yukon a baissé pour la troisième année consécutive en raison de la chute des prix de l'or sur les marchés mondiaux. En 1999, la valeur de la production est de 29,7 millions de dollars, ce qui représente une diminution de 900 000 dollars par rapport à la production de 30,6 millions de dollars de 1998.

En 1999, on a mis en application le règlement sur les conditions d'exploitation et d'utilisation du territoire pour toutes les exploitations d'extraction placériennes et la saison d'extraction minière de l'an 2000 sera la première pendant laquelle les exploitants devront détenir un permis d'utilisation du territoire minier. Pour l'année 2001, Il y a de plus une révision des normes concernant les rejets d'effluents qui sont déterminés par la Yukon Placer Authorization, tout ceci constitue une partie des défis auxquels doit faire face, dans un avenir rapproché, l'industrie de l'exploitation des placers au Yukon.

GOVERNMENT

Yukon Geology Program

Grant Abbott
Yukon Geology Program

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Yukon Geology Program

***Grant Abbott*[1]**
Yukon Geology Program

Abbott, G., 2000. Yukon Geology Program. *In:* Yukon Exploration and Geology 1999, D.S. Emond and L.H. Weston (eds.), Exploration and Geological Services Division, Yukon, Indian and Northern Affairs Canada, p. 39-48.

OVERVIEW

Now in its fourth year, the Yukon Geology Program (Fig. 1) is a *de facto* Yukon Geological Survey consisting of two integrated and jointly managed offices with different administrative structures (Fig. 2). Federal funding is provided through the Exploration and Geological Services Division (EGSD) of the Department of Indian Affairs and Northern Development (DIAND), while territorial and cost-shared (YTG/DIAND) funding comes through the Mineral Resources Branch of the Department of Economic Development, Yukon Government (YTG). The Geological Survey of Canada (GSC) also maintains an office with the Program.

Figure 1. *(Top) Grant Abbott, Shirley Abercrombie. (Bottom, from left to right) Tanya Gates, Diane Emond, Jo-anne vanRanden, Bill Lebarge, Ali Wagner, Robert Deklerk, Mike Burke, Leyla Weston, Don Murphy, Gord Nevin, Dennis Ouelette, Lee Pigage, Craig Hart, Ken Galambos, Danièle Héon, Maurice Colpron, Jeff Bond, Kaori Torigai, Julie Hunt, Melanie Reinecke, Grant Lowey, Charlie Roots, Panya Lipovski, Anna Fonseca, Mark Nowasad. Missing: Monique Shoniker, Tammy Allen and Jason Adams.*

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The Yukon Geology Program (YGP) is an informal and temporary organization that will be transformed into a Yukon Geological Survey when the responsibilities of the Northern Affairs Program are devolved to YTG. Negotiations have met delays, and the target date for devolution has been moved ahead one year to April 1, 2001. The agreement in principal for the transfer is near completion and all parties expect negotiations to be successful.

During the past year, the Program benefited greatly from staff stability after the turnover of five management positions and five technical positions in the previous two years. Staff changes this year included the appointment by the Government of Yukon, of Anna Fonseca as a third Resource Assessment Geologist and Dennis Ouelette as a term Yukon Minfile geologist. YTG is also in the process of hiring two GIS technicians. Grant Abbott and Jeff Bond now have permanent positions.

A milestone for the program this year was the completion of the second Yukon Geoscience Planning Workshop in March, when 42 representatives from industry, academia, and government met for two days in Whitehorse to re-examine the state of Yukon Geoscience. The group produced a new set of priorities that will be an essential planning tool for the Yukon Geology Program over the next few years.

PROGRAM HIGHLIGHTS FOR 1999

FIELDWORK

The Yukon Geology Program has committed substantial resources to a joint Geological Survey of Canada – British Columbia Geological Survey Branch – Yukon Geology Program initiative, the Ancient Pacific Margin NATMAP (National Mapping Program) project. This project is a multidisciplinary

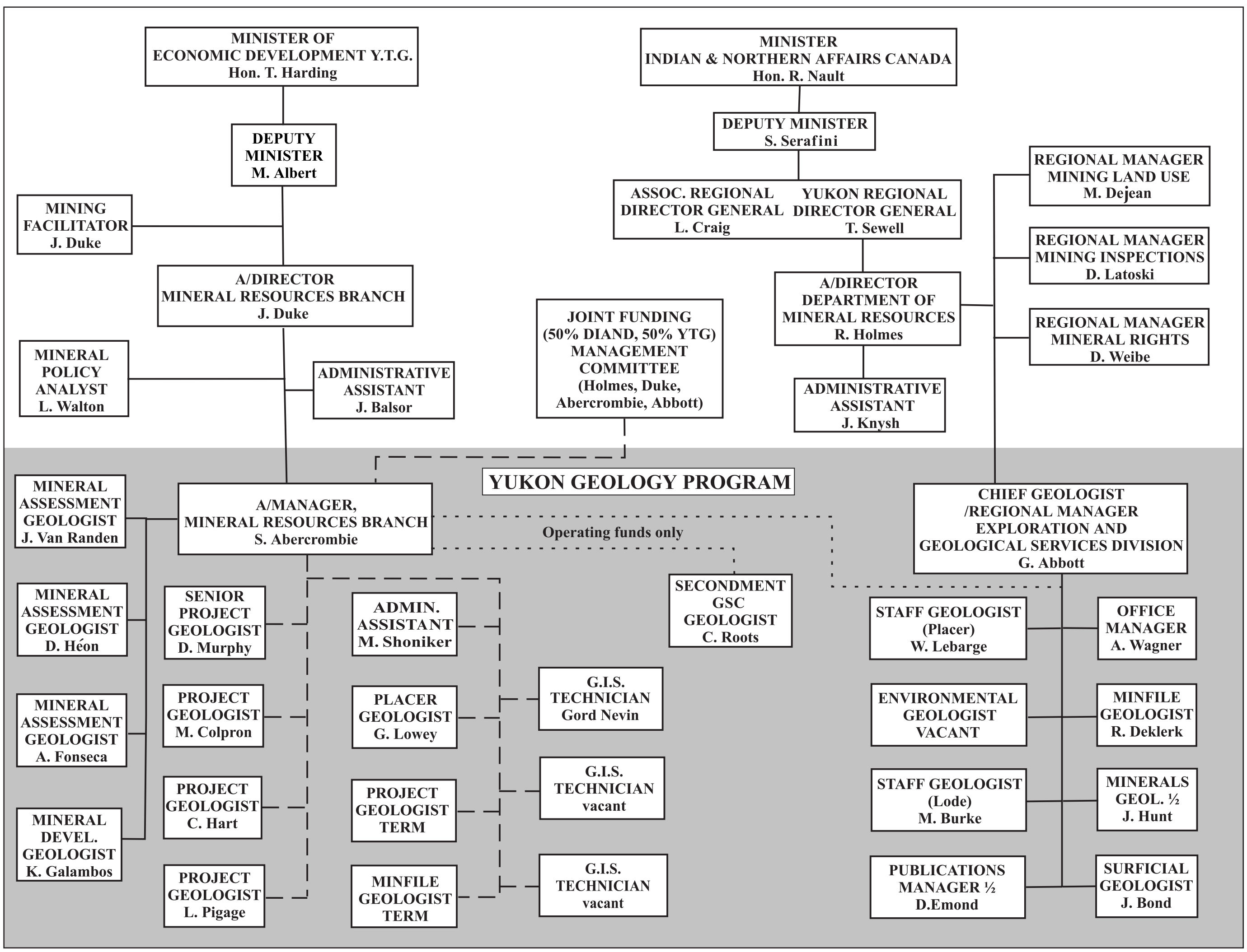

Figure 2. *Yukon Mineral Resources organization chart.*

effort to better understand Yukon-Tanana (YTT) and Kootenay terranes, arguably the least understood parts of the North American Cordillera. The Yukon Geology Program contribution includes the ongoing work of Don Murphy in the Finlayson Lake massive sulphide district; fieldwork begun last year by Maurice Colpron in the Glenlyon area; mapping by Charlie Roots of the western half of Wolf Lake map area and the northern half of Jennings River map area in B.C. in partnership with Joanne Nelson and Mitch Mihalynuk of the B.C. Geological Survey Branch; and surficial studies by Grant Lowey in the Stewart River map area in conjunction with regional surficial studies by Lionel Jackson of the GSC. Other parts of the Ancient Pacific Margin NATMAP include bedrock mapping of Stewart River map area in the Yukon by Steve Gordey of the GSC; in southern B.C., regional mapping by Bob Thompson of the GSC; and in east-central Alaska, mapping by David Szumigala of the Alaska State Geological Survey, and mineral deposit studies by Cynthia Dusel-Bacon of the U.S. Geological Survey. Participation by numerous university researchers, graduate students and other specialists has greatly added to the depth and complexity of the project. In the Yukon, these include lithogeochemical studies in the Finlayson Lake area by Steve Piercey and Jim Mortenson of the University of British Columbia, and mineral deposit studies by Suzanne Paradis of the GSC. Regular workshops and field trips are one of the main benefits of such a large and diverse project. This summer Don Murphy and Maurice Colpron led a field trip to the Finlayson Lake and Glenlyon areas. Already the benefits of this multidisciplinary, collaborative approach are being seen in the publication of papers, which begin to define the architecture of the YTT over great distances.

Another major effort by the YGP is to synthesize and enhance the geological database of the Anvil District. The Faro mine remains closed for the foreseeable future, but the possibility remains for renewed exploration and mining at some point. Lee Pigage has completed bedrock mapping and expects to release a complete set of 11 geological compilation maps of the district at 1:25 000 scale by the end of 2000. Jeff Bond has completed surficial mapping and a till-geochemical survey and expects to release 11 final maps and a bulletin in the spring of 2000. Cliff Stanley has completed a lithogeochemical study of the Grizzly deposit, and will release a report later in the year.

In 1998, responsibility for oil and gas resources was transferred to YTG from the federal government, and in 1999, the Yukon's first land sale in more than 20 years was successfully completed. In order to accommodate increasing interest from YTG and industry in hydrocarbon-related geoscience, Tammy Allen began a mapping project near Division Mountain along the western margin of Whitehorse Trough. The area has some of the most prospective coal deposits in the Yukon. The area was poorly understood and previously untested for oil and gas potential.

Craig Hart continued his studies of Yukon gold occurrences, splitting his time between those related to the Tombstone intrusive suite northeast of the Tintina Fault, and those in the Dawson Range along trend from the Pogo deposit in Alaska. Craig also assisted some of the students who received support from the YGP to study various aspects of Yukon gold deposits. These included Mark Lindsay and Julian Stephans, under the supervision of Tim Baker at James Cook University, Australia; John Mair at University of Western Australia; Erin Marsh and Seth Mueller under the supervision of Rich Goldfarb at the U.S. Geological Survey; and Scott Heffernan and Kelly Emon under the supervision of Jim Mortensen at the University of British Columbia.

Bill Lebarge and Mark Nowasad continued their studies of the relationship between sedimentology, grain size distribution, and water quality of effluent from placer deposits. Data gathered from this study should assist with the review of the Yukon Placer Authorization in 2001.

OTHER PROJECTS

The YGP supported the work of several scientists at the Geological Survey of Canada. The Yukon Digital Geology Compilation by Steve Gordey and Andrew Makepeace was finally completed at the end of the year and is now available. It includes compiled data sets of bedrock geology and glacial limits (new syntheses), geochronology, paleontology, mineral occurrences (Yukon Minfile), a compendium of coloured aeromagnetic images, Yukon Park boundaries, and physiography. The glacial limits map for the Yukon, by Alejandra Duk-Rodkin, has also been released separately.

Julie Hunt who is now working half time, is nearing completion of her bulletin on Yukon volcanogenic massive sulphide deposits and has begun an overview of the metallogeny of the Yukon, which combines the new Yukon Digital Geology with the Yukon Minfile.

Diane Emond, is also working half time as publications manager. Diane also represents DIAND on the Mining and Environmental Research Group (MERG), and manages the Yukon Geoprocess File (see below). MERG is a cooperative working group promoting research into mining-related environmental issues. It is made up of the federal and Yukon governments, mining companies, Yukon First Nations and non-governmental organizations.

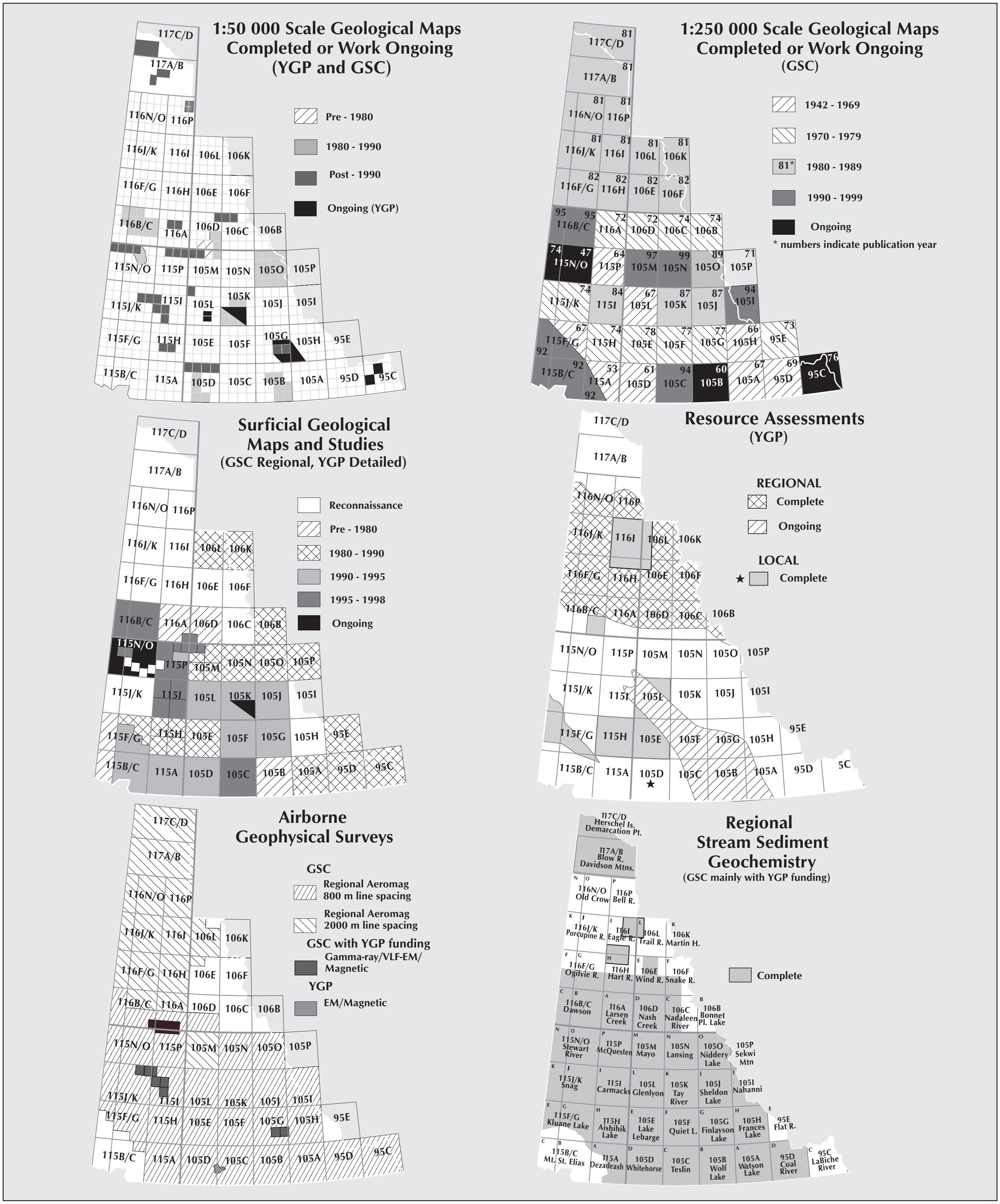

Figure 3. *Summary of available geological maps and regional geochemical and geophysical surveys in the Yukon.*

INDUSTRY LIAISON AND SUPPORT

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.

YUKON MINFILE

Yukon Minfile, another mainstay of the Yukon Geology Program, is maintained by Robert Deklerk. We have completed an upgrade from Microsoft Access Version 2 to Access 97 with major revision and simplification of the database structure. The updated digital version will be released on CD-ROM this spring and sold by Hyperborean Productions of Whitehorse. The text version of Minfile is available on our Website and in hard copy through the Geoscience and Information Sales office, c/o the Whitehorse Mining Recorder's Office.

YUKON GEOPROCESS FILE

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 will soon be available in colour, on a single compact disk.

H.S. BOSTOCK CORE LIBRARY

The H.S. Bostock Core Library is maintained by Mike Burke and Ken Galambos. 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.

MINERAL RESOURCE ASSESSMENTS

The Yukon Geology Program is responding to an increasing need for geological and metallogenic information to assist resolution of land use issues and conflicts. Some of the pressures have come from native land claims negotiations, and localized land use conflicts such as one within the city limits of Whitehorse. Also important is the priority of the Yukon government to implement the Yukon Protected Areas Strategy. The goal of the Yukon Protected Areas Strategy is protection and withdrawal of land from industrial activity in all 23 ecoregions in the Yukon. YTG Economic Development intends to provide efficient and cost-effective input into the selection process by undertaking a Yukon-wide mineral potential study. Providing information on mineral potential at a regional scale will assist in guiding the selection of candidate protected areas towards areas of lower potential, in order to minimize the impact on the access to mineral wealth.

A regional mineral potential exercise was conducted in the spring of 1999 for northern Yukon (Fig. 3). A panel of experts estimated the probability of discovering new mineral deposits in 80 geological tracts. Their estimations were processed through the Monte Carlo computer simulator and the resulting map displays the relative mineral potential of the tracts. The draft mineral potential map was used in the planning of the proposed Fishing Branch Park. The final map will also be used in other upcoming protected area plans.

A mineral assessment was conducted in June, 1999 for the proposed Tombstone Territorial Park, based on a compilation of public data as well as the results of the previous field season. An expert panel ranked the different geological tracts relative to one another but insisted on the fact that the whole area was considered to have high mineral potential. The resulting mineral potential map was provided to the Tombstone Steering Committee, as well as comments on access considerations.

Presentations were made to the planning teams of both Tombstone and Fishing Branch proposed parks. One week of fieldwork was spent documenting known mineral occurrences in the Fishing Branch study area. No mineral assessment was conducted for Fishing Branch, due to the paucity of data and extremely short timeframe.

Staff thoroughly review Land Claim selections and provide technical information to territorial Land Claim negotiators. We comment on mineral potential, exploration history, mineral land tenure and access. We also update and distribute the Yukon Land Status Map.

Compilation is ongoing for the next regional assessment, which will address Cassiar Platform and southern Yukon-Tanana Terrane. This project will provide a regional context for proposed protected areas within the Teslin Tlingit Council Traditional Territory, one of which is the Wolf Lake Federal initiative. Our study area covers most of the Traditional Territory and the portions of Pelly Mountains and the Yukon southern lakes ecoregions within it. The assessment is planned for early February, 2000.

YUKON MINING INCENTIVE PROGRAM

The Yukon government provides grants for grass roots exploration and initial developmegt of properties. This year, a total of $378,000 was distributed to 27 prospectors under the supervision of Ken Galambos.

PUBLICATIONS

The Yukon Geology Program is now converted to fully digital publishing. All geological maps are now printed and new publications are being produced from a digital format, on-demand. This advance will greatly reduce our printing and storage costs. We expect to eventually distribute digital files through our website. Yukon Geology Program publications are published by Exploration and Geological Services Division, DIAND and are available through:

Geoscience Information and Sales
c/o Whitehorse Mining Recorder
102-300 Main Street
Whitehorse Yukon Y1A 2B5
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RÉSUMÉ

Le Service de géologie du Yukon (Fig. 1), qui en est maintenant à sa quatrième année d'existence, est dans les faits la commission géologique du Yukon et consiste en deux bureaux intégrés présentant des structures administratives différentes mais qui sont gérés conjointement (Fig. 2). Le financement par le fédéral est fourni par l'entremise de la Division des Services d'exploration et de géologie du ministère des Affaires indiennes et du Nord canadien (MAIN), alors que le financement par le territoire et à coûts partagés (GTY/MAIN) est obtenu par l'entremise de la Direction des ressources minérales du ministère de l'Expansion économique, gouvernement du territoire du Yukon (GTY). La Commission géologique du Canada (CGC) maintient également un bureau auprès du Service.

Le Service de géologie du Yukon est une organisation informelle et temporaire qui sera transformée en commission géologique du Yukon lorsque les responsabilités du Programme des affaires du Nord seront dévolues au GTY. Il y a eu des retards dans les négociations et la date cible de cette dévolution a été devancée d'un an et fixée au premier avril 2001. L'entente de principe concernant le transfert est presque complétée et toutes les parties s'attendent à ce que les négociations soient couronnées de succès.

Pendant l'année écoulée, le Service a grandement profité de la stabilité de son effectif après le remplacement de cinq de ses gestionnaires et de cinq de ses techniciens au cours des deux années précédentes. Parmi les changements de personnel survenus cette année, mentionnons la nomination par le gouvernement du Yukon d'Anna Fonseca comme troisième géologue responsable de l'évaluation des ressources et de Dennis Ouelette comme géologue affecté pour une durée déterminée au projet MINFILE. Le GTY procède en outre actuellement à l'embauche de deux techniciens en systèmes d'informations géographiques. Grant Abbott et Jeff Bond occupent maintenant des postes permanents.

La tenue en mars du deuxième atelier de planification pour les géosciences au Yukon a été l'un des faits marquants du programme cette année; il a permis de réunir à Whitehorse pendant 2 jours 42 représentants de l'industrie, du secteur de l'enseignement et du gouvernement pour un nouvel examen de l'état des géosciences au Yukon. Le groupe a élaboré un nouvel ensemble de priorités qui s'avérera un outil essentiel de planification des activités du Service de géologie du Yukon pendant les quelques années à venir.

APPENDIX 1: RECENT PUBLICATIONS

EGSD GEOSCIENCE MAPS

Geoscience Map 1999-2 or GSC Open File 3694: Glacial limits map of Yukon (1: 1 000 000 scale), by Alejandra Duk-Rodkin.

EGSD OPEN FILES

Bond, J.D., 1999. Surficial geology map and till geochemistry of Swim Lakes (105K/2 NW), central Yukon (1:25 000 scale); Open File 1999-5.

Bond, J.D., 1999. Surficial geology map and till geochemistry of Swim Lakes (105K/2 NE), central Yukon (1:25 000 scale); Open File 1999-19.

Bond, J.D., 1999. Surficial geology map of Mount Mye and Faro (105K/3 W and 6 W), central Yukon (1:25 000 scale); Open File 1999-8.

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Bond, J.D., 1999. Surficial geology map and till geochemistry of Blind Creek (105K/7 SW), central Yukon (1:25 000 scale); Open File 1999-6.

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Bond, J.D., 1999. McConnell ice-flow map of the Anvil District (105K), central Yukon (1:250 000 scale); Open File 1999-14.

Bond, J.D., 1999. Glacial limits and ice-flow map, Mayo area (105M), central Yukon (1:250 000 scale); Open File 1999-13.

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Colpron, M., 1999. Preliminary geological map of Little Salmon Range (parts of 105L/1, 2 and 7), central Yukon (1:50 000 scale); Open File 1999-2.

Gordey, S.P. and Makepeace, A.J., 1999. Yukon Digital Geology, 2 CD-ROMs; Open File 1999-1(D); (or GSC Open File D3826).

Murphy, D.C. and Piercey, S.J., 1999. Geological map of Finlayson Lake area, southeast quarter (105G/7, 8 and parts of 1, 2 and 9), southeastern Yukon (1:100 000 scale); Open File 1999-4.

Murphy, D.C. and Piercey, S.J., 1999. Geological map of Wolverine Lake area (105G/8), Pelly Mountains, southeastern Yukon (1:50 000 scale); Open File 1999-3.

Pigage, L.C., 1999. Geological map of Rose Mountain (105K/5 NW), central Yukon (1:25 000 scale); Open File 1999-11.

Pigage, L.C., 1999. Geological map of Blind Creek (105K/7 NW), central Yukon (1:25 000 scale); Open File 1999-12.

Pigage, L.C., 1999. Geological Map of Blind Creek (105K/7 SE), central Yukon (1:25 000 scale); Open File 1999-15.

OUTSIDE ARTICLES

Colpron, M., Price, R.A. and Archibald, D.A., 1999 (in press). $^{40}Ar/^{39}Ar$ thermochronometric constraints on the tectonic evolution of the Clachnacudainn complex, southeastern British Columbia. Canadian Journal of Earth Sciences, vol. 36.

Goldfarb, R.J., Hart, C.J.R. and Mortensen, J., 1999. Metallogeny of the northeastern Pacific Rim: An example of the distribution of ore deposits along a growing continental margin. PacRim Proceedings Volume, AusIMM, Bali, Indonesia, p. 273-286.

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Yukon Mining Incentives Program Overview, 1999

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Mineral Resources Branch
Yukon Government

Seventy-one applications were received by the program deadline of March 1, 1999. These prospectors and exploration companies were applying for a share of the Yukon Mining Incentives Program (YMIP) contribution budget of $378,000. In an attempt to fund as many of the excellent proposals as possible, the Department of Economic Development, Yukon Government decided to increase the monies offered to a total of $467,600. As a result, 35 individuals and junior companies were able to participate in YMIP this year.

Approximately 80% of the projects contained a precious metal component. The vast majority of these undertakings were searching for the Yukon equivalent to the Pogo deposit, an intrusive-related deposit located 180 km west of the Yukon/Alaska border. These projects generally focussed their exploration near mid-Cretaceous intrusions of the Tombstone Suite, part of what is now being termed the Tintina gold belt. Most programs, with the exception of Barramundi's Longline project, remain at a very early stage in their exploration history and results are pending.

The remaining 20% of programs focussed on base metals exploration, with zinc as the primary target. Initial results from a number of small programs are promising and reveal extraordinarily rich mineralization.

Highlights for the year include grassroots and initial stage exploration programs on three base metals properties.

On the Andrew claims, **RON BERDAHL** discovered smithsonite mineralization in a large kill zone north of Ross River (Fig. 1). A small trenching program revealed a zone of zinc enrichment with values as high as 19.9% Zn and 1.4% Pb over 6 m, and 34.4% Zn over 1 m. The property contains numerous base metal showings over a wide area, which have yet to be thoroughly explored.

SHAWN RYAN, this year's "Prospector of the Year" (Fig. 2), revisited the Jabberwock and Sterling properties in the Fortymile Creek area and discovered a zone of flat-lying quartz-sulphide mineralization which returned values as high as 22% Zn. This zone sits stratigraphically below coincident geophysical and geochemical anomalies, which remain untested.

WADE CARRELL and **STEVE TRAYNOR** (Tanana Exploration Ltd.) staked a large claim block south of Ross River near Fox Creek. Historical sampling is reported to have returned assays as high as 11.5% Pb, 10.2% Zn and 78.9 g/t Ag from large quartz-sulphide boulders. This year's program discovered a new massive sulphide showing and a new area of mineralization in talus. They have also found what is believed to be feeder style mineralization in talus assaying 17.5% Zn and 28 ppm Hg (Fig. 3).

Figure 1. *Ron Berdahl with the Andrew "Kill Zone" in the background.*

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Figure 2. *Shawn Ryan at the quartz-sulphide showing on his Alpine property.*

Figure 3. *High-grade sphalerite float from Tanana Exploration's Fox property.*

The Robert E. Leckie Award for Outstanding Reclamation Practices

***Hugh Copland*[1]**
Mining Land Use Division, Indian and Northern Affairs Canada

In 1999, the Mineral Resources Directorate of the Department of Indian Affairs and Northern Development awarded the first Robert E. Leckie awards for outstanding reclamation practices in both quartz and placer mining. The award goes to companies or individuals who go beyond legislated reclamation requirements, pioneer new reclamation techniques in the north, and show leadership in enhancing the environment.

The award is proudly named after Robert (Bob) Leckie who passed away in November, 1999 after a two-year battle with cancer.

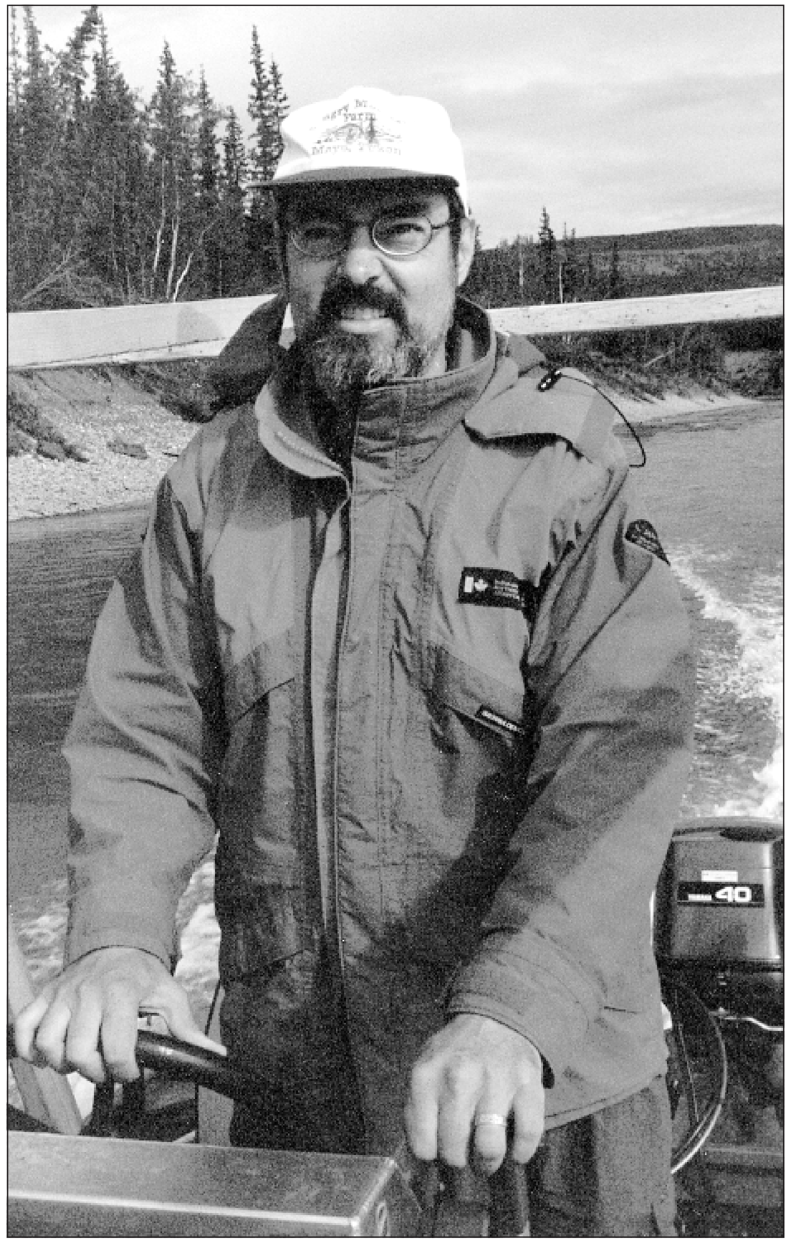
Bob was born in Calgary and, in 1984, graduated from the University of Calgary with a Master's Degree in Environmental Sciences. He joined DIAND Mineral Resources in 1987 as a mining inspector in Mayo and remained in that position until his death.

During his time in Mayo, Bob was influential in educating area miners in the benefits of thoughtful reclamation practices as they applied to placer mining. Bob was also instrumental in the implementation of research projects aimed at defining acceptable standards for placer mining discharge. His forward thinking and valuable contributions to the department and the industry will be remembered in this annual award which will go to both a quartz mining or exploration program and a placer mining operation for outstanding reclamation practices.

The award winners are chosen by a committee comprised of representatives from DIAND Mineral Resources, Yukon Government Economic Development, Yukon Chamber of Mines, and Klondike Placer Miners Association.

The 1999 award winners are:

- *Quartz Exploration and Mining*: Viceroy Minerals Corporation
- *Placer Mining*: Al Dendys (Tic Exploration)



Robert E. Leckie

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VICEROY MINERALS CORPORATION, BREWERY CREEK MINE

The Brewery Creek Mine is located approximately 30 km east of Dawson City. The property was discovered in 1987, and went into production in 1996 as the northernmost heap leach operation in Canada. The mine is characterized by a series of oxidized deposits that are being mined in a sequential fashion. Early in the mine planning it was recognized that it would be advantageous to utilize mined-out pits as waste rock disposal facilities for the next pit under development. The first pit to be mined out in 1996 and early 1997 was the Canadian pit. This was subsequently filled in 1997 with waste from the Kokanee pit. After re-contouring of the waste material, vegetation test plots were immediately planted on the dump to determine the best seed mixes to use in subsequent reclamation.

The Canadian pit reclamation has now been successfully reclaimed. The photo below illustrates how well the pit/waste dump blends into the existing topography. Viceroy Minerals Corporation has continued to have a good relationship with the community and contributes to training courses, provides tours of the mine and runs programs for children on site to learn about reclamation.

Honourable mentions in the Quartz Exploration Mining category were:

- Expatriate Resources Ltd., Breakaway and Macmillan Pass properties,
- Cash Resources Ltd., Killermun Lake property,
- Pamicon Developments Ltd., Bonnet Plume River properties,
- Placer Dome Inc., Howard's pass Properties.

Brewery Creek Mine - Canadian pit reclamation

AL DENDYS, TIC EXPLORATION

Al Dendys has been mining on Gladstone Creek (flows into the eastern shore of Kluane Lake) since 1992, using two floating trommel wash plants. These plants operate almost 23 hours a day, processing a large volume of pay material. The large-scale disturbance resulting from an operation of this size has been mitigated by excellent restoration work. The most impressive characteristic of this work is how quickly it follows extraction of the ore.

Immediately following work in any given area, the tailings have been levelled, re-contoured and covered with fine material stockpiled during preparation of the mining cut. To date, this is the finest example of progressive placer mining restoration work in the Whitehorse Mining District.

Honourable mentions in the Placer Mining category were:

- Norm Ross, Ross Mining Company, Dominion Creek,
- Frank Hawker, Indian River Operation,
- David McBirney, Indian River Operation,
- Doug Busat, T.D. Oilfields Services Ltd., Hunker Creek,
- George Lewans, Seymour Creek,
- Teck Corporation, Gold Run Creek.

Tic Exploration Operation - Gladstone Creek

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Syn-mineralization faults and their re-activation, Finlayson Lake massive sulphide district, Yukon-Tanana Terrane, southeastern Yukon[1]

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Murphy, D.C. and Piercey, S.J., 2000. Syn-mineralization faults and their re-activation, Finlayson Lake massive sulphide district, Yukon-Tanana Terrane, southeastern Yukon. *In:* Yukon Exploration and Geology 1999, D.S. Emond and L.H. Weston (eds.), Exploration and Geological Services Division, Yukon, Indian and Northern Affairs Canada, p. 55-66.

ABSTRACT

Although deformed and metamorphosed, the strata hosting volcanogenic massive sulphide deposits in the Finlayson Lake district retain characteristics that suggest the influence of syn-depositional faults near the deposits. The Fyre Lake deposit occurs within a mafic schist unit near where notable changes in thickness, rock type and amount of comagmatic metaplutonic rocks occur. These changes occur across a north-northwest-striking corridor along which deposits and prospects in the overlying felsic metavolcanic schist are distributed (including Kudz Ze Kayah). Syn-volcanic, syn-mineralization faulting would explain the association of these deposits with the observed changes in host rock characteristics. Using similar arguments, syn-mineralization faults have been inferred on the Hat Trick property southwest of Fire Lake, as well as in Pennsylvanian and Permian rocks of the Campbell Range succession. Finally, stratigraphic differences between coeval rocks in the hanging wall and footwall of the Money Creek thrust imply that the thrust may have re-activated a syn-depositional structure. The regions of hanging wall and footwall cut-offs of the Money Creek thrust would therefore be considered as highly prospective for massive sulphide deposits.

RÉSUMÉ

Bien qu'elles soient affectées par la déformation et le métamorphisme régionaux, les strates contenant les gisements de sulfures massifs volcanogènes de la ceinture de Finlayson Lake préservent encore des indices de l'influence de failles synvolcaniques près des gisements. Le gisement de Fyre Lake est situé dans une zone caractérisée par des variations important en épaisseur, en lithologies, et en quantité de roches métaplutoniques comagmatiques. Ces changements se produisent le long d'un corridor d'orientation nord-nord-ouest, où l'on retrouve des gisements et des indices minéralisés au sein des roches métavolcaniques felsiques susjacentes (incluant le gisement de Kudz Ze Kayah). La formation de failles synvolcaniques et synminéralisation expliquerait la corrélation entre ces gisements et les changements reconnus dans les roches encaissantes. De mêmes, la présence de failles synminéralisation sont inférées sur la propriété Hat Trick, au sud-ouest de Fire Lake, et dans les roches d'âge Pennsylvanien et Permien de la succession de Campbell Range. Finalement, les différences stratigraphiques entre les roches contemporaines dans le toit et le mur du chevauchement de Money Creek suggèrent fortement que ce chevauchement a réactivé une structure synvolcanique. Par conséquent, les régions où le chevauchement de Money Creek recoupe les strates, à la fois dans le toit et le mur de cette faille, doivent être considérées comme très prometteuses pour la découverte de gisements de sulfures massifs.

[1]*Contribution to the Ancient Pacific Margin NATMAP project.*

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INTRODUCTION

As emphasized in Nelson (1997), an empirical spatial relationship between syngenetic volcanic-associated massive sulphide deposits (VMS) and syn-volcanic faults has been documented in many mature VMS districts (e.g., Noranda, Setterfield et al., 1995) and from studies of modern seafloor hydrothermal systems (e.g., Middle Valley, Goodfellow and Franklin, 1993). Such a relationship underscores the importance of the early identification of these structures for exploration in frontier areas. However, even in the least deformed areas, syn-volcanic faults are subtle features and are typically identified only after detailed mapping and facies analysis of volcanic rock sequences are completed around known deposits (e.g., Gibson et al., 1999). Finding syn-volcanic faults, or their zones of influence, in highly deformed and metamorphosed regions may be an insurmountable challenge.

In spite of the potential difficulty of finding syn-volcanic faults in deformed regions, a number of the criteria that have been used to identify them in pristine areas may have broader application in more highly deformed areas. Gibson et al. (1999) summarized criteria that have been used in recognizing syn-volcanic faults in less deformed areas. These include: 1) localized concentrations of dykes or apophyses of syn-volcanic intrusions; 2) intensification of discordant hydrothermal alteration and/or abrupt change in type of alteration; 3) abrupt change(s) in thickness(es) of pyroclastic, volcaniclastic or sedimentary units; 4) the offset of a volcanic rock unit with subsequent units not being offset; and 5) localized monolithic to heterolithic coarse breccia deposits. Of these, criteria 1), 3), 4) and 5) may not be obscured to any great extent by deformation and metamorphism, and are potentially useful even where rocks are highly deformed. Furthermore, these features may have an influence on subsequent deformation. Stratigraphic perturbations such as thickness/facies changes may provide the nuclei for later folds, and syn-depositional faults may be suitably oriented to be re-activated as thrust faults during later shortening. Hence, structures that appear to be post-depositional must be scrutinized carefully for indications that they may have been controlled by syn-depositional features.

In this paper, we present evidence of syn-volcanic faulting from the Finlayson Lake massive sulphide district of southeastern Yukon, an emerging VMS district hosted in variably deformed and metamorphosed mid- to Upper Paleozoic rocks of Yukon-Tanana Terrane (Mortensen, 1992; Murphy, 1998; Murphy and Piercey, 1999; Figs. 1, 2). We show that the deposits at Fyre Lake and Kudz Ze Kayah, as well as other areas of mineralization, are distributed along a trend that spatially coincides with fundamental changes in the host volcano-sedimentary succession and spatially associated meta-plutonic rocks. Using the criteria listed above, these changes are interpreted in terms of syn-volcanic faulting. We present evidence that the Money prospect, located in less deformed rocks of the Campbell Range belt, occurs along a syn-volcanic structure marked by a pronounced facies change and a localized concentration of co-magmatic intrusions. We describe stratigraphic and structural relationships from the Hat Trick prospect, southwest of Fire Lake that suggest the presence of a syn-volcanic fault that influenced later deformation. Finally, we describe the Money Creek thrust, a newly defined regional-scale

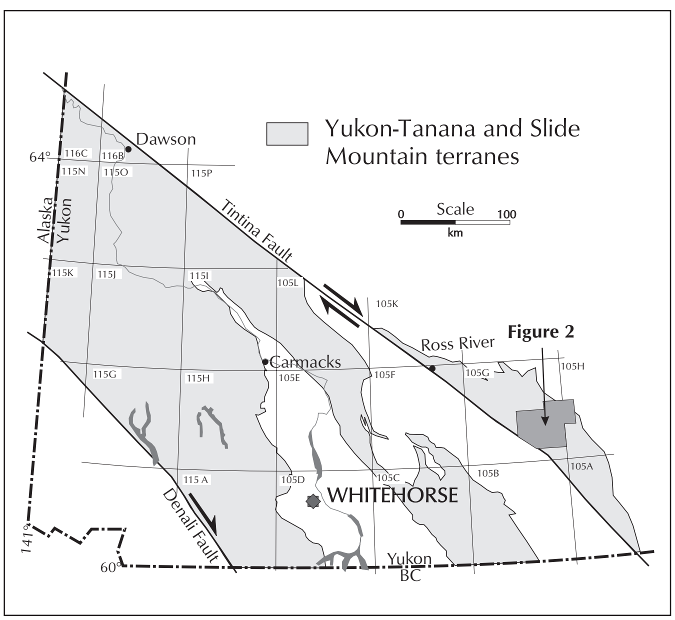
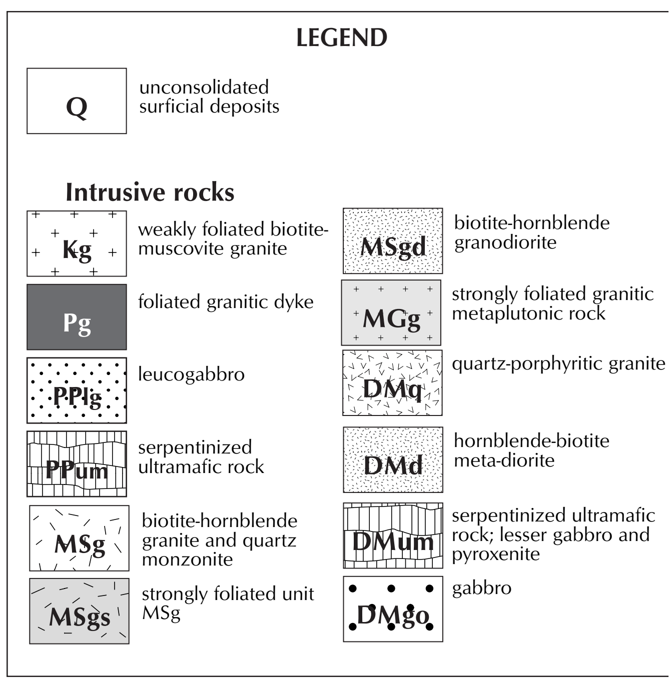


Figure 1. Location of the study area with respect to the distribution of Yukon-Tanana and Slide Mountain terranes in the Yukon (modified from Wheeler and McFeely, 1991). Mesozoic plutons and metamorphic complexes are not differentiated.



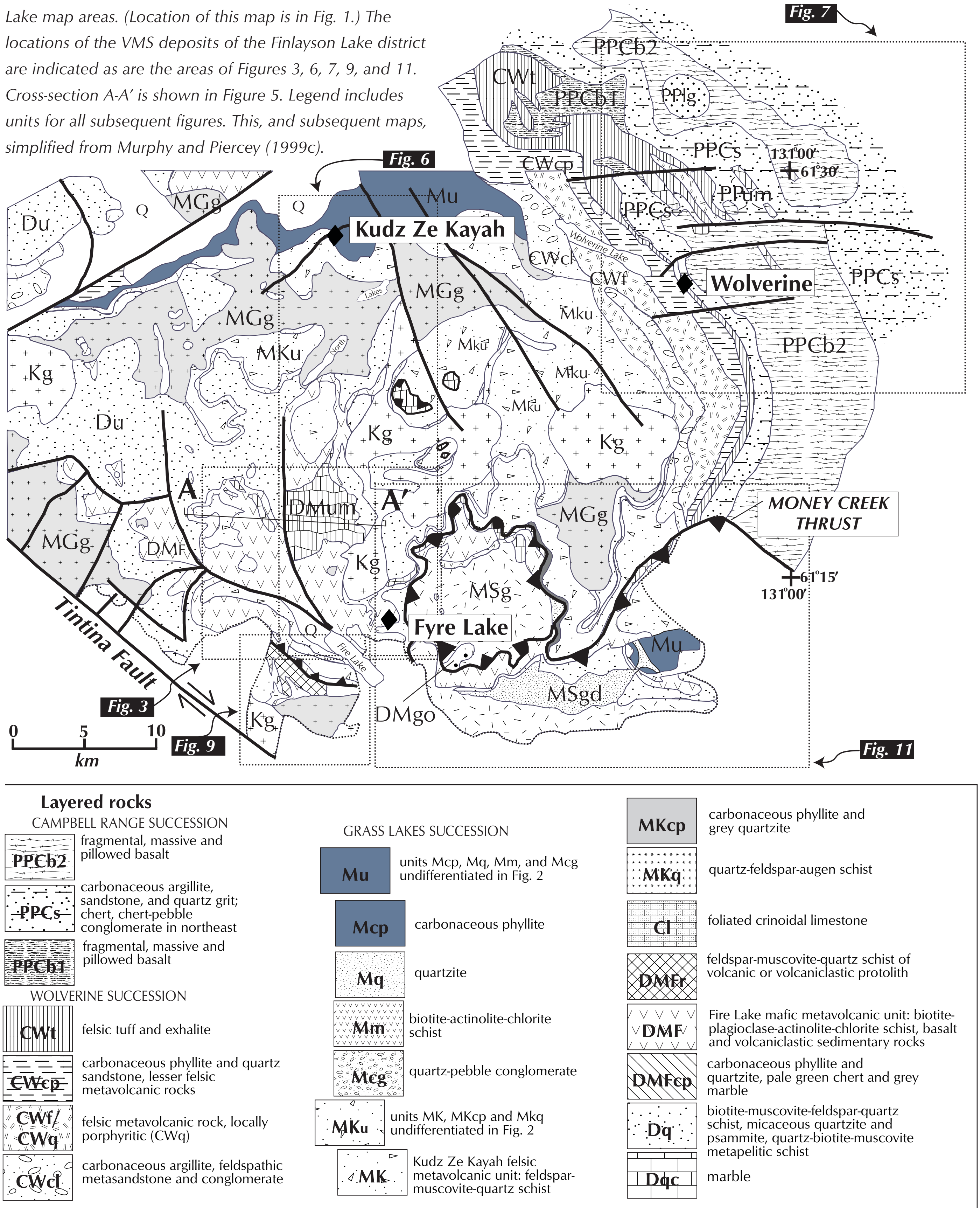


Figure 2. *Geological map of parts of Finlayson and Frances Lake map areas. (Location of this map is in Fig. 1.) The locations of the VMS deposits of the Finlayson Lake district are indicated as are the areas of Figures 3, 6, 7, 9, and 11. Cross-section A-A′ is shown in Figure 5. Legend includes units for all subsequent figures. This, and subsequent maps, simplified from Murphy and Piercey (1999c).*

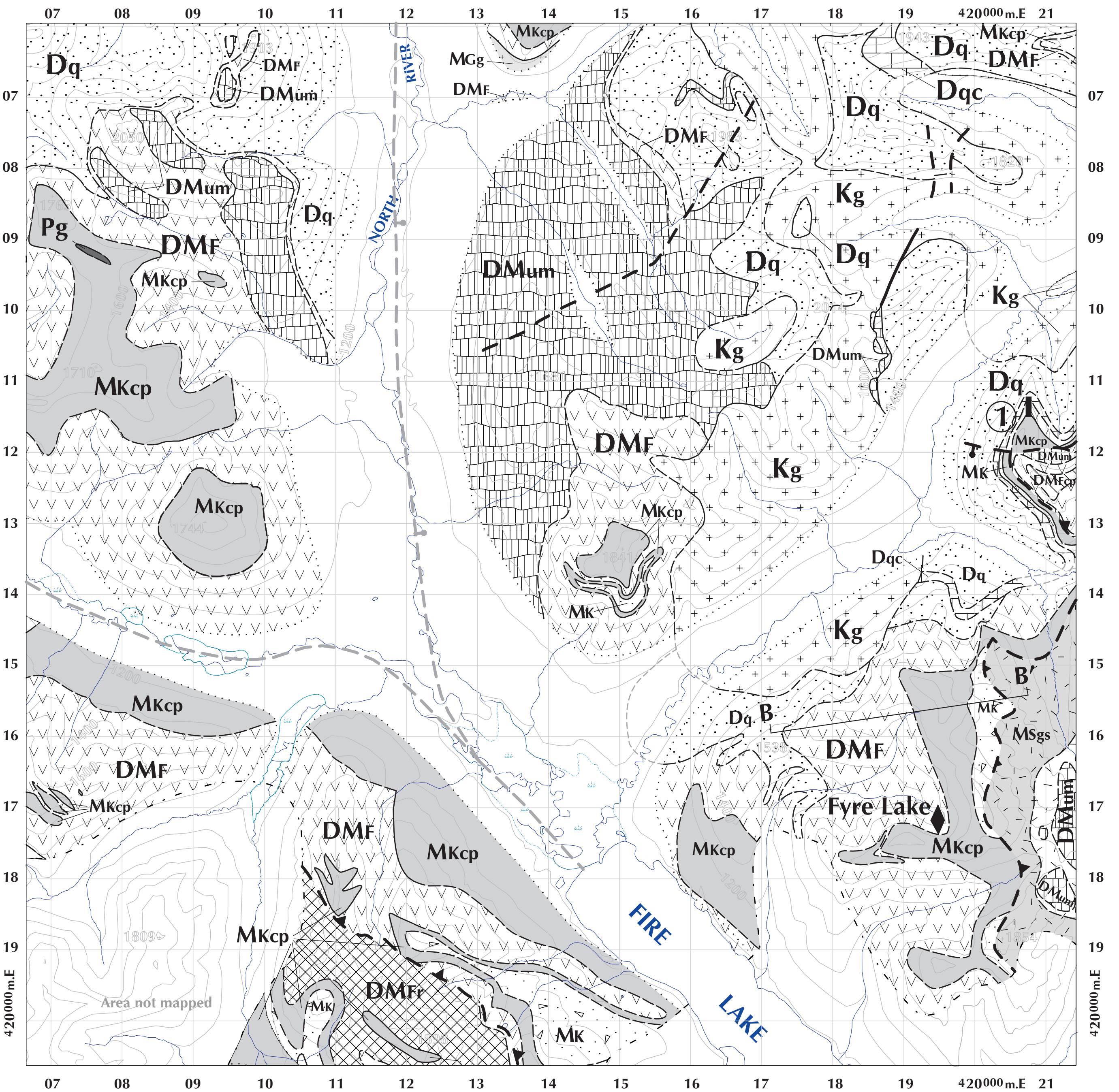


Figure 3. *Geological map of the area around the Fyre Lake Cu-Co-Au VMS deposit. Location and legend in Figure 2. Cross-section B-B′ is shown in Figure 4. Location 1, discussed in text, is indicated by the dark bar. Grid lines are spaced 1 km apart.*

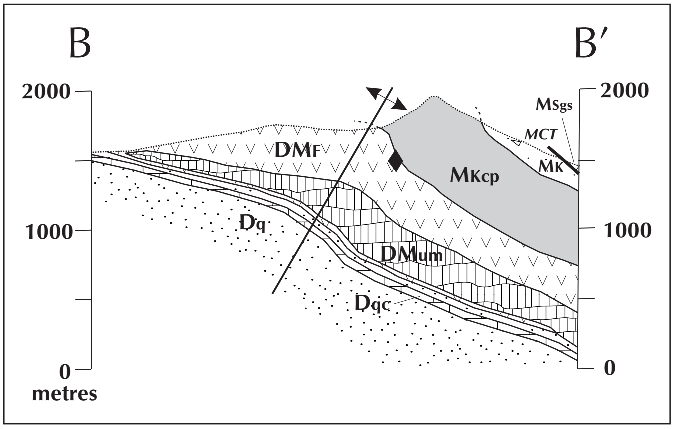


Figure 4. *Cross-section along line B-B′ in Figure 3, about 1.5 km north of the Fyre Lake deposit. The stratigraphic level of the Fyre Lake deposit is indicated by the diamond symbol. At the deposit, the upper part of unit DMF comprises a significant amount of carbonaceous schist and felsic schist of volcanic and volcaniclastic protolith. See text for discussion. The mafic and ultramafic metaplutonic rocks are projected into the line of section from north of the section line. MCT, Money Creek thrust. Legend as in Figure 2.*

thrust fault that juxtaposes coeval, although subtly different, stratigraphic sections and interpret it as a re-activated syn-depositional fault.

FYRE LAKE – KUDZ ZE KAYAH TREND

The characteristics of the host rocks around the Fyre Lake deposit (Pacific Ridge Resources Ltd., 15.4 million tonne preliminary resource containing 8.2 million tonnes, 2.1% Cu, 0.11% Co, 0.73 g/t Au; Yukon Minfile, 1997, 105G 034) satisfy most of the criteria for the presence of a syn-volcanic fault. Regional mapping has shown that the Fyre Lake deposit is spatially associated with profound changes in the nature and thickness of the host Upper Devonian to Lower Mississippian Fire Lake mafic schist unit (Murphy, 1998; Murphy and Piercey, 1999b, c; unit DMF, Figs. 2 and 3). Four kilometres northeast of the deposit (Location 1, Fig. 3), the Fire Lake unit comprises about 40 m of biotite-actinolite-chlorite schist. Near the deposit, the unit is nearly 800 m thick (section B-B′, Fig. 4). At the deposit, unit DMF is at least this thick (the bottom was not intersected in drill holes). It includes 5 to over 200 m of felsic schist of volcanic and volcaniclastic protolith, and siliceous carbonaceous phyllite (quartz-chlorite mica schist of Blanchflower et al., 1997; transition zone of Foreman, 1998; psammitic schist and felsic metavolcanic rocks of Sebert and Hunt, 1999). Massive sulphide mineralization occurs in the upper part of the unit just below the base of the overlying carbonaceous schist, the same carbonaceous schist that overlies the section 4 km to the northeast.

The changes in the thickness and nature of the mafic metavolcanic host rocks of the Fire Lake deposit also coincide with a change in the amount of mafic and ultramafic metaplutonic rocks spatially associated with the host schist. No mafic and ultramafic metaplutonic rocks are found in or near the unit 4 km northeast of the deposit (except in the hanging wall of the Money Creek thrust, discussed later). However, 2 km north of the deposit, over 100 m of massively serpentinized ultramafic rock (meta-peridotite), massive coarse-grained amphibolite (meta-pyroxenite) and coarse-grained actinolite-plagioclase-chlorite schist (meta-gabbro) occur at the base of the unit, directly overlying the marble-quartz psammite unit. On the ridge directly north of the deposit, meta-gabbro makes up about 10% of the mafic schist unit.

Mafic and ultramafic meta-plutonic rocks in southeastern Grass Lakes map area (105G/7, Fig. 2, Murphy, 1997), north-northwest along strike of the Fyre Lake deposit, show characteristics and relationships that suggest they are sills that flowed from dykes lying along the trend of thickness changes in unit DMF. These rocks occur primarily in an approximately 600-m-thick sheet lying near the base of unit DMF (section A-A′, Figs. 2, 5). The sheet tapers to zero thickness over a 6 km horizontal distance westwardly across the North River valley and over a 4 km horizontal distance eastwardly. In addition, to the east, smaller bodies of ultramafic rock occur at different levels within the muscovite-quartz psammite unit (unit Dq) under the mafic schist. East of the Cretaceous granite in this area, bodies of ultramafic rock occur in the lower part of unit Dq, below the calcareous member Dqc. West of the granite, at approximately

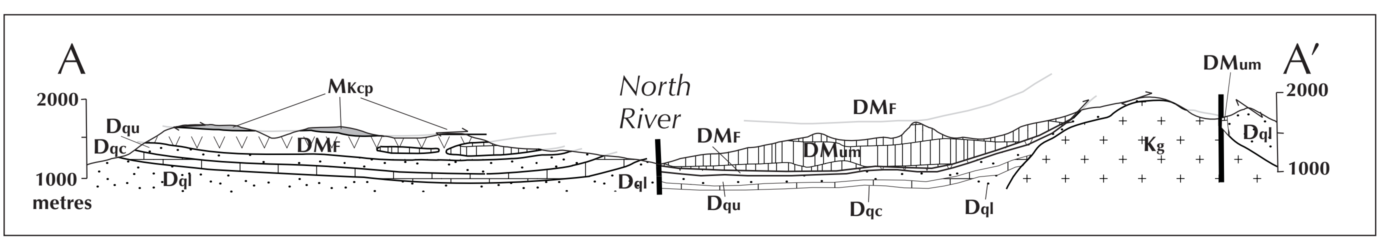


Figure 5. *Cross-section along line A-A′ shown in Figure 2. Legend as in Figure 2. Thickness of unit Dqc east of the North River is not known with certainty. The lower and upper parts of unit Dq are indicated as units Dql and Dqu, respectively.*

the same structural level, ultramafic rocks occur in the part of unit Dq above the calcareous member. These occurrences of ultramafic rock below unit DMF are unusual, observed only in one other place in the area shown in Figure 2, and are interpreted as dykes feeding the stratabound sheet within the overlying mafic schist unit. Furthermore, as two different stratigraphic levels of unit Dq are juxtaposed at the same structural level on either side of the Cretaceous granite, these dykes likely intruded along a fault.

Regionally, the changes identified above occur across a north-northwest-trending corridor that can be traced from the Fyre Lake deposit into east-central Grass Lakes map area and as far north as the large body of Grass Lakes granitic meta-plutonic rock (Fig. 6). The Pack prospect (Yukon Minfile, 1997, 105G 032) occurs along this trend, and occurrences on the OVERTIME, COBB, NHL and GOAL NET properties occur just off the trend both to the east and west. All of these showings occur in or just above the Kudz Ze Kayah felsic metavolcanic unit (MK), the unit that stratigraphically overlies the Fire Lake unit (DMF). Lying directly along this trend, across the Grass Lakes metaplutonic body, is Cominco Ltd.'s Kudz Ze Kayah deposit (>13 million tonne mineable reserve, 1.0% Cu, 1.3% Pb, 5.5% Zn, 123 g/t Ag, 1.2 g/t Au; Yukon Minfile, 1997, 105G 117). The spatial association of prospects and deposits in unit MK, with the projected trace of the Fyre Lake structure, implies that this feature may have controlled hydrothermal fluid flow during the deposition of unit MK.

CAMPBELL RANGE BELT

Pennsylvanian-Permian basalt, chert, and carbonaceous metaclastic rocks of the Campbell Range belt are the youngest stratified rocks of Yukon-Tanana Terrane in the Finlayson Lake area. They represent the culmination of the transition from arc-rifting or back-arc extension to oceanic or back-arc marginal basin magmatism and sedimentation (Plint and Gordon, 1997; Piercey et al., 1999; Figs. 2 and 7). The stratigraphic succession of the Campbell Range belt comprises a lower unit composed primarily of fragmental, pillowed and massive basalt and lesser argillite and chert; a heterogeneous middle unit composed of carbonaceous argillite, quartz sandstone, chert, chert-pebble conglomerate, discontinuous bodies of limestone, and diamictite; and an upper unit similar to the lower one (Murphy and Piercey, 1998, 1999a, b). Diabase, gabbro, leucogabbro and ultramafic rocks intrude all levels of the succession.

Two features of the Campbell Range belt imply the presence of syn-volcanic faults active during the formation of the basin. First of all, the middle heterogeneous sedimentary unit undergoes a facies change from one side of the Campbell Range to the other, over a horizontal distance of about 10 km (Fig. 8). On the southwest side, unit PPCs passes upward from a basal diamictite into carbonaceous phyllite and sandstone with glassy black

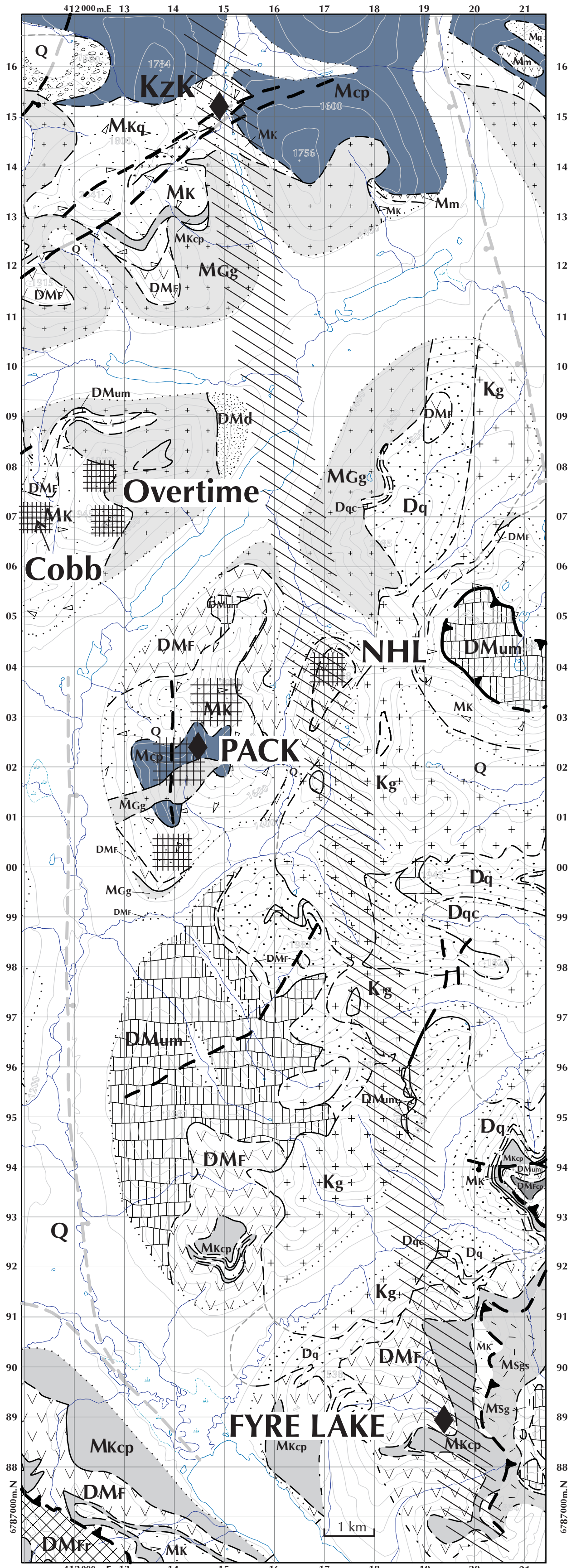


Figure 6. caption on next page.

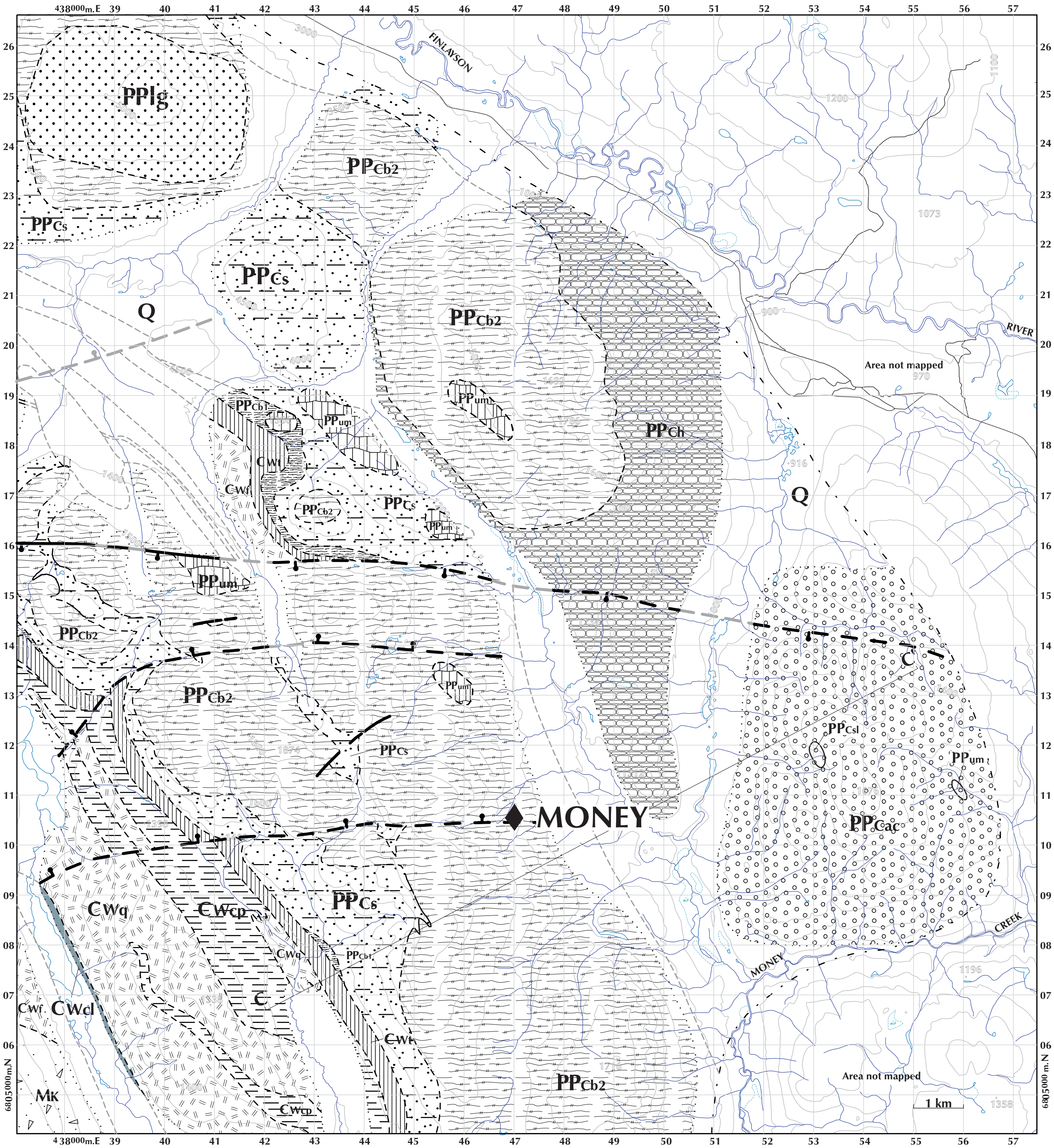


Figure 7. *Geological map of the Campbell Range. Cross-section C-C′ is shown in Figure 8. Location and legend in Figure 2, except for PPCcc and PPCch, which are discussed in the text. Grid lines are spaced 1 km apart.*

Figure 6, opposite. *Geological map of the area between the Fyre Lake and Kudz Ze Kayah (KZK) VMS deposits showing the locations of VMS prospects and gossanous areas (grid pattern). The trend of the inferred syn-volcanic fault discussed in the text is indicated by the diagonal ruled pattern. Location and legend in Figure 2. Grid lines are spaced 1 km apart.*

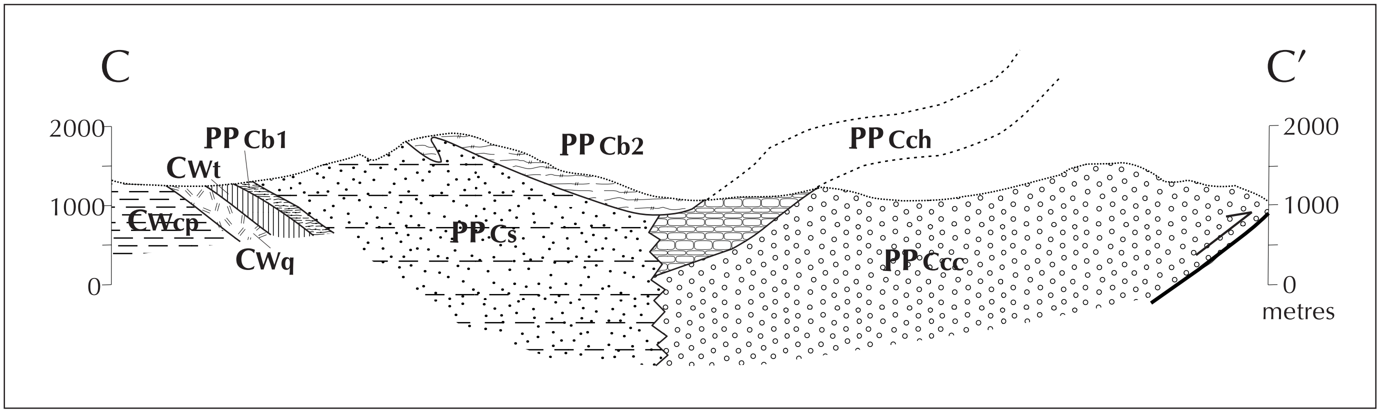


Figure 8. *Cross-section across Campbell Range along line C-C′ in Figure 7. Legend as in Figure 2. In this figure, unit PPCs, on the northeast side of the Campbell Range, is subdivided into a lower unit PPCcc and an upper unit PPCch. See text for discussion.*

quartz grains, and finally into greywacke and chert in the uppermost part of the unit. On the northeast side of the range, the middle unit comprises two chert- and argillite-dominated subdivisions. The basal subdivision (unit PPCcc in Fig. 8) consists of carbonaceous argillite, dark chert, rare sandstone or greywacke with glassy black quartz grains, and chert-pebble conglomerate. The upper subdivision (unit PPCch in Fig. 8) consists of thin-bedded maroon, green and tan chert and argillite. The lateral facies change between unit PPCs and units PPCcc/PPCch is not exposed in the map area. Secondly, the approximate location of this facies change is marked by a concentration of northwestwardly elongate bodies of mafic and ultramafic metaplutonic rocks, intruding all the units but mainly the upper basalt unit. The spatial association of a dramatic facies change, along with a concentration of potential feeders to the basalts, suggests the presence of a syn-volcanic fault (Gibson et al., 1999).

Few massive sulphide occurrences have been discovered in the Campbell Range belt, but those that have been found occur along or near the trace of the proposed fault. The Money prospect (Yukon Minfile, 1997, 105H 078; Baknes, M., in Hunt et al., 1997) occurs in the upper basalt along this trace. Anomalously high Cu values have been found on Cominco Ltd.'s STRIKE claims along this trend (Mann and Mortensen, this volume). Although there is little detailed geological control along strike, it should be noted that 70 km to the northwest, Expatriate Resources' Ice deposit (about 4.5 million tonnes of 1.48% Cu and minor Au, Ag and Co credits; Yukon Minfile, 1997, 105G 118) occurs in a basalt-rich succession similar to the upper basalt of the Campbell Range belt (Hunt, 1998a, b, 1999), near large bodies of ultramafic rock (see Tempelman-Kluit, 1977). Between the Campbell Range belt and the Ice deposit lies a poorly exposed corridor of greenstone, mafic and ultramafic intrusive rocks, dark argillite and chert-pebble conglomerate, and discontinuous pods of limestone (Tempelman-Kluit, 1977; Mortensen and Jilson, 1985). As has been inferred in the Campbell Range belt, this corridor may host the trace of syn-basinal faults and should be considered to have significant mineral potential for Ice-type deposits. Similar rocks also lie along strike to the southeast of the Money prospect, extending the corridor of high mineral potential in that direction.

HAT TRICK PROPERTY

At Expatriate Resources' Hat Trick property (Fig. 9), both stratigraphic and structural features are evidence for syn-volcanic, syn-mineralization faulting. The property is underlain by two coeval yet different stratigraphic sections separated by a steep, north-dipping fault (Fig. 10). North of the fault, biotite-actinolite-chlorite schist of the Fire Lake mafic meta-volcanic unit (unit DMF) passes upward into siliceous and carbonaceous schist (unit MKcp) with upwardly increasing amounts of quartz-muscovite schist (felsic metavolcanic rock, unit MK). South of the fault, a thick section of locally gossanous and highly altered magnetite-bearing felsic schist, massive siliceous rock, and lesser mafic and carbonaceous schist (unit DMFF) occurs between unit DMF and the carbonaceous schist of unit MKcp. The presence of the thick felsic schist section between units DMF and MKcp south of the fault is reminiscent of the lateral change of unit DMF at the Fyre Lake deposit and is attributed to the presence of a syn-volcanic fault. The fault between the two sections dips to the north and was initially inferred to be a southwest-directed thrust fault. However, the small thrust-sense offset of the top of unit DMF, combined with the stratigraphic difference across the fault, suggest that it is better interpreted as an originally steep, south-dipping, syn-volcanic fault that rotated through the vertical and was possibly re-activated during Cretaceous southwest-directed deformation.

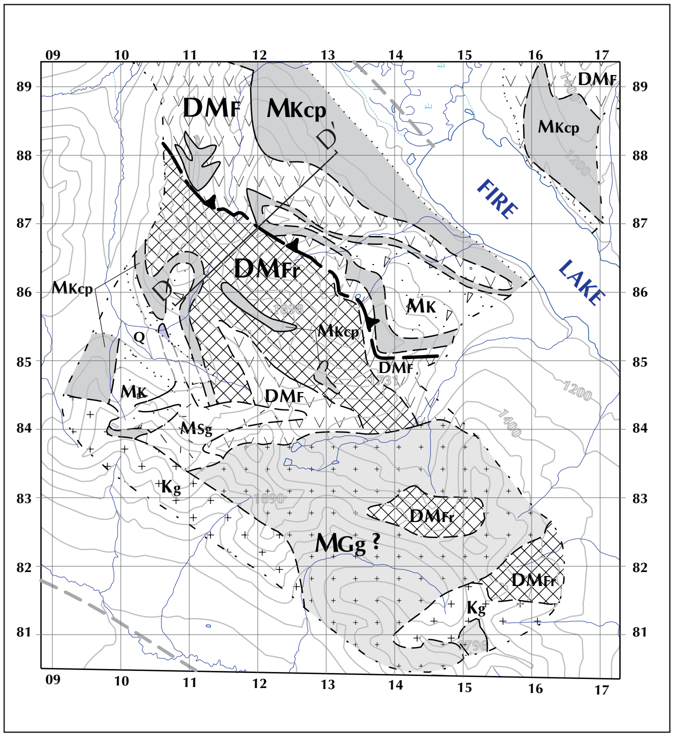


Figure 9. Geological map of part of Expatriate Resources' Hat Trick property, southwest of Fire Lake. Cross-section D-D' shown in Figure 10. Location and legend in Figure 2. Grid lines are spaced 1 km apart.

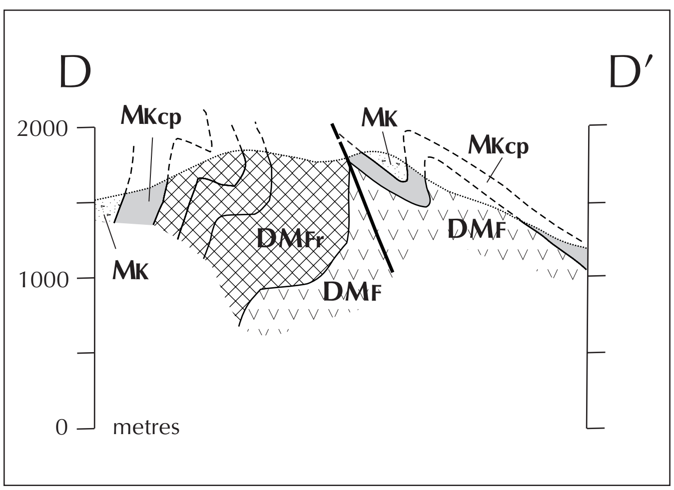


Figure 10. *Cross-section along line D-D' in Figure 9. Form lines in unit DMFr indicate altered and mineralized horizons. Legend as in Figure 2.*

MONEY CREEK THRUST

The Money Creek thrust (Figs. 2 and 11) is interpreted as another example of a fault that was active during the evolution of Yukon-Tanana volcanism and that was re-activated as a thrust fault during Late Paleozoic or Mesozoic shortening. The stratified rocks of the Money Creek thrust sheet were previously included in the Money and North Klippe and considered to be allochthonous and unrelated to footwall rocks (Tempelman-Kluit, 1979; Erdmer, 1985; Mortensen and Jilson, 1985; Mortensen, 1992b). More recently, Hunt and Murphy (1998), Murphy and Piercey (1999b, c), and Piercey and Murphy (this volume), have shown that the stratified rocks of the thrust sheet resemble rocks in the immediately underlying footwall, both in composition and succession (Fig. 12). Furthermore, U-Pb geochronological constraints (Mortensen, 1992a, b; Grant, 1997; Mortensen, pers. comm., 1996-1999) affirm that the successions are coeval.

Although similar and coeval, there are important differences between the hanging wall and footwall of the Money Creek thrust. These include: 1) the quartz-rich metaclastic rocks in unit Dq of the thrust sheet are primarily quartzite, whereas in the footwall, they are primarily micaceous quartz psammite; 2) both basalt (unit DMF) and rhyolite (unit DMFr) of the thrust sheet are locally subaerial, while coeval rocks of the footwall are intercalated mainly with carbonaceous argillite, implying a basinal setting; 3) a laterally continuous, eastwardly thickening fossiliferous limestone with a shallow water conodont form (Orchard, M., GSC Microfossil Report MJO-1997-14 on sample collected by D. Rhodes) occurs in the thrust sheet and is absent in the footwall; 4) bedded barite occurs in unit MK within the thrust sheet and has not been observed in the footwall; and 5) plutonic rocks in the thrust sheet are hornblende-bearing granodiorite and granite in contrast to the primarily peraluminous granitic meta-plutonic rocks of the footwall (see below). Taken together, these differences suggest that the rocks of the Money Creek thrust sheet may have formed in a different, possibly higher-standing, crustal block than the rocks of the footwall. In such a scenario, the Money Creek thrust may simply be a thrust re-activation of the structure that separated the different crustal blocks in Devonian and Mississippian time.

If a re-activated feature, the areas near the hanging wall and footwall cut-offs would be likely sites for syngenetic mineralization. Bedded barite, altered pyritic felsic metavolcanic rocks, and an altered and locally malachite-stained hornblende granodiorite occur on Cominco Ltd.'s EXPO claims which lie about 10 km behind the leading edge of the thrust. The footwall cut-off has probably been offset along the Tintina Fault. The thrust sheet overlies the same footwall unit (MK) almost to the Tintina Fault (Fig. 2). However, as hornblende-bearing granitic meta-plutonic rocks similar to those in the Money Creek thrust sheet appear in the footwall near the Tintina Fault (Figs. 2 and 9), the footwall cut-off may not have been far to the south or

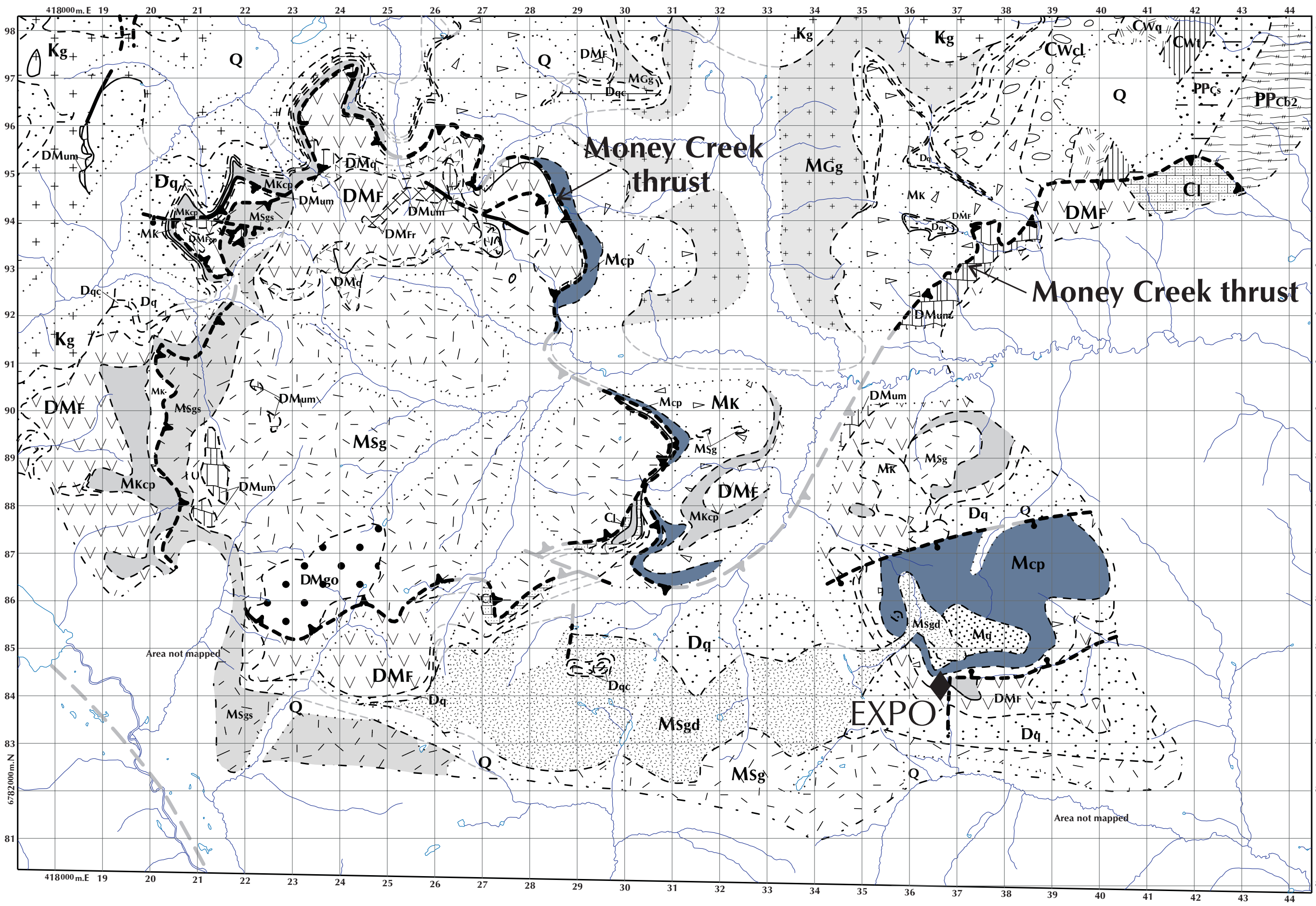


Figure 11. *Geological map of parts of Wolverine Lake (105G/8) and Waters Creek (105G/1) map areas showing the Money Creek thrust sheet and its footwall. Location and legend in Figure 2. Grid lines are spaced 1 km apart.*

southwest. If so, the region of the footwall cut-off may currently be just southwest of the Tintina Fault near Dawson City.

Structural fabrics in the deformation zone immediately above the fault, indicate that the Money Creek thrust sheet was thrust towards the north-northeast. Its displacement was at least 30 km based on the amount of overlap of the footwall by the hanging wall.

SUMMARY

Several lines of evidence suggest that syngenetic mineralization in the Finlayson Lake massive sulphide belt, as in other VMS districts, was focussed along syn-volcanic faults. Although the host rocks are deformed and metamorphosed, the trends of these structures can be estimated, primarily by looking for concentrations of comagmatic intrusions. These trends define corridors of high potential for new discoveries.

ACKNOWLEDGEMENTS

The ideas in this contribution have jelled from four (DM) and two (SP) field seasons in the Finlayson Lake area where we have benefited from discussions with Paul MacRobbie and Derek Rhodes of Cominco Ltd., Bill Wengzynowski of Expatriate Resources, Lee Pigage, formerly of Expatriate Resources, and Peter Holbek of Atna Resources. We would also like to thank Jim Mortensen of the University of British Columbia for sharing his knowledge of the 'Banana,' Suzanne Paradis and Jan Peter of the Geological Survey of Canada for discussions about the inner workings of VMS deposits, and Grant Abbott, Maurice Colpron and Lee Pigage of Yukon Geology Program for stimulating regional discussions. We would like to thank Annie Daigle for field assistance, Kaori Torigai for pulling together much of the CAD work for this article and Maurice Colpron for his initial reading of an early draft of this paper. Leyla Weston and Diane Emond are thanked for careful editing of this manuscript.

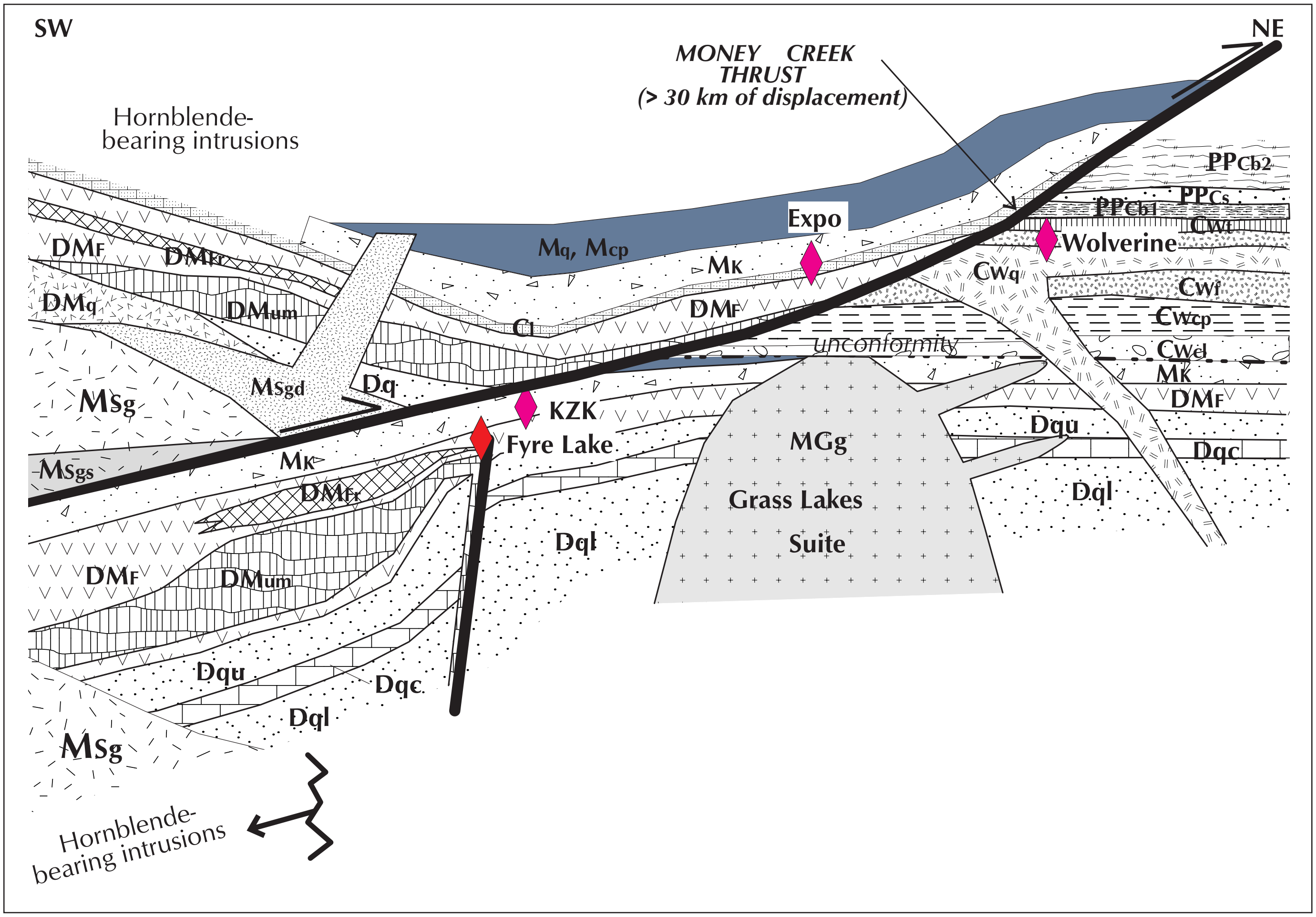


Figure 12. Schematic northeast-southwest cross-section summarizing the stratigraphy and intrusive rocks in the hanging wall and footwall of the Money Creek thrust sheet. Legend as in Figure 2. The appearance of hornblende-bearing granitic meta-plutonic rocks in the footwall near the Tintina Fault is indicated schematically by the jagged vertical line. KZK = Kudz Ze Kayah.

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Stratigraphy and regional implications of unstrained Devono-Mississippian volcanic rocks in the Money Creek thrust sheet, Yukon-Tanana Terrane, southeastern Yukon[1]

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Piercey, S.J. and Murphy, D.C., 2000. Stratigraphy and regional implications of unstrained Devono-Mississippian volcanic rocks in the Money Creek thrust sheet, Yukon-Tanana Terrane, southeastern Yukon. *In:* Yukon Exploration and Geology 1999, D.S. Emond and L.H. Weston (eds.), Exploration and Geological Services Division, Yukon, Indian and Northern Affairs Canada, p. 67-78.

ABSTRACT

Relatively unstrained Devonian-Mississippian volcanic and volcano-sedimentary rocks have been documented in the Money Creek thrust sheet in Finlayson Lake map area. The succession comprises a five-unit volcanic stratigraphy containing subaerial and subaqueous mafic and felsic volcanic and volcaniclastic rocks and associated sedimentary rocks that are underlain, and locally crosscut by, sub-volcanic mafic intrusions and quartz porphyritic granite. Magma-mingling relationships between mafic dykes and quartz-porphyritic granite suggest that mafic and felsic volcanism was broadly coeval. A published 360.5 ± 1 Ma U-Pb date on a quartz porphyritic granitic intrusion establishes the age of volcanism.

Biotite-hornblende granitic rocks of the Simpson Range Plutonic Suite (SRPS) intrude and metamorphose the volcanic sequence and related sub-volcanic intrusive rocks, and coupled with previously published U-Pb dates (345-350 Ma), this relationship implies that the SRPS is a distinctly younger pulse of magmatism.

Mafic and ultramafic rocks of the Money Creek thrust sheet have previously been correlated with the Pennsylvanian-Permian Campbell Range belt and together both have been considered part of the Anvil Allochthon or Slide Mountain Terrane. Field characteristics, age, and geochemistry show that neither correlation is valid.

RÉSUMÉ

Des roches volcaniques et volcanosédimentaires relativement peu déformées, datant du Dévonien-Mississipien, ont été documentées dans la nappe de charriage de Money Creek, dans la région de Finlayson Lake. La succession inclue un ensemble stratigraphique volcanique de cinq unités comprenant des roches volcaniques et volcanoclastiques mafiques et felsiques subaériennes et subaquatiques, ainsi que des roches sédimentaires associées. Ces roches recouvrent des intrusions subvolcaniques mafiques et du granite à phénocristaux de quartz qui par endroits peuvent recouper les roches volcaniques. Les relations de mélange magmatique entre les dykes mafiques et le granite à phénocristaux de quartz suggèrent que le volcanisme mafique et le volcanisme felsique étaient généralement contemporains. Une datation à l'U-Pb, précédemment publiée, de 360,5 ± 1 Ma pour une des intrusions de granite à phénocristaux de quartz fixe l'âge du volcanisme.

Les roches granitiques à biotite-hornblende de la Série plutonique de Simpson Range (SPSR) recoupent et métamorphisent la séquence volcanique et les roches intrusives subvolcaniques associées. Cette observation combinée avec des datations à l'U-Pb déjà publiées (345 à 350 Ma) implique que la SPSR représente un épisode magmatique sensiblement plus jeune.

Les roches mafiques et ultramafiques de la nappe de charriage de Money Creek ont auparavant été corrélées avec la ceinture de Campbell Range du Pennsylvanien-Permien et ont été interprétées comme appartenant soit à l'allochtone d'Anvil ou au terrane de Slide Mountain. Les caractéristiques de terrain, l'âge et la géochimie démontrent que ces corrélations ne sont pas valables.

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INTRODUCTION

The Yukon-Tanana Terrane (YTT) over much of the Yukon is characterized by the presence of abundant greenstone, chloritic schist, gabbro, diabase and ultramafic rocks (e.g., Tempelman-Kluit, 1979; Mortensen, 1992a, b; and others). The origin and significance of the greenstones are ambiguous and the source of controversy (e.g., Tempelman-Kluit, 1979; Mortensen and Jilson, 1985). In most previous work, all mafic rocks have been placed under the same header, be that Anvil Allochthon (Tempelman-Kluit, 1979; Erdmer, 1981, 1985), Slide Mountain Terrane (Mortensen and Jilson, 1985; Mortensen, 1992a, b), or Anvil Assemblage (Wheeler and McFeely, 1991). However, recent mapping in different parts of the YTT has shown that there are different greenstone units within the YTT (e.g., Stevens et al., 1995; Murphy and Timmerman, 1997; Murphy, 1998; Murphy and Piercey, 1999; Piercey et al., 1999a, b). Others have questioned the validity of correlating the Slide Mountain Terrane with the Anvil Assemblage based on geochemical and isotopic grounds (Creaser et al., 1997; Grant, 1997; Grant et al., 1996).

Recent geochemical and isotopic data suggest that there are differences in the chemical and isotopic compositions of the greenstones (e.g., Piercey et al., 1999a, b; Creaser et al., 1997; Grant et al., 1996; Grant, 1997); however, only a few workers have outlined field criteria to distinguish between the different greenstone units (e.g., Murphy and Timmerman, 1997; Murphy, 1998; Murphy and Piercey, 1999a, b, c). Most of the ambiguities in the distinction between the greenstone units arise because of the highly variable degree of strain recorded within them. In the Finlayson Lake region, Murphy and Timmerman (1997), Murphy (1998), and Murphy and Piercey (1999a, b, c) show that the YTT contains at least three distinct mafic horizons at different stratigraphic levels. Similarly, other workers have shown the different mafic units have distinctive geochemical characteristics. For instance, the lowermost mafic unit (unit 2) exhibits primitive arc (Piercey et al., 1999a, b; Sebert and Hunt, 1999) through calc-alkalic geochemistry (Grant et al., 1996; Grant, 1997; Piercey et al., 1999a, b); the middle mafic unit (unit 4) has rift-like geochemistry (Piercey, unpublished data); and the upper mafic units of the Campbell Range belt exhibit rift alkaline through E-MORB to N-MORB signatures (Plint and Gordon, 1997; Piercey et al., 1999a, b; Piercey, unpublished data).

In this paper we present results from mapping of a previously undocumented section of Devono-Mississippian basalt and rhyolite and spatially associated intrusive rocks in the hanging wall of the Money Creek thrust (Murphy and Piercey, 2000; Figs. 1 and 2). These rocks are now considered unique in that they are essentially unstrained and relatively undeformed,

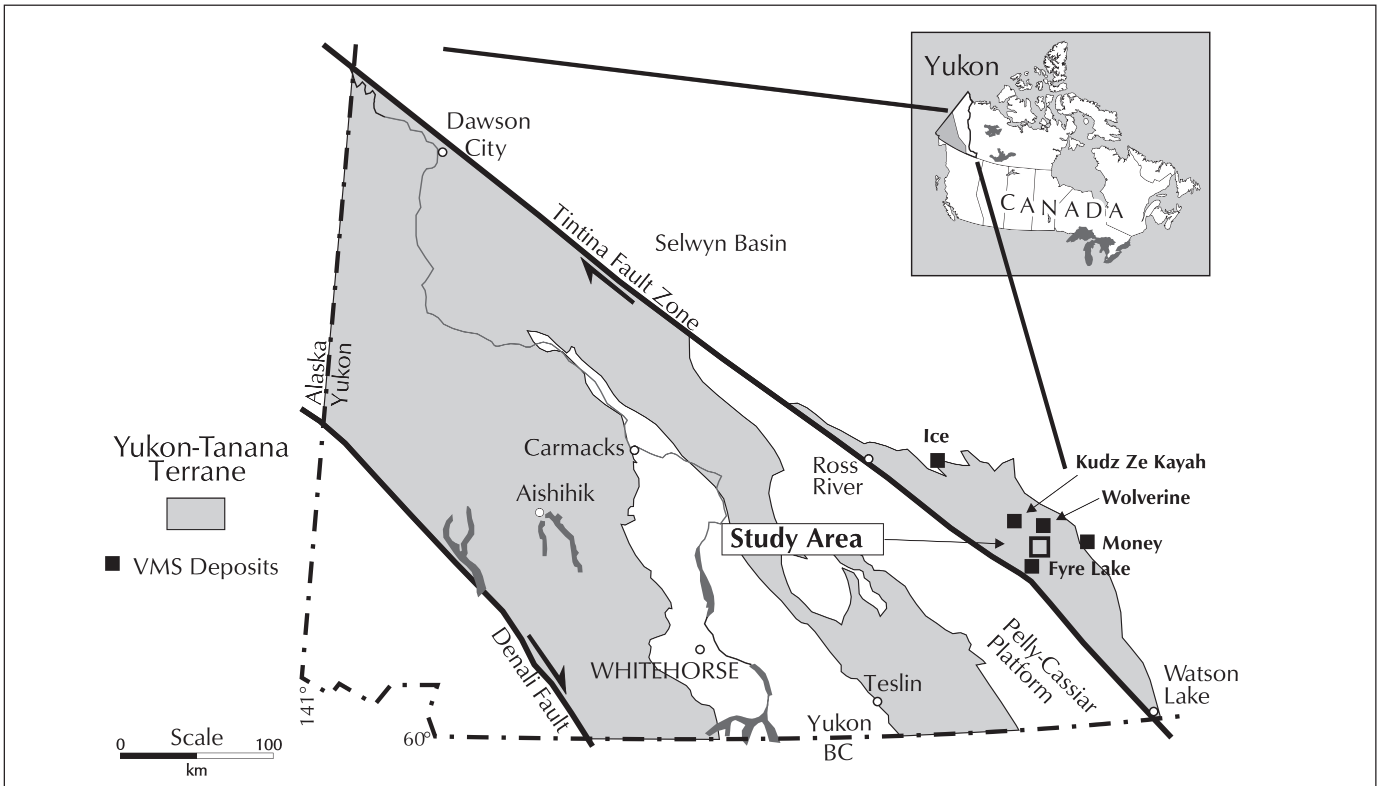


Figure 1. Geological setting and distribution of the Yukon-Tanana Terrane in the Yukon and the location of the study area with respect to the Finlayson Lake region. Map modified from Hunt (1998) and Wheeler and McFeely (1991).

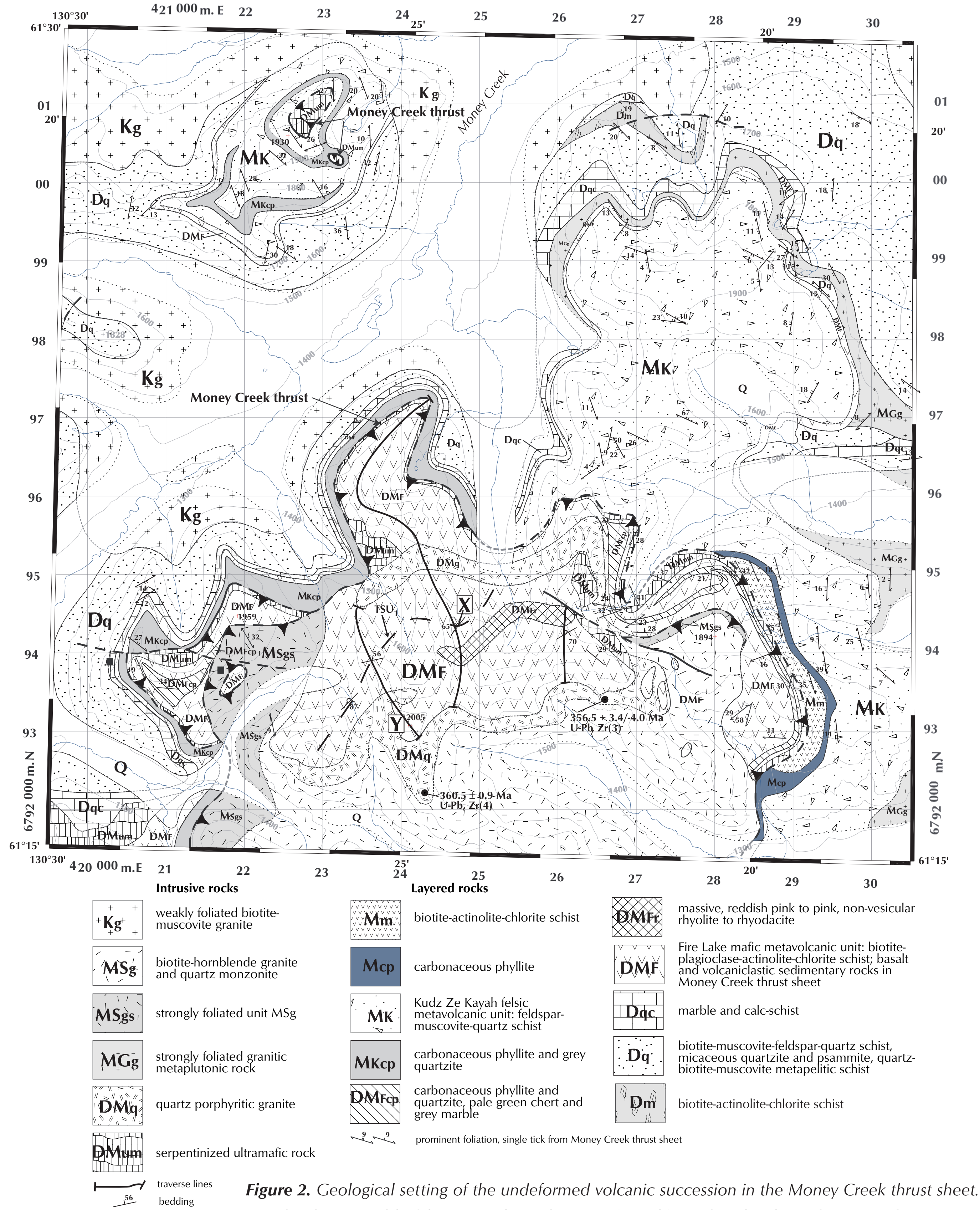


Figure 2. *Geological setting of the undeformed volcanic succession in the Money Creek thrust sheet. Map has been modified from Murphy and Piercey (1999b). Further details on the regional setting can be obtained from Murphy and Piercey (1999a, b, c). X and Y are locations discussed in the text.*

providing a window into the early Mississippian tectonic setting that has not been complicated by strain and metamorphism. Our goals for this paper are as follows:

1) to describe the stratigraphy of the undeformed volcanic sequence;
2) to describe the spatially associated intrusive rocks and clarify the definition of the Simpson Range Plutonic Suite (SRPS);
3) to provide insights into the nature and setting of volcanism recorded in the undeformed volcanic sequence; and
4) to compare and contrast the style of volcanism with that of the younger, and also relatively well-preserved rocks of the Campbell Range belt with which they have been correlated and lumped together into Slide Mountain Terrane.

PREVIOUS WORK

Tempelman-Kluit (1977, 1979) briefly described the volcanic rocks as an undeformed Cretaceous volcanic 'plug' comprising subequal amounts of porphyritic, pyritic quartz-rhyolite and hornblende andesite that were inferred to 'invade' the Money Klippe. Erdmer (1981) also interpreted the volcanic assemblage to be a Cretaceous 'plug' that 'invaded' the Money Klippe. He stated that the margins of the plug overlie the cataclastic rocks, but the contact was not readily visible and did not exhibit significant thermal alteration. He also said that the present outcropping of the plug likely represented the erosion level of a subaerial volcanic edifice. Mortensen (1983) questioned the Cretaceous age for the volcanic 'plug' based on a ca. 345-380 Ma U-Pb age from near-concordant zircon fractions from a quartz-porphyry body that intruded the mafic rocks of the plug. Although imprecise, these ages disproved a Cretaceous age and Mortensen (*op cit*) included the plug in the Anvil Assemblage. Similarly, the latter age designations led Erdmer (1985) to include the volcanic plug in the Anvil Allochthon. Mortensen and Jilson (1985) and Mortensen (1992b) suggested that the plug intruded the Anvil Assemblage and was transported with it during subsequent, post-Mississippian thrusting. Mortensen (1992b) refined the age of the quartz-porphyry body within the plug, producing a discordant crystallization age of 360.5 ± 1.9 Ma.

Grant (1997) undertook a geochemical, isotopic and U-Pb geochronological study of SRPS and YTT metasedimentary rocks, and his study partly encompassed the undeformed volcanic sequence. He mapped a small portion of the sequence and documented the occurrence of rhyolites, flow-banded rhyolites, quartz-potassium feldspar rhyolitic porphyry, and black to green plagioclase- and augite-bearing mafic rocks. He suggested that the composite plug was part of the SRPS and was the structural top of the Money Klippe. U-Pb dating of the quartz-feldspar porphyry (356.5 +3.4/-4.0 Ma) affirmed Mortensen's (1992b) age; geochemical and isotopic data suggested that both the felsic and mafic members of the plugs reflected magmatism within a continental arc with variable crustal thickness.

Hunt and Murphy (1998) mapped a portion of the composite plug as part of a study of the geology near the Fyre Lake Cu-Co-Au volcanogenic massive sulphide (VMS) deposit (Yukon Minfile, 1997, 105G 034). Their work documented mafic volcanic breccias and augite-porphyritic volcanic rocks lying as roof pendants within quartz-porphyry. Furthermore, they suggested that the mafic rocks were not part of the SRPS, but were part of Yukon-Tanana Terrane, correlating with the mafic metavolcanic unit that hosts the Fyre Lake deposit. Additional regional mapping in the vicinity of the porphyry and outside this region is also presented in Murphy and Piercey (this volume).

STRATIGRAPHY OF THE VOLCANIC SUCCESSION

The unstrained volcanic succession consists of subaqueous and subaerial mafic and felsic volcanic rocks and associated marine sedimentary rocks. Most rocks are pristinely preserved within the sequence. However, near the margins of the sequence along the Money Creek thrust (cf. Murphy and Piercey, this volume), or near younger SRPS intrusive rocks, the volcanic rocks have been altered and deformed (see Intrusive Rocks; Fig. 2).

UNIT MVU_1

In the lower unit (MVU_1), mafic volcanic rocks are subaqueous in nature and range from pillowed to massive flows with abundant volcaniclastic rocks. Pillowed flows typically contain green to black pillows that are well preserved with very little flattening, and range in size from 10-15 cm up to 1.5 m in diameter (Fig. 4a). Typically all pillows have ~1-2 cm glassy rinds that grade into inter-pillow hyaloclastite breccia that contains 1-2 cm angular fragments of commonly glassy pillowed material, and are associated with red (hematitic) to purple inter-pillow chert. Pillow lavas are variably vesicular and range from non-vesicular up to 10% vesiculation. Minor vesiculation is common in all pillow lavas. Vesicles are often infilled with quartz and/or carbonate material.

The relationship between massive and pillowed flows within MVU_1 is uncertain; however, it is assumed, based on the stratigraphic continuity of the unit, that the relationships are conformable. Massive flows (?) have similar colouration as the pillowed flows, but their extent is uncertain.

Mafic volcanic rocks of unit MVU_1 are somewhat distinctive from the other mafic units; they contain abundant spherulites up to 13 mm in diameter. The spherulites occur as rounded blebs with radial devitrification structures. One to 3 mm-sized euhedral augite (?) or hornblende phenocrysts are common within the volcanic rocks of unit MVU_1.

Volcaniclastic rocks of unit MVU_1 consist primarily of pillowed breccias and re-sedimented (?) pillowed fragments (Fig. 4b). Most volcaniclastic breccias contain 0.5- to 3.5-cm-sized angular fragments of variably vesicular (+amygdaloidal) pillow material that are locally bleached to a white colouration (Fig. 4b). The angular nature of the clasts suggests deposition proximal to the parent mafic flows, possibly due to auto-brecciation of the parent flows. Volcaniclastic fragments of similar size but with more rounded character may have been re-sedimented by bottom currents; however, this interpretation needs to be tested by more detailed mapping. No tuffaceous rocks or other rocks indicative of explosive volcanism were documented or observed by the authors.

UNIT $FMVU_1$

Both felsic and mafic rocks occur in unit $FMVU_1$ and are in part sub-aerial. The top of unit MVU_1 exhibits a ~25 m transition zone of interlayered (?) reddish, highly vesiculated mafic lavas ($FMVU_1$), and green, weakly to non-vesiculated mafic lava. Mafic volcanic rocks from unit $FMVU_1$ are typically reddish to maroon in colour and locally have a white bleached appearance. Typically, the mafic rocks in this unit exhibit a

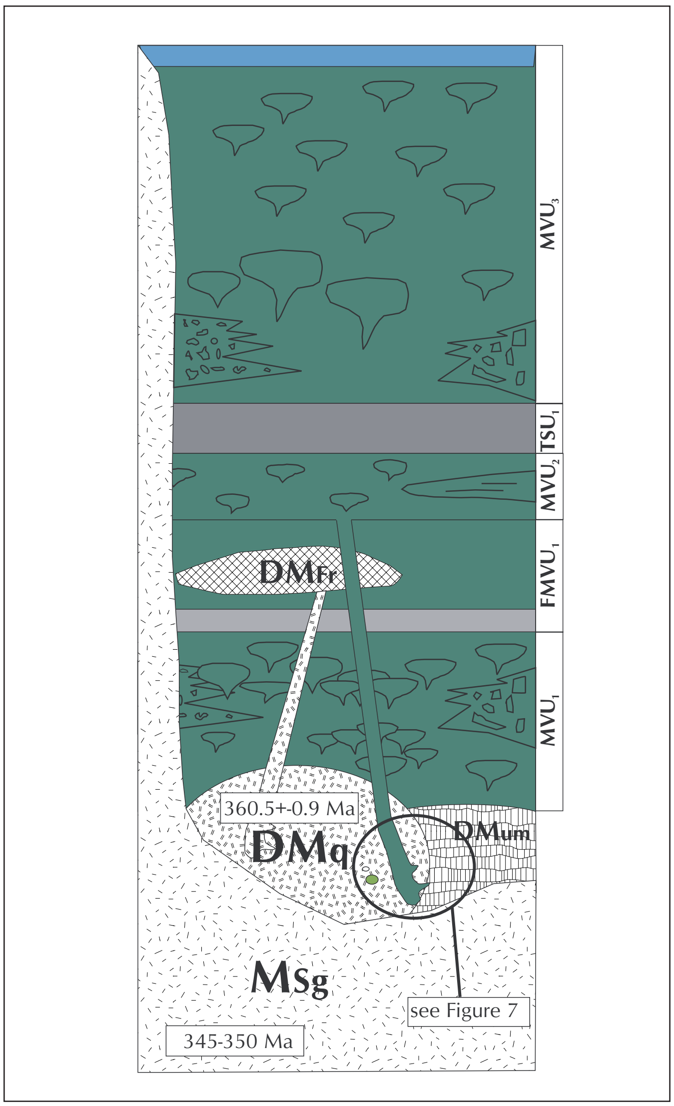
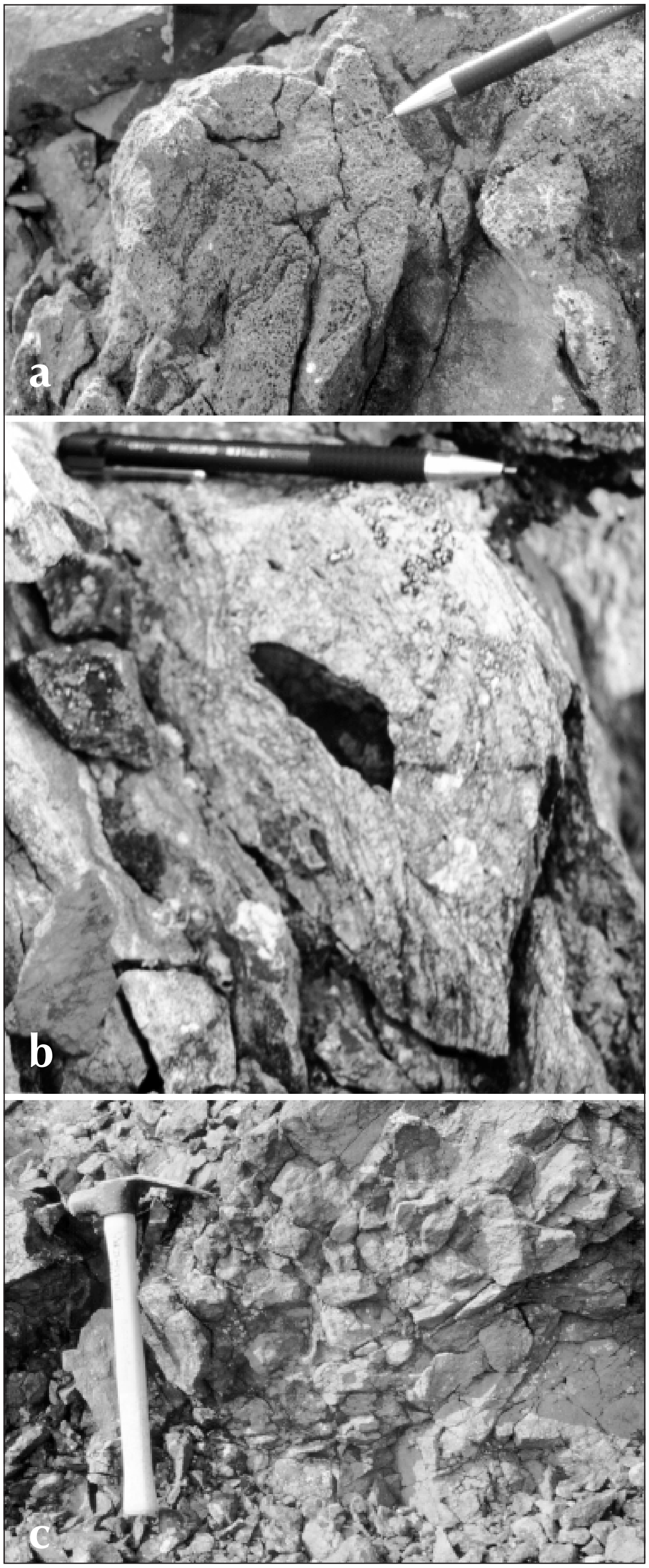


Figure 3. *Schematic composite stratigraphic section of the undeformed unit DMF in the hanging wall of the Money Creek thrust and its relationship to intrusive rocks in the region. Section was compiled from observations along traverses indicated in Figure 2. Ages are from Mortensen (1992a, b) and Grant (1997).*

Figure 4. *(a) Typical large-sized pillowed mafic lava flows from unit MVU_1. These pillowed flows are not dissimilar to those found in units MVU_2 and MVU_3. (b) Typical pillowed breccias and volcaniclastic rocks of MVU_1. Directly above the pen is a dark fragment of pillowed material that is similar to the dark finer grained mafic matrix; to the left of the pen are bleached augite-bearing pillowed fragments.*



greater degree of vesiculation than in unit MVU_1 ranging from 5-30%, with mostly ~10-15% (Fig. 5a). Vesicles are commonly relatively small, leading to the surfaces of the basalt flows having a very pumiceous nature. In other places the vesicles are up to 5 mm in diameter; most larger vesicles are 2-3 mm in size (Figs. 5a and b). In many outcrops, the vesicles exhibit a trachytic alignment that gives a crude indication of flow banding; however, this feature is not ubiquitous. Commonly, the larger vesicles are infilled by carbonate and/or quartz.

Fragmentation and brecciation of the mafic lavas is not as common as in unit MVU_1; however, this may be a function of the limited exposure of unit $FMVU_1$. Breccias that have been observed have fragments that are angular and typically range in size from 1-5 cm. Locally, these breccias have a matrix of rusty carbonate that may represent a post-depositional (post-volcanic) infilling and breakup by later carbonate-rich fluids, possibly from the SRPS.

Felsic volcanic rocks (DMFr on Figure 2) are interlayered with the mafic volcanic flows, but are less abundant than the mafic volcanic rocks (Fig. 5c). The felsic volcanic rocks are typically massive, reddish pink to pink, non-vesicular rhyolite to rhyodacite (Fig. 5c). They are of limited areal extent (Fig. 3) and are commonly associated with rhyolitic hyaloclastite breccias with large 20-30 cm blocky fragments (Fig. 5d).

UNIT MVU_2

The contact between unit $FMVU_1$ and the mafic volcanic rocks of unit MVU_2 is gradational and characterized by an increase in green mafic volcanic rocks, somewhat similar to those of unit MVU_1. Mafic volcanic rocks from unit MVU_2 are typically pillowed to massive, dark black to greenish with 0-5% vesiculation. Inter-pillow hyaloclastite breccias are common, as are minor cherts; however, on the whole, volcaniclastic rocks are minor in comparison to unit MVU_1.

UNIT TSU_1

Although relatively thin (~5-50 m, Fig. 2), turbiditic clastic rocks of unit TSU_1 form a distinctive marker horizon within the undeformed volcanic sequence. The thickest section of unit TSU_1 consists of minor interlayered coarse, green greywacke, coarse white greywacke, and finely laminated finer grained

Figure 5. *In (a) are highly vesiculated (pumiceous) subaerial basaltic lavas from unit $FMVU_1$. Some of the vesicles in the basaltic rocks become quite large; in (b) this single vesicle is nearly 2 cm in diameter. Subaerial to subaqueous felsic flows in unit $FMVU_1$ commonly exhibit a rubbly in situ brecciation along their margins as show in (c).*

clastic rocks. Laterally away from this location where the unit is thinner, finely laminated clastic rocks predominate (Figs. 3 and 6). Green greywacke is volumetrically minor and consists of green medium-grained sand with fragments of ~0.5 to 1-cm-sized volcanogenic (?) material and mafic minerals. Green greywacke was observed in only one location forming 2- to 5-m-thick beds, capped by very fine- to fine-grained, dark green to grey, finely laminated cherty siltstone (Fig. 6a). These generally occur in 0.5- to 1-m-thick beds with abundant mm-scale internal laminae interlayered with beds of white greywacke (Figs. 6a and b). Laterally away from the interlayered coarse clastic rocks, finely laminated turbiditic rocks predominate, and in one location they are very fine-grained to glassy. These glassy units may be turbiditically re-sedimented volcanogenic ash.

In the thickest portion of this section, the white greywacke unit is composed of coarse white sand with reddish pink and green fragments (Fig. 6b). The sands typically form 0.5- to 2-m-thick beds which are commonly interlayered with ~30-cm-thick fine cherty layers as described above. The reddish pink clasts are typically rounded and 2-3 mm in diameter with some resemblance to the underlying rhyolitic rocks of unit $FMVU_1$. Similarly, smaller green fragments have features akin to the underlying mafic volcanic rocks; however, some larger fragments appear to be akin to the finely laminated chert layers. The white sand layers of this unit provide the best evidence for the upright-facing direction of the sequence. The lower parts of white sandy beds consist of abundant clasts of the underlying rocks, as described above. Well defined 2- to 3-cm-lode and flute casts ornament the bases of beds (Fig. 6b), providing unambiguous stratigraphic-top indicators. The sandy material within the TSU_1 unit decreases laterally from point X to nil to the northeast and southwest (Fig. 2) and is replaced by very siliceous, in places glassy, fine-grained laminated turbiditic sedimentary rocks.

UNIT MVU_3

The contact between unit TSU_1 and MVU_3 is abrupt, and marked by an abundance of mafic and lesser felsic volcanic rocks. Immediately above the TSU_1 – MVU_3 contact is a variably vesiculated and plagioclase-phyric, green, pillowed basalt sequence that is interlayered with ~5-m-thick flows (?) of plagioclase-phyric, red to white rhyolite and rhyodacite. Felsic volcanic rocks are only observed in this location. The remainder of the unit consists predominantly of pillowed and massive flows, akin to the underlying mafic units. Pillowed lavas are variably vesicular and have vesicles infilled with carbonate and/or quartz. Pillows range from 30-60 cm in diameter and commonly have reddish to purple inter-pillow chert. Pillows and massive flows range in colour from black to purple and in places greenish. The areal extent of the massive flows is uncertain. Plagioclase phenocrysts are present in some samples; rarely hornblende (pyroxene?) phenocrysts are present. Sedimentary and volcaniclastic rocks are rare in unit MVU_3. Locally, near the top of this unit, are discontinuous marble horizons of detrital origin.

INTRUSIVE ROCKS

Intrusive rocks are spatially associated with the undeformed volcanic sequence; however, not all of them are temporally or genetically related to the sequence. Intrusive rocks in this region include: 1) mafic/ultramafic intrusive phases; 2) quartz-porphyritic intrusions; and 3) intrusions of the Simpson Range Plutonic Suite (SRPS). Our data show that the first two types are coeval and comagmatic with the undeformed volcanic sequence and the SRPS post-dates the volcanic rocks.

Gabbroic and ultramafic rocks are common within the undeformed sequence, particularly along the Money Creek thrust (see Murphy and Piercey, 1999b, c). Near the thrust, the gabbroic rocks are variably strained; however, original gabbroic textures are recognizable. Spatially associated with the gabbroic rocks are serpentinized harzburgitic ultramafic rocks that appear

Figure 6. *Typical finely laminated, locally glassy, siliceous sedimentary rocks common in unit TSU_1 (a). These laminated sedimentary rocks are interlayered with white sandy layers at location X in Figure 2. Directly atop of the pencil in (b) is a typical flute cast within a white greywacke common along their basal surfaces in unit TSU_1.*

to underlie the gabbros and may represent either residues from gabbroic melt extraction or cumulations of ultramafic minerals below a gabbroic magma chamber. The authors infer that the mafic and ultramafic intrusions are comagmatic with the basalts based on their spatial association, similar U-Pb age constraints and similarity in the petrology of the volcanic and gabbroic rocks (Grant, 1996). The gabbroic and ultramafic rocks may thus be the intrusive roots of the basalts in the undeformed volcanic sequence.

Quartz-porphyritic intrusive rocks (Dmq) look superficially similar to the SRPS rocks, but typically lack hornblende and biotite and are older than the SRPS (~357-361 Ma; Mortensen,

Figure 7. *Mafic dykes intruding and mingling with a ~361 Ma (Mortensen, 1992b) quartz-porphyritic granite intrusion. In (a) the dyke margins are characterized by flame-like terminations into the granite host. Commonly, the dykes have ball structures of mafic material disassociated from the dyke margins within the granite host. Tentacle-like intrusive contacts and very diffuse margins of the mafic dykes with the granite host are also common (b). These features suggest that the granite host was still warm and not solidified during the intrusion of the dykes implying that they are nearly coeval.*

1992a, b; Grant, 1997; Grant et al., 1996). Unit DMq is generally medium-grained, less commonly fine-grained, and are typically pink to pink-white to white-grey. It typically contains 2-3 mm quartz phenocrysts dispersed in a pink to white, fine- to medium-grained groundmass.

At location Y in Figure 2, the quartz-porphyritic rocks are intruded by, yet mingle with, mafic dykes that are interpreted to represent feeders to the overlying basaltic units (Fig. 7). The mafic dykes that intrude the QP are medium- to fine-grained with abundant 2-3 mm euhedral augite and plagioclase phenocrysts, and are widely spaced with south-southeast trends. Dyke margins are variably straight, but do not exhibit well defined chill margins typical of warm dykes intruding cold wall rocks (Fig. 7). In places along the dykes they exhibit tentacle-like terminations into quartz-porphyritic granite (Fig. 7b), whereas in other places the dyke walls are bulbous and grade into a flame-like termination into the quartz porphyry (Fig. 7a). Common are ball structures of mafic material disassociated from the dyke margins and floating within the granite (Fig. 7a). These magma-mingling relationships with the quartz-porphyritic rocks suggest that they are coeval and that the quartz-porphyritic intrusions are the sub-volcanic feeders to rhyolite and rhyodacite interstratified with basalt in parts of the volcanic sequence. The ~357-361 Ma ages on the quartz porphyry would therefore constrain the age of part of the volcanic succession.

The SRPS consists of numerous granitoid types including hornblende-granodiorite, biotite-monzogranite, and K-feldspar granite (cf. Mortensen, 1983; Mortensen, 1992a, b; Grant, 1997). The relationships between the different granitoid phases were not discerned during our field study. The SRPS clearly intrudes the mafic rocks of the undeformed sequence, as evidenced by distinctive patchy purple-yellow epidote-rich alteration of the mafic rocks along the contact, dykes of hornblende-bearing granitoids cutting the sequence, and pendants and xenoliths of mafic volcanic rock within the granitoids. U-Pb geochronological constraints suggest that the Simpson Range Plutonic Suite intruded between 345 and 350 Ma (Mortensen, 1992b; personal communication, 1997; Grant, 1997), well after the extrusion of the volcanic sequence at ~357-361 Ma.

DISCUSSION

The new data and conclusions from our study of the undeformed volcanic rocks of the Money Creek thrust sheet have broader implications. This discussion will be divided into three parts, dealing with: 1) definition of the Simpson Range Plutonic Suite; 2) emergent volcanism in the undeformed sequence; and 3) criteria to distinguish the succession in the Money Creek thrust sheet from the Campbell Range belt with which it has been correlated.

DEFINITION OF THE SIMPSON RANGE PLUTONIC SUITE

As defined by Mortensen (1983), the SRPS consists of hornblende-biotite granodiorite and quartz diorite; that is, granitoids of metaluminous affinity that differ from suites of peraluminous affinity in YTT such as the Mink Creek or Houle River orthogneiss bodies. Erdmer (1985), Grant et al. (1996) and Grant (1997) subsequently included the mafic and felsic rocks of the volcanic 'plug' and related gabbroic intrusions in the SRPS. The geological relationships described in this report, as well as published and unpublished U-Pb geochronological data, show that the volcanic succession is older than and crosscut by intrusions of the SRPS; hence, they should not be included in the SRPS.

EMERGENT VOLCANISM IN THE UNDEFORMED SEQUENCE

Given the state of strain that most greenstones within the YTT exhibit, it is typically impossible to determine the ambient volcanic environment in most areas of the YTT. The lack of strain in volcanic rocks in this part of the Money Creek thrust sheet gives us the opportunity to determine the local environment of deposition. The change from predominantly subaqueous pillowed flows and related volcaniclastic rocks in unit MVU_1 to mixed subaerial and subaqueous volcanism in unit $FMVU_1$ is inferred to represent the emergent growth of a volcanic edifice from subaqueous to subaerial conditions. Unit MVU_1 basalts are unequivocally subaqueous, exhibiting features such as pillowed flows, pillowed breccias, and inter-pillow chert and hyaloclastite breccias. Near the top of MVU_1, however, the dominantly subaqueous basalts change to reddish lava flows alternating with black to green subaqueous flows, implying a transition to more oxidizing conditions indicative of a subaerial environment. Furthermore, in the overlying $FMVU_1$ the presence of trachytic textures, abundant vesiculation, scoriaceous textures, and predominant reddish colouration are features typical of volcanism in a subaerial environment. We suggest that, based on this transition from subaqueous to subaerial conditions, there was growth of a volcanic edifice from below to above the ambient sea level, akin to many volcanic archipelagos present in the modern oceans.

It appears from the volcanic stratigraphy that the phase of emergent volcanism in $FMVU_1$ was replaced by subaqueous turbiditic sedimentation, and mixed mafic and felsic magmatism (TSU_1, MVU_2, MVU_3). It is possible that this return to subaqueous activity may represent either an inundation of the volcanic edifice by rising sea levels, or more likely, rifting or intra-volcano subsidence (caldera?) with subsequent subaqueous activity. Given the presence of turbiditic sedimentation in association with subaqueous lavas, the latter situation is most probable.

COMPARISON WITH CAMPBELL RANGE BELT

The correlation between the mafic and ultramafic rocks of the Money Creek thrust sheet and similar rocks in the Campbell Range belt (CRB) is rendered obsolete by the geological relationships presented in this study, and published and unpublished U-Pb geochronological data. The volcanic and sub-volcanic rocks of the Money Creek thrust sheet are Devono-Mississippian and those of the CRB are Pennsylvanian to Permian (Harms, in Plint and Gordon, 1997). In this section (Table 1), we compare and contrast the volcanic rocks of the

Table 1. *Sumary of salient stratigraphic, geochemical and temporal differences and similarities of the volcanic rocks of the Money Creek thrust sheet and the Campbell Range belt.*

	Money Creek thrust sheet	**Campbell Range belt**
Mafic volcanism[1]	Pillowed to massive flows and volcaniclastic rocks; subaqueous and subaerial	Pillow to massive flows and volcaniclastic rocks; all subaqueous
Felsic volcanism[1]	Rhyolite-rhyodacite; subaqueous and subaerial	Felsic volcanism absent
Sedimentary rocks[1]	Turbiditic sedimentary rocks; minor detrital carbonate rocks; minor volcanic greywackes; rare chert	Dark argillite and sandstone; diamictite; volcanic greywacke; abundant chert and chert-pebble conglomerate; carbonate (possibly as olistostromes)
Age[2]	Devonian-Mississippian	Pennsylvanian-Permian
Geochemistry[3]	Arc - calc-alkaline	Non-Arc - N-MORB, E-MORB, OIB
Tectonic setting[4]	Continental arc	Marginal basin with terrigenous input

[1]CRB data from Murphy and Piercey (1999a, b, c) and Plint and Gordon (1997).

[2]Age data from Mortensen (1983, 1992b), Grant et al. (1996) and Grant (1997).

[3]Geochemical attributes for undeformed sequence from Grant (1997), CRB from Plint and Gordon (1997) and Piercey et al. (1999a,b); N-MORB = normal mid-ocean ridge basalt (MORB), E-MORB = enriched MORB, and OIB = ocean island basalt.

[4]Interpretations based on inferences from this paper and Grant (1997), Grant et al. (1996) and Plint and Gordon (1997).

Money Creek thrust sheet and the Campbell Range belt to provide criteria with which to distinguish them.

Mafic volcanic rocks are common to both sequences; the sequences differ primarily in the nature of the other rock types. For example, subaqueous pillow lavas and massive flows are common to both sequences, as are pillowed breccias and vent-proximal volcaniclastic material (e.g., Murphy and Piercey, 1999a; Plint and Gordon, 1997). However, rhyolitic and rhyodacitic rocks are a common feature of the rocks of the Money Creek thrust sheet and are notably absent in the CRB rocks. Turbiditic sedimentary rocks such as TSU_1 are present, although not necessarily abundant, in the Money Creek thrust sheet. In contrast, sedimentary rocks including chert, chert-pebble conglomerate, cherty argillite, siltstones, sandstones and olistostromal carbonate blocks are the common sedimentary rocks of the CRB (Plint and Gordon, 1997; Murphy and Piercey, 1999a, b, c; this volume). Although the sedimentary rocks of the CRB may have had similar origins as TSU_1 (i.e., mass flows), they do not exhibit the turbiditic layering and characteristics common of those in the Money Creek thrust sheet (*op cit*). There is also a significantly greater abundance of chert and chert-rich material in the CRB than in the Money Creek thrust sheet, suggestive of a quiescent environment with significant gaps in volcanism that allowed the accumulation of chemical sediments. The sequence in the Money Creek thrust sheet also contains abundant evidence for subaerial volcanism that has yet to be described or observed in the CRB (*op cit*).

In addition to the field-based differences, the sequences differ geochemically. Grant (1997) showed that the mafic and felsic rocks from the Money Creek thrust sheet have geochemical and isotopic signatures typical of calc-alkalic continental arc magmatism. In contrast, the CRB is characterized by non-arc signatures consisting of various basalt types ranging from rift through normal mid-ocean ridge basalt (N-MORB) composition (Plint and Gordon, 1997; Piercey et al., 1999a, b).

To summarize, the undeformed Money Creek package can be distinguished from the Campbell Range belt (and possibly similar rocks of the Slide Mountain Terrane?) lithologically, geochemically (arc versus non-arc) and geochronologically (mid-versus late Paleozoic). By using this combined approach greenstones from other portions of the YTT and Slide Mountain Terrane may be effectively discriminated and separated.

CONCLUSIONS

- Undeformed volcanic rocks of the Money Creek thrust sheet provide a window into the mid-Paleozoic volcanic history of this portion of the YTT. This undeformed sequence consists of a five-component volcano-sedimentary stratigraphy with associated sub-volcanic intrusions that record volcanism in a shallow water subaqueous to subaerial setting (archipelago-like environment);
- Magma-mingling relationships between augite-plagioclase-porphyritic mafic dykes, interpreted as feeders to the basalts in the volcanic sequence, and ~357-361 Ma quartz-porphyritic granitoids, inferred to feed the felsic volcanic rocks, imply coeval Devono-Mississippian mafic and felsic volcanism. This relationship provides a key temporal pin on primitive through mature arc activity (e.g., Grant, 1997; Piercey et al., 1999a, b) in Yukon-Tanana Terrane.
- Many workers have suggested that the mafic and felsic volcanic rocks, as well as quartz-porphyritic granitoids and gabbroic-ultramafic intrusions were part of the SRPS (e.g., Erdmer, 1981, 1985; Grant et al., 1996; Grant, 1997). We exclude these units from the SRPS based on our field observations and U-Pb geochronological data and restrict the SRPS to metaluminous granitoids of ~345-350 Ma age.
- Field, geochemical and geochronological criteria can be used to distinguish the Devono-Mississippian mafic volcanic rocks from Pennsylvanian-Permian rocks of the Campbell Range belt.

Greenstones within the Yukon-Tanana Terrane are diverse in geological character and paleotectonic environments of formation. It is only with keen field observations and geological mapping augmented with relevant laboratory data (i.e., geochemistry, geochronology) that we can obtain a clearer picture of the nature and origin of mafic to felsic volcanism within the YTT and other terranes of the northern Cordillera.

ACKNOWLEDGEMENTS

We wish to acknowledge the various people who have made contributions to this paper. Discussions and interaction with the following individuals is gratefully acknowledged: Maurice Colpron (Yukon Geology Program), Suzanne Paradis (GSC), Peter Holbek (Atna Resources), Harlan Meade and Bill Wengzynowski (Expatriate Resources), Jim Mortensen and Tom Danielson (University of British Columbia, UBC), and Paul MacRobbie (Cominco). Annie Daigle (University of New Brunswick) is thanked for her field assistance. This constitutes part of the senior author's Ph.D. research undertaken at the Mineral Deposit Research Unit at UBC under the supervision of Jim Mortensen. Funding for this project has been provided by the MDRU Finlayson Lake Metallogeny Project supported by Atna Resources and Expatriate Resources; the Yukon Geology Program (D. Murphy); Geological Survey of Canada and Ancient Pacific Margin NATMAP Project (Paradis); a Natural Sciences and Engineering Research Council (NSERC) of Canada operating grant (Mortensen); and an NSERC postgraduate scholarship and the Hickok-Radford Fund of the Society of Economic Geologists (Piercey). Jim Mortensen is thanked for an earlier review of this manuscript. Review of this manuscript by Diane Emond is gratefully appreciated. This is MDRU contribution P120.

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Ancient Pacific Margin: A preliminary comparison of potential VMS-hosting successions of the Yukon-Tanana Terrane, from Finlayson Lake district to northern British Columbia[1]

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This paper is also published as:

Nelson, J.L., Mihalynuk, M.G., Murphy, D.C., Colpron, M., Roots, C.F., Mortensen, J.K. and Friedman, R.M., 2000. Ancient Pacific Margin Part II: A preliminary comparison of potential VMS-hosting successions of the Yukon-Tanana Terrane, from Finlayson Lake district to northern British Columbia. *In:* Geological Fieldwork 1999, B.C. Ministry of Energy and Mines, paper 2000-1, p. 21-28.

ABSTRACT

In the inaugural year of the joint Geological Survey of Canada – British Columbia Geological Survey Branch – Yukon Geology Program Ancient Pacific Margin NATMAP project, substantial progress was made in documenting the nature of Yukon-Tanana Terrane in Yukon and northern British Columbia and how the different parts may have been linked paleogeographically. When ca. 425 km of displacement on the Tintina Fault are restored, the Finlayson Lake massive sulphide district lies north of and along strike from the Glenlyon and Wolf Lake – Jennings River study areas. Stratigraphic sections from the component study areas illustrate similarities and differences along strike; both the similarities and differences with the Finlayson Lake stratigraphy affirm the potential of this belt to host volcanogenic massive sulphide mineralization.

RÉSUMÉ

La première année du programme CARTNAT de la marge pacifique ancienne (un programme conjoint des Commissions géologiques du Canada et de la Colombie Britannique, et du Service géologique du Yukon) a mené à de grands progrès dans la documentation de la nature et des liens paléogéographiques possibles entre divers éléments du terrane de Yukon-Tanana, situé au Yukon et dans le nord de la Colombie Britannique. Lorsque l'on enlève quelque 425 km de rejet horizontal le long de la faille de Tintina, la ceinture de sulfures massifs de Finlayson Lake se retrouve au nord des régions à l'étude de Glenlyon et de Wolf Lake – Jennings River. Les colonnes stratigraphiques pour les diverses régions à l'étude illustrent les similarités et les différences entre les différentes portions du terrane. Une comparaison des ressemblances ainsi que des différences entre la stratigraphie de la région de Finlayson Lake et celle des régions à l'étude démontre le potentiel pour des minéralisations de sulfures massifs volcanogènes le long de cette ceinture.

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INTRODUCTION

The Yukon-Tanana Terrane of Yukon, Alaska and northern British Columbia consists of poorly understood, lithologically diverse successions of metasedimentary and metavolcanic rocks, and voluminous Mid- and Late Paleozoic granitic metaplutonic bodies (Mortensen and Jilson, 1985; Mortensen, 1992). Significant volcanogenic massive sulphide deposits occur in the terrane in the Delta and Bonnifield districts in Alaska and in the Finlayson Lake district in southeastern Yukon, and the potential for further discoveries is considered to be high. However, exploration for new deposits has been hindered by the paucity of stratigraphic information from the terrane as a whole.

One of the goals of the Ancient Pacific Margin NATMAP (National Mapping Program) project is to address the deficiencies in stratigraphic information from the Yukon-Tanana Terrane. The central component of the Ancient Pacific Margin Project, which spans both Yukon and British Columbia, includes bedrock geological mapping of the Finlayson Lake district (Murphy and Piercey, 1999b and c; this volume; location 1 on Fig. 1), the Glenlyon area in central Yukon (Colpron, 1998, 1999c; Colpron and Reinecke, this volume; locations 2 and 3 on Fig. 1), the Big Salmon Complex in northern Jennings River map area (Mihalynuk et al., 2000; location 4 on Fig. 1), the Wolf Lake/Jennings River map area straddling the Yukon/B.C. border (Roots et al., 2000a and b; locations 5a and 5b on Fig. 1), and the southeastern Dorsey Terrane in south-central Jennings River map area (Nelson, 2000; location 6 on Fig. 1). The Finlayson Lake district is currently separated from the other areas by the Tintina Fault. Restoration of about 425 kilometres of displacement on the fault (Roddick, 1967; Murphy, Mortensen and Abbott, in prep.) aligns all of these areas in a continuous belt from the Finlayson Lake area to the southern Jennings River (Fig. 1). The Yukon-Tanana Terrane along this belt represents a target for volcanogenic massive sulphide deposits that extends over 500 kilometres of strike length.

Sufficient geological mapping and uranium-lead dating have now been done to construct preliminary stratigraphic sections for areas scattered along the extent of the southeastern Yukon-Tanana Terrane (Fig. 2). In the Finlayson project, Murphy and collaborators have covered the area of the Fyre Lake, Kudz Ze Kayah and Wolverine volcanogenic massive sulphide deposits. Their work provides a preliminary stratigraphic template that is useful for workers throughout the terrane where the potential for volcanogenic massive sulphide deposits is less known. This template is used in this paper as a point of comparison for the stratigraphic columns farther south along the restored pericratonic belt. Figure 2 shows fundamental similarities between these areas and the Finlayson Lake district, as well as highlighting significant differences in the ages of volcanism along the belt.

FINLAYSON LAKE DISTRICT

(Fig. 2, column 1) Stratified rocks in the Finlayson Lake massive sulphide district have been subdivided into three first-order successions, each hosting volcanogenic massive sulphide deposits and prospects (Murphy and Piercey, 1999; Fig. 2). The lower succession comprises pre-Late Devonian quartz-rich metaclastic rocks, marble and pelitic schist; Late Devonian to early Misisissippian mafic metavolcanic rocks with lesser amounts of carbonaceous metaclastic rocks, felsic metavolcanic and volcaniclastic rocks, and marble; early Mississippian felsic metavolcanic and volcaniclastic rocks, and carbonaceous phyllite; and early Mississippian carbonaceous phyllite, quartzite, quartz-feldspar pebble meta-conglomerate and mafic metavolcanic rocks. These units were intruded by early Mississippian peraluminous granitic metaplutonic rocks, then deformed, and re-intruded by slightly younger, late-kinematic, early Mississippian granitic metaplutonic rocks, before the unconformable deposition of the overlying middle stratigraphic succession. The lower succession hosts both the Fyre Lake Cu-Co-Au deposit and the Kudz Ze Kayah Cu-Pb-Zn-Au-Ag deposit, the former in the Late Devonian to early Mississippian mafic metavolcanic unit and the latter in overlying early Mississippian felsic metavolcanic rocks.

The middle succession, also of probable early Mississippian age, comprises carbonaceous metaclastic rocks, felsic schist and quartz-feldspar metaporphyry of volcanic, volcaniclastic and subvolcanic intrusive protolith. A distinctive, laterally persistent felsic tuff and exhalite unit caps the middle succession. The Wolverine Cu-Pb-Zn-Au-Ag deposit occurs near the top of the unit, just below the tuff/exhalite unit.

The upper succession corresponds to the Campbell Range belt of Mortensen and Jilson (1985). It consists of two intervals of basaltic volcanic and volcaniclastic rocks separated by a lithologically diverse and laterally variable unit of carbonaceous phyllite, greywacke, diamictite, variegated chert, chert-pebble conglomerate and limestone. Mid-Pennsylvanian to Early Permian radiolaria have been obtained from chert in the upper basalt (Harms, in Plint and Gordon, 1997) and Pennsylvanian conodonts were obtained from limestone (M.J. Orchard, in Tempelman-Kluit, 1979). The Money occurrence is hosted by the upper Campbell Range basalt and the Ice Cu-Au volcanogenic massive sulphide deposit occurs in lithologically similar rocks about 70 kilometres northwest along strike from the Campbell Range succession.

GLENLYON AREA

(Fig. 2, columns 2, 3) Detailed mapping in Glenlyon map area has identified two mid-Mississippian volcanic arc sequences of slightly different ages (Colpron, 1998, 1999a, 1999c; Colpron and Reinecke, this volume). In Little Kalzas Lake area, to the

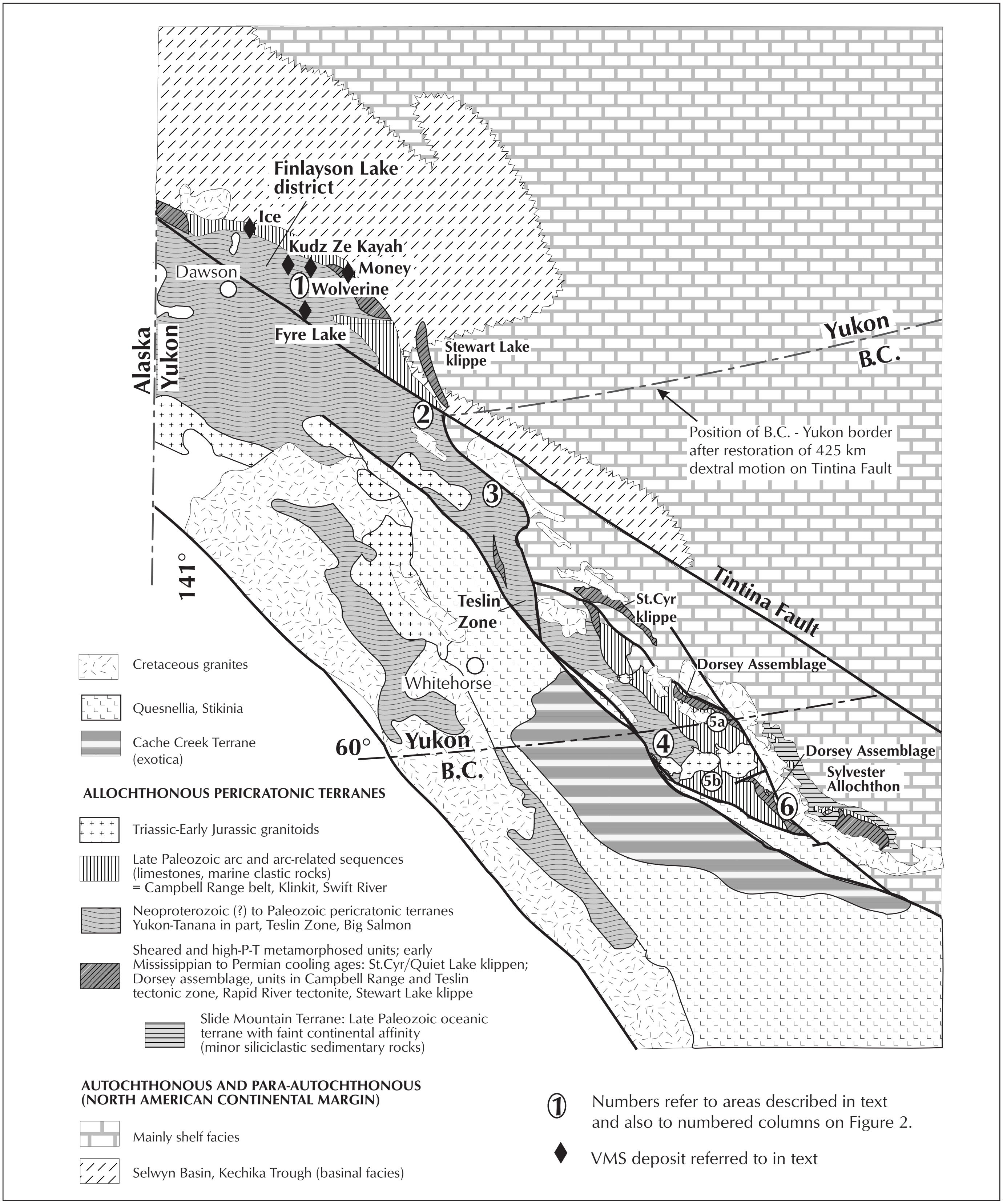

Figure 1. *Generalized terrane map of northern British Columbia and Yukon prior to ~425 km of dextral displacement along Tintina Fault. Areas discussed in text and in Figure 2 are indicated by numbers.*

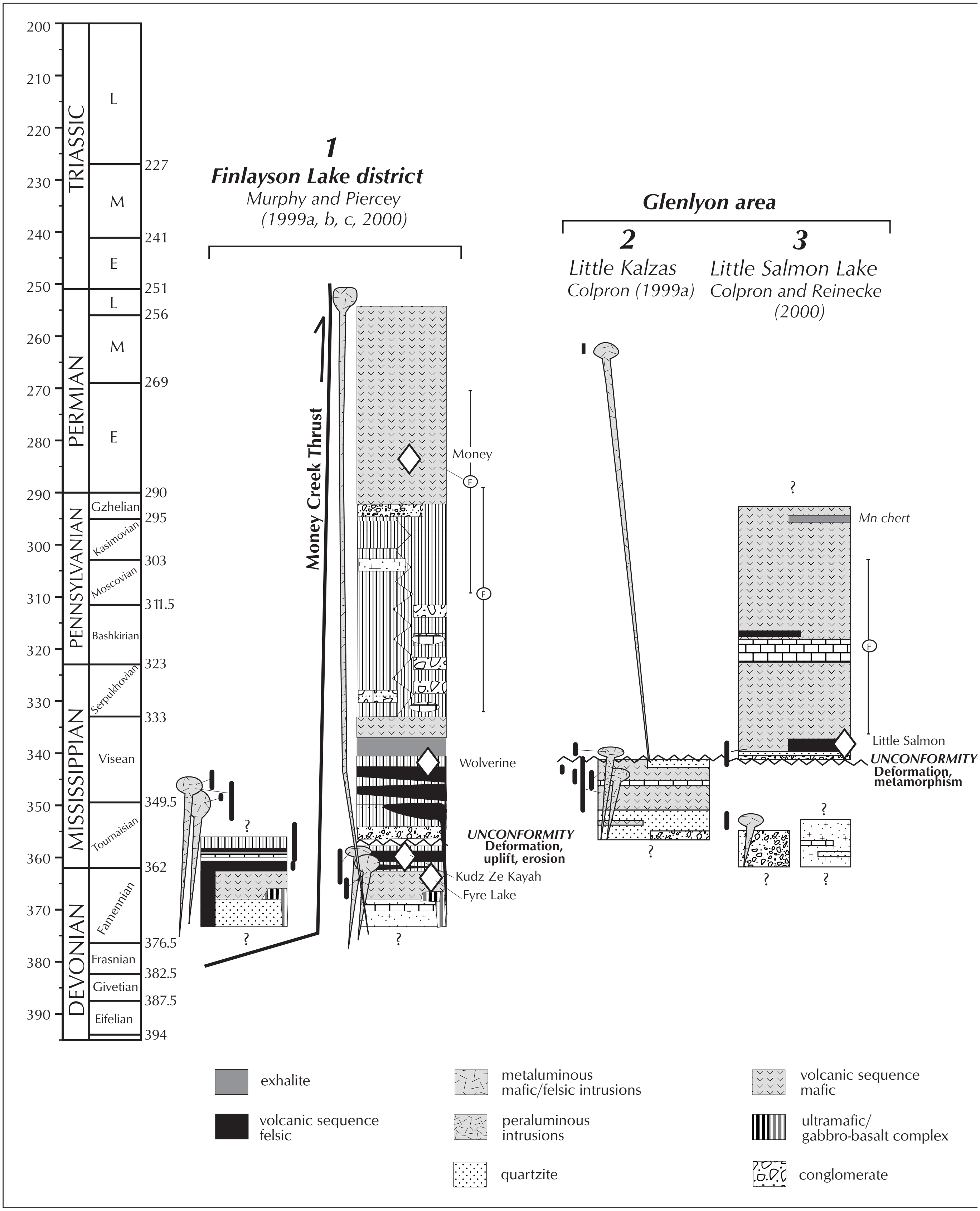

Figure 2. *Comparative stratigraphic columns for the various areas discussed in the text and located on Figure 1.*

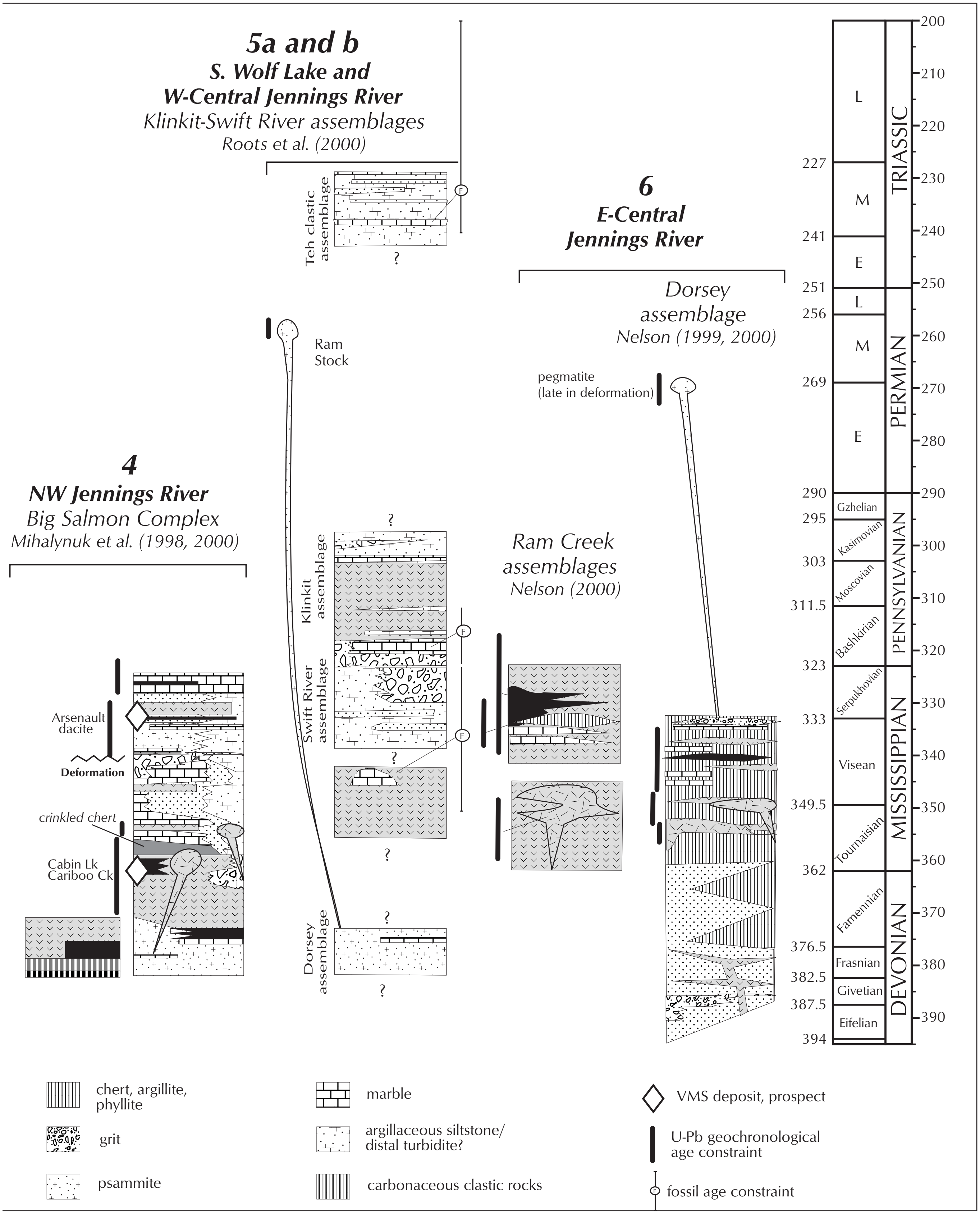

Figure 2. *continued*

northwest, early Visean calc-alkaline volcanic and volcaniclastic rocks conformably overlie a thick orthoquartzite unit (location 2 on Fig. 1). This sequence was apparently deformed and metamorphosed prior to intrusion of the Tatlmain batholith in mid-Visean time. To the southeast, in Little Salmon Range, mid-Visean (and younger) volcanic and volcaniclastic rocks have mixed calc-alkaline and alkaline affinities (location 3 on Fig. 1). The Little Salmon volcanic sequence rests unconformably on two different clastic units, exposed on the east and west limbs of a gentle synclinorium. On the east, it overlies arkosic grit intruded by a 353 Ma pluton (Oliver and Mortensen, 1998). On the west, it overlies a heterogeneous sequence of unknown age, which consists of quartzite, psammitic and pelitic schists, marble, greenstone and abundant discontinuous sills of meta-igneous rocks. The Little Salmon volcanic sequence contains Mn chert horizons and hosts a massive sulphide occurrence (Colpron, 1999b).

NORTHWESTERN JENNINGS RIVER

(Fig. 2, column 4) The Big Salmon Complex is the southernmost projection of assemblages now considered to be equivalents of the Yukon-Tanana Terrane in the Teslin Zone. It underlies the northwestern corner of the Jennings River map area and northeastern corner of the Atlin map area in far northern British Columbia (Fig. 1), and is bounded to the west by the Teslin Fault. Three distinctive units form a marker succession within it (Mihalynuk et al., 1998; 2000). Based on new isotopic and geologic constraints, their stratigraphic order, from oldest to youngest, is:

1. thick, tuffite-dominated greenstone, intruded by the 362 Ma Hazel orthogneiss (Mihalynuk et al., 2000).
2. thin buff- to grey-weathering limestone with metre-thick tuffaceous and thin, centimetre to decimetre, quartzite layers; and
3. thinly bedded, finely laminated manganiferous ‘crinkle chert’/ quartzite with muscovite partings.

The three-part marker succession persists in southeast and northwest 104O/13, and south-central 104O/12. In northern 104N/16, a hybrid unit of felsic tuff mixed with crinkle chert occurs in place of the crinkle chert unit.

Two other, more broadly defined, rock packages are also recognized; both lie stratigraphically high in the sequence, above the greenstone unit. They include:

4. ‘dirty clastics’: brown to tan wacke, stretched quartzite-pebble and granule conglomerate and slate; and
5. heterolithic, quartz-rich clastic rocks interbedded with thin limestone and mafic and felsic tuffs, including late Mississippian dacite.

This general stratigraphy projects north across the British Columbia/Yukon border into southwestern Wolf Lake and probably Teslin map areas (Roots et al., 2000). Vigorous continental arc volcanism in the Late Devonian to early Mississippian (ca. 370-360 Ma) resulted in the accumulation of voluminous, submarine, dominantly mafic tuff and tuffite on a substrate of pericratonic strata. A pulse of felsic volcanism and arc rifting at the end of the magmatic cycle resulted in formation of exhalative chert (the crinkle chert), as well as coeval clastic facies (dirty clastics) preserved in fault-bounded basins. Felsic volcanic intervals with pyritic quartz-sericite schist occur in the greenstone unit immediately beneath the crinkle chert, for instance at the Cabin, Caribou and Mor properties in southern Yukon: they are specific targets for volcanogenic massive sulphide exploration.

SOUTHERN WOLF LAKE AND WEST-CENTRAL JENNINGS RIVER AREA

(Fig. 2, column 5) This section is derived from two areas, one straddling the Yukon/British Columbia border near Swift River, Yukon (location 5a on Fig. 1), and one in the west-central Jennings River map area, B.C. (location 5b). It spans the Ram Creek, Dorsey, Swift River and Klinkit assemblages (Harms and Stevens, 1996). As suggested by Harms and Stevens, and corroborated in 1999 field mapping (Roots et al, 2000), each assemblage consists of related sedimentary and volcanic strata that are mappable and lithologically distinct from adjacent assemblages.

The oldest known rocks are included in the Dorsey assemblage (location 5a, Fig. 1), which is exposed as a narrow, elongate strip near the northeastern side of the pericratonic belt. It is a siliceous succession including quartzite and quartzo-feldspathic metasedimentary protoliths, interspersed with quartz-augen felsic meta-tuff and marble layers, as well as foliated, sill-like leucocratic intrusions. It is characterized by a medium- to high-pressure metamorphic mineral assemblage. The Dorsey assemblage in the Yukon was deformed prior to the emplacement of the mid-Permian Ram Stock (Stevens and Harms, 1995). Its oldest protoliths are probably pre-Devonian-Mississippian, the age of intrusions in southern Dorsey assemblage in British Columbia (see below).

The Swift River assemblage comprises several hundred metres, in structural thickness, of dark meta-siltstone and argillite with interbeds of quartzite; and thick-bedded, dark coloured chert. There is no age control, except that a distinctive chert-pebble conglomerate facies at the top interfingers with, and is conformably overlain by Carboniferous (in part lower Pennsylvanian) Screw Creek limestone.

The Screw Creek limestone is white, thick-bedded, and contains abundant macrofossil debris. As mass flow deposits from a reef environment, this limestone is not a direct stratigraphic marker, but the Bashkirian conodonts (Abbott, 1981) provide an approximate age.

The Klinkit assemblage in central Jennings River area (location 5b, Fig. 1) contains dark coloured, thick-bedded chloritic meta-tuffs and breccias, volcanic-derived meta-siltstone and minor mafic flows, light-coloured limestone and siltstone-argillite layers. One or two prominently red quartzite (possible metamorphosed chert) layers lie several tens of metres above the base, which is locally a limestone that contains Carboniferous macrofauna, correlated with the Screw Creek limestone. The top of Klinkit assemblage, as used here, is a variable succession of meta-siltstone through quartzite with chloritic meta-tuff layers of unknown age.

The Triassic succession in west-central Jennings River area (Teh clastic assemblage; location 5b, Fig. 1) consists of interbedded black argillite, meta-siltstone and quartzite, with minor chert, fetid limestone and conglomerate (T. Harms, pers. comm., 1999). One limestone bed yielded a single Triassic conodont (M. Orchard, pers. comm. to T. Harms, 1997). This single age is considered preliminary. Moreover, although rocks that visually resemble this lithologic succession are found in several places in direct contact with Klinkit assemblage, field evidence for their stratigraphic relationship and even their stratigraphic order remains to be found.

EAST-CENTRAL JENNINGS RIVER

(Fig. 2, column 6) In east-central Jennings River area, rocks of the Big Salmon Complex disappear eastwards below less-metamorphosed younger strata of the Klinkit and Swift River assemblages. Possible equivalents, including Mississippian felsic volcanic units, reappear from beneath these to the east. They are assigned to the Dorsey and Ram Creek assemblages (Location 6 on Fig. 1). The Dorsey assemblage, also described in the Wolf Lake map area (Location 5a), structurally overlies the Ram Creek assemblage across a post-mid Permian thrust fault (Nelson, 2000). For this reason, sections from these two assemblages are presented separately (Fig. 2). The Dorsey assemblage is a metamorphic complex containing a variety of protoliths that range from siliciclastic to basinal sedimentary rocks and tuffs, with isolated metabasic and ultramafic bodies. It is intruded by early Mississippian deformed granitoids. Early Mississippian intrusions also form part of the underlying Ram Creek assemblage. It is possible that during Mississippian time, the Dorsey assemblage was basement to the Ram Creek magmatic arc (Nelson, 2000). The Ram Creek assemblage contains tracts of mafic to rhyolitic meta-tuffs with local limestone and chert sequences. Two uranium-lead dates from the felsic tuffs are late Mississippian, coeval with tuffs in the Big Salmon Complex (Fig. 2, column 4) and Little Salmon Lake sequence (Fig. 2, column 3).

CONCLUSIONS

The columns described above demonstrate both the integrity and the variability of the southeastern Yukon-Tanana Terrane. Mafic to felsic arc activity in a pericratonic setting ranges in age from early Mississippian (ca. 360-350 Ma) to late Mississippian-early Pennsylvanian (ca. 335-320 Ma). The Finlayson Lake district contains significant volcanogenic massive sulphide deposits associated with the early Mississippian event (Murphy and Piercey, this volume). This syngenetic event is represented in the Big Salmon Complex near the British Columbia-Yukon border by the crinkle chert, a siliceous meta-exhalite containing anomalous barium and manganese, and by small felsic accumulations with associated base-metal geochemical anomalies (Mihalynuk et al., 2000). Late Mississippian felsic tuffs occur in the Ram Creek assemblage, in the upper part of the Big Salmon Complex, and near Little Salmon Lake, where a small massive sulphide showing and cherty exhalite like the “crinkled chert” are also reported (Colpron, 1999b; Colpron and Reinecke, this volume). The late Mississippian volcanic suite, not apparently present in the Finlayson Lake district, represents a new, largely unexplored host for volcanogenic massive sulphide deposits in northern British Columbia and south-central Yukon.

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Glenlyon project: Coherent stratigraphic succession of Yukon-Tanana Terrane in the Little Salmon Range, and its potential for volcanic-hosted massive sulphide deposits, central Yukon[1]

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ABSTRACT

Geological mapping of Yukon-Tanana Terrane in Little Salmon Range has outlined a coherent stratigraphic succession in rocks that were previously described as strongly foliated and lineated mylonitic tectonites. The widespread occurrence of primary sedimentary and volcanic textures and the lateral continuity of the units are incompatible with the previous interpretation of the area. A laterally continuous volcanic arc sequence occupies the core of a broad synclinorium and rests unconformably on disparate clastic units to the east and west. The volcanic sequence is structurally overlain by an allochthonous sheet of distal turbidites. The occurrence of massive sulphide and exhalite within the volcanic sequence attests to the high mineral potential of this largely unexplored region.

RÉSUMÉ

La cartographie géologique du terrane de Yukon-Tanana, dans la chaîne de Little Salmon, a permis l'ébauche d'une succession stratigraphique cohésive, là où les roches étaient au préalable décritent comme des mylonites à forte schistosité et linéation. L'abondance de structures primaires d'origines sédimentaires et volcaniques, de même que la continuité des unités vont à l'encontre de l'interpretation antérieure pour cette région. Une séquence volcanique latéralement continue occupe le coeur d'un grand synclinorium. Elle repose en discordance sur deux unités sédimentaires clastiques différentes à l'est et à l'ouest. La séquence volcanique est surmontée structuralement par une écaille allochthone composée de turbidites distales. La présence de sulfures massifs et de roches exhalatives au seins de la séquence volcanique témoigne du haut potentiel minéral de cette région pratiquemment inexplorée.

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INTRODUCTION

Glenlyon area was first mapped between 1949 and 1954 at the scale of 1:253 440 by Campbell (1967). Campbell identified a 30-50 km-wide, northwest-trending belt of metasedimentary, metavolcanic and metaplutonic rocks which correlates with Yukon-Tanana Terrane (Wheeler et al., 1991).

The portion of Yukon-Tanana Terrane exposed along Little Salmon Lake, in southeastern Glenlyon area (Fig. 1), corresponds to the northern extension of the *Teslin suture zone* of Tempelman-Kluit (1979). Building on this model, and on the basis of micro-structural analysis, Oliver (1996) concluded that Yukon-Tanana rocks along Little Salmon Lake are the product of deformation in a subduction zone *(trench mélange)* and that the stratigraphic succession in the eastern part of the area (Oliver and Mortensen, 1998) represents a crustal fragment incorporated in the mélange. A key argument for this model was that regionally mappable units had not been identified in this portion of Yukon-Tanana Terrane. On the contrary, recent studies to the south, in the core of the Teslin suture zone, show that regionally mappable units can be outlined by careful, detailed mapping (e.g., Stevens et al., 1996; de Keijzer et al., 1999) and much of the structural features that had been attributed to deformation in a subduction zone are in fact later, post-accretionary tectonic features.

With these opposing interpretations of Yukon-Tanana Terrane geology in mind, a 1:50 000-scale regional mapping program of Little Salmon Range was undertaken by the Yukon Geology Program in 1999. This study was also fueled by the recent discovery of massive sulphide mineralization along the Robert Campbell Highway (Colpron, 1999a) and the potential for correlations with massive-sulphide-bearing strata of the Finlayson Lake district.

This report presents a brief overview of the stratigraphic and structural relationships in Little Salmon Range, north of the Robert Campbell Highway. It accompanies a preliminary geological map of the area (Colpron, 1999b) and includes a field guide to the roadside geology of Yukon-Tanana Terrane along the Robert Campbell Highway (see Appendix).

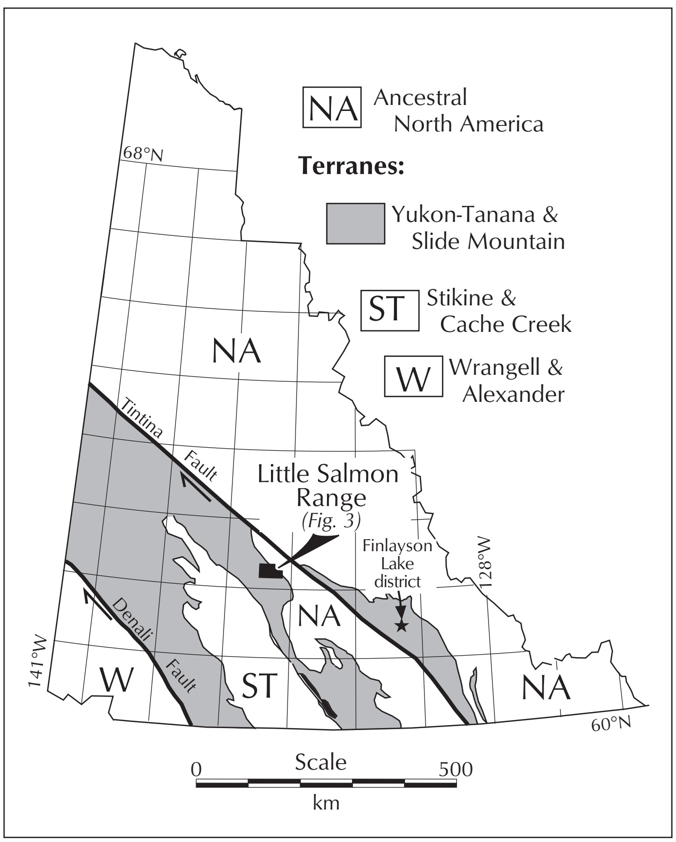

Figure 1. *Location of the Little Salmon Range area with respect to the Finlayson Lake district and to distribution of Yukon-Tanana Terrane in Yukon.*

COHERENT STRATIGRAPHY

Detailed mapping in Little Salmon Range (Colpron, 1999b) shows that Yukon-Tanana Terrane consists of coherent stratigraphic units that can be followed for tens of kilometres and that primary textures are commonly well preserved (Figs. 2 and 3). Four distinct rock assemblages have been identified (Fig. 2): Unit 1: an arkosic grit sequence; Unit 2: a heterogeneous sequence of quartzite and psammitic schist, including several marble units and abundant orthogneiss sills; Unit 3: a volcanic sequence, which includes a fossiliferous

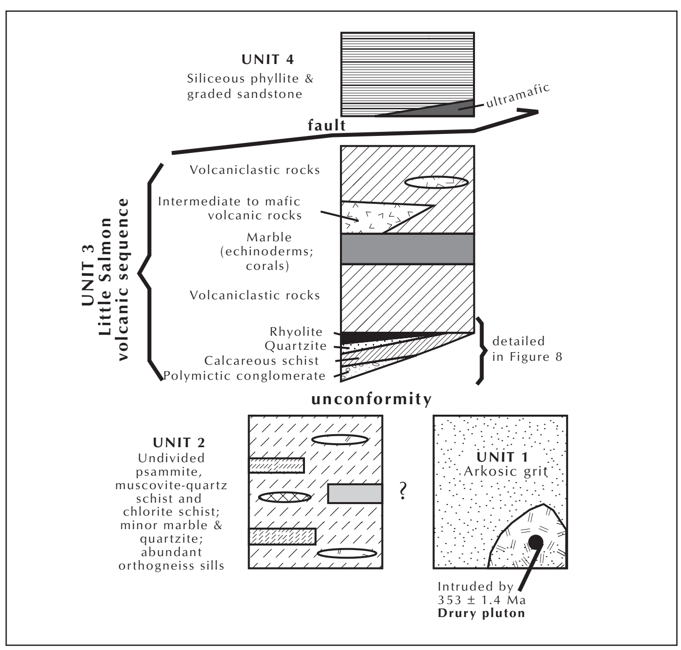

Figure 2. *Schematic stratigraphic columns for Yukon-Tanana Terrane in Little Salmon Range. Legend is shown on Figure 3.*

marble unit and is inferred to unconformably overlie Units 1 and 2; and Unit 4: an allochthonous sheet of dark grey siliceous phyllite, graded sandstone, and minor serpentinite. At the eastern edge of the study area, near d'Abbadie Fault (Fig. 3), undeformed aphanitic basalt of presumed Tertiary age is inferred to be faulted against Yukon-Tanana rocks.

UNIT 1

The arkosic grit sequence (Unit 1) is restricted to the northeastern part of the map area (Fig. 3). It consists predominantly of coarse-grained arkosic grit with up to 20% angular feldspar granules (Fig. 4). Grey and light green quartzite are also common. The grit and quartzite are locally intercalated with dark grey, carbonaceous phyllite. The grit unit is the oldest unit in the area; it is intruded by a granodiorite gneiss dated at 353 ± 1.4 Ma (Oliver and Mortensen, 1998).

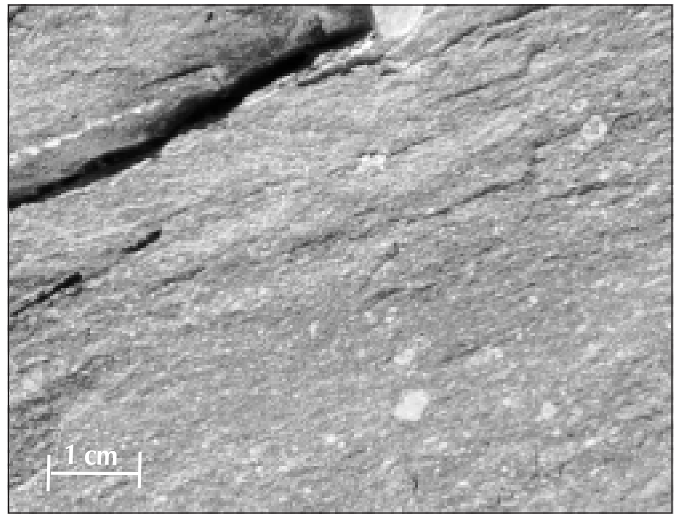

Figure 4. *Coarse-grained arkosic grit (Unit 1).*

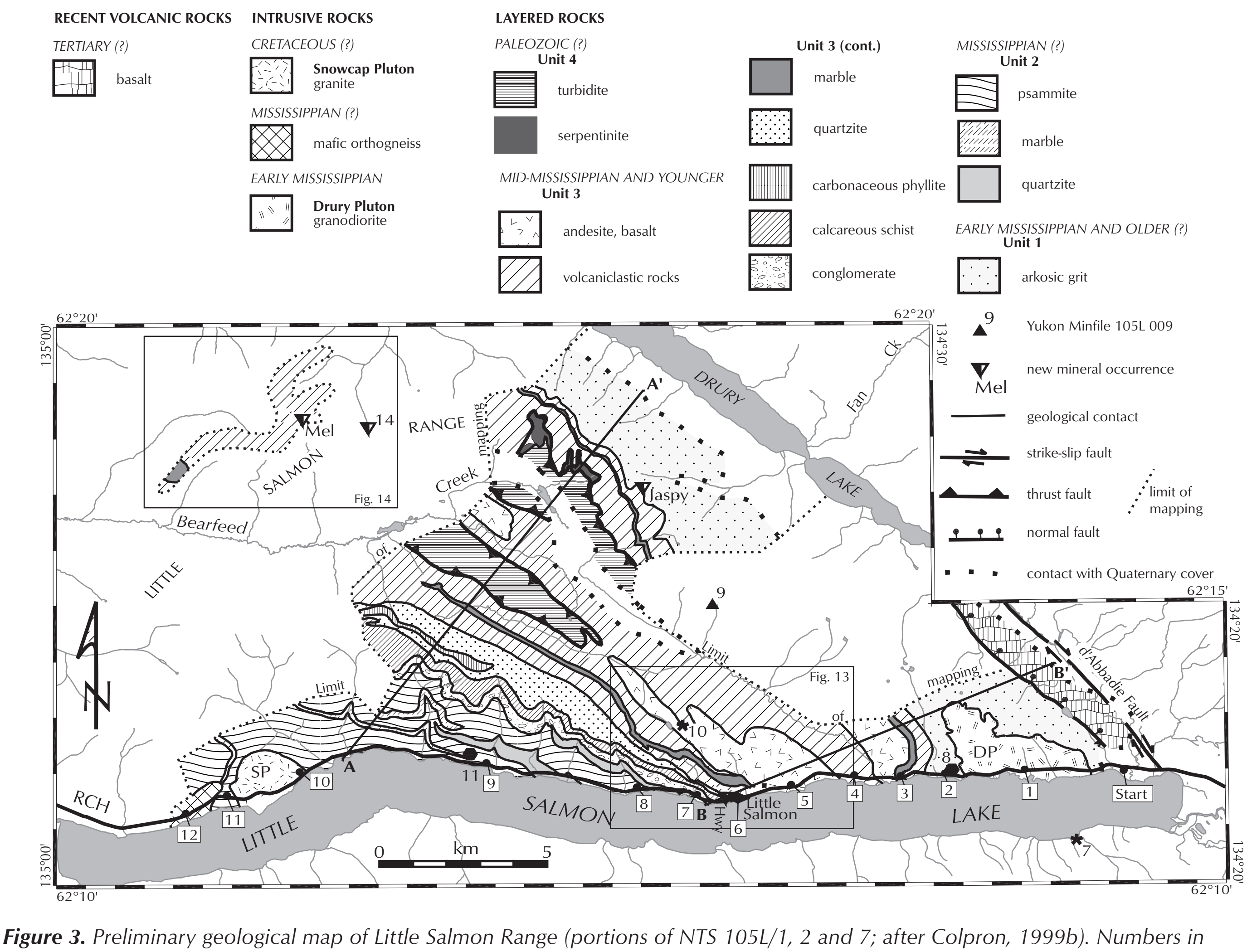

Figure 3. *Preliminary geological map of Little Salmon Range (portions of NTS 105L/1, 2 and 7; after Colpron, 1999b). Numbers in boxes correspond to field trip stops described in Appendix 1; bold numbers and symbols refer to Yukon Minfile, 1997, occurrences. New occurrences are named and described in the text. Sections A-A' and B-B' are shown in Figure 11. SP = Snowcap Pluton; DP = Drury Pluton; RCH = Robert Campbell Highway.*

UNIT 2

Unit 2, which is confined to the area southwest of the volcanic sequence (Unit 3; Fig. 3), comprises a mixture of light to medium grey quartzite and psammitic schist, medium to dark grey carbonaceous muscovite-quartz schist, light green chlorite-actinolite-carbonate schist, and light green quartzite. These rocks are commonly calcareous; marble layers are ubiquitous at scales ranging from centimetres to hundreds of metres in thickness. An important characteristic of this lithologic assemblage is the abundance of felsic to intermediate meta-igneous bodies. These commonly occur as foliation-parallel, 1- to 10-m-thick, discontinuous lenses throughout Unit 2.

UNIT 3 (LITTLE SALMON VOLCANIC SEQUENCE)

The Little Salmon volcanic sequence (Unit 3) occupies the core of a northwest-trending synclinorium in the centre of the map area (Fig. 3). It is inferred to unconformably overlie Units 1 and 2 (Fig. 2). This interpretation is primarily based on the apparent hiatus between the pre-353 Ma (early Mississippian) arkosic grits (Unit 1) and mid-Mississippian felsic volcanic rocks (preliminary U-Pb age; Mortensen, pers. comm., 1999) near the base of the volcanic sequence along the west flank of the synclinorium. In addition, the occurrence of a conglomerate at the base of the volcanic sequence, along the west flank of the synclinorium, also suggests an unconformity.

The bulk of the Little Salmon volcanic sequence (Unit 3) consists of volcaniclastic rocks. These include: light grey, light green and medium green epiclastic sandstone which are locally graded (Fig. 5); dark grey phyllite; brown-weathering calcareous schist and marble; olive-green phyllite; banded chlorite-epidote-plagioclase schist (intermediate to mafic tuff); plagioclase-muscovite-biotite schist (felsic tuff); and, in the northern part of the area, plagioclase-phyric crystal lithic tuff (Fig. 6) and polymictic volcanic conglomerate. The volcaniclastic rocks are intercalated with intermediate to mafic volcanic rocks which consist predominantly of medium green, massive chlorite-plagioclase-epidote ± biotite schist. The volcanic rocks locally display pillow structures, and at one locality, contain a mafic dyke swarm.

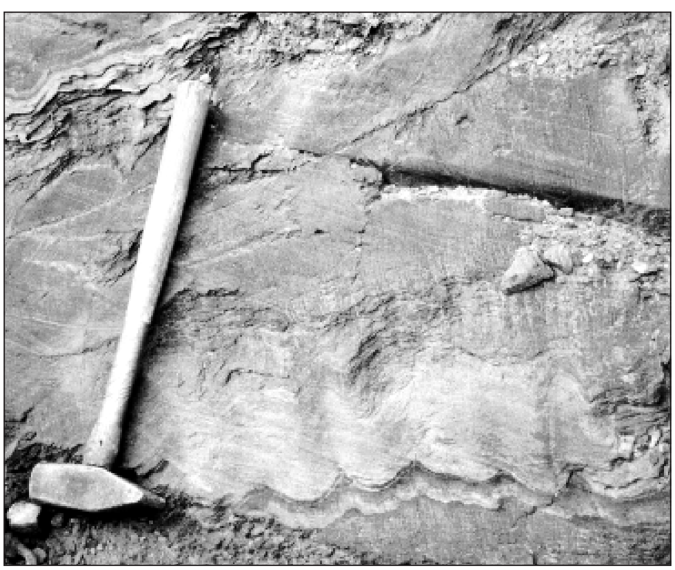

Figure 5. Graded bedding in epiclastic sandstone of the Little Salmon volcanic sequence (Unit 3). Exposure is located in borrow pit along the Robert Campbell Highway (Stop 4 in field trip guidebook, Appendix 1).

Felsic volcanic rocks, namely rhyolite and quartz-feldspar porphyry, are locally interspersed within the Little Salmon volcanic sequence. They occur at various stratigraphic levels within the sequence. These rocks host massive pyrite-magnetite-chalcopyrite horizons at the Little Salmon occurrence, where a quartz-feldspar porphyry yielded a preliminary mid-Mississippian U-Pb zircon age (J.K. Mortensen, pers. comm., 1999). Rhyolite is also found intercalated with pink manganiferous chert horizons north of Bearfeed Creek (Fig. 3). At this locality, one rhyolite horizon contains quartz lenses which may be flattened amygdules similar to those observed in rhyolite above the Kudz Ze Kayah deposit in the Finlayson district (Murphy, 1998).

An important marble marker horizon occurs within the Little Salmon volcanic sequence (Figs. 2 and 3). It consists of light to medium grey marble, light grey phyllitic marble, and lesser black calcareous phyllite and dark grey carbonaceous phyllite. The local occurrences of carbonate rhythmite, poorly sorted carbonate granule to pebble conglomerate, and coarsely crystalline marble (bioclastic calcarenite ?) strongly suggest that these carbonates were resedimented, perhaps as limestone turbidites. The marble marker locally contains echinoderm columnals and corals. Coral specimens collected along the west flank of the Little Salmon volcanic sequence (Fig. 7) indicate a

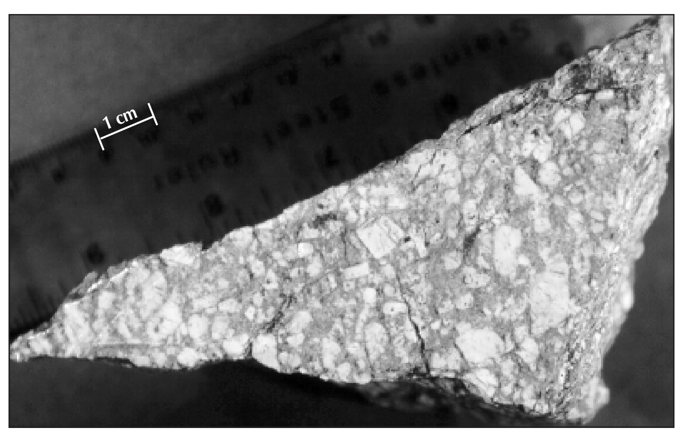

Figure 6. Plagioclase-phyric crystal lithic tuff, Little Salmon volcanic sequence (Unit 3). Hand sample collected north of Bearfeed Creek.

probable late Mississippian to mid-Pennsylvanian age (late Viséan to Moscovian) for this marble (E.W. Bamber, GSC Paleontological Report 3-EWB-1999). Although, these specimens are too poorly preserved for further identification and provide only a tentative age, it must be noted that this determination is consistent with the mid-Mississippian age of underlying felsic volcanic rocks.

A single conodont collection, from a correlative marble along the east flank of the volcanic sequence, yielded a probable Ordovician age (Poulton et al., 1999). Since the sequence is now firmly established as mid-Mississippian to Pennsylvanian in age, this conodont determination must reflect the age of the source rock from which the Little Salmon carbonates were derived.

Along the west flank of the synclinorium, the base of the Little Salmon volcanic sequence is marked by a distinct, mixed carbonate and siliceous clastic unit which commonly contains polymictic pebble to boulder conglomerate (Figs. 8 and 9). The

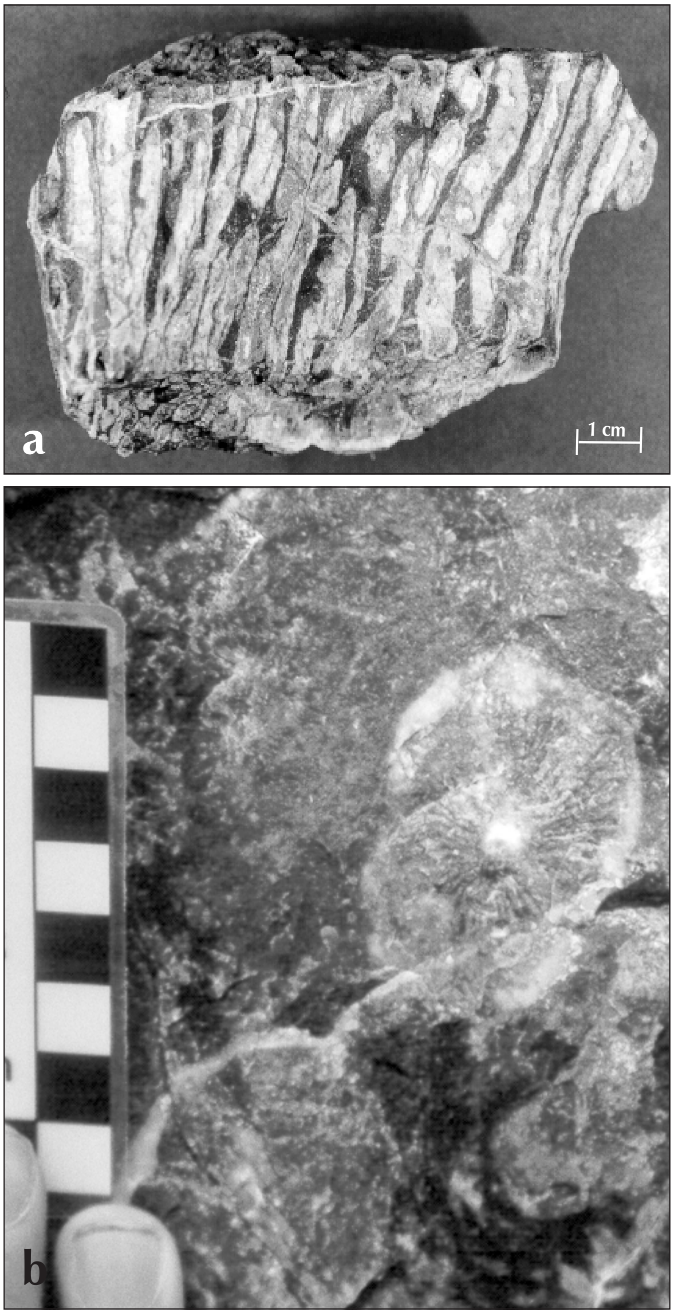

Figure 7. *Coral specimens from marble marker unit in Little Salmon volcanic sequence (Unit 3), from location near Robert Campbell Highway, above Little Salmon occurrence. a) colonial aulophyllid coral, possibly Cowenia sp. b) solitary dibunophyllid (?) coral (E.W. Bamber, GSC Paleontological Report 3-EWB-1999).*

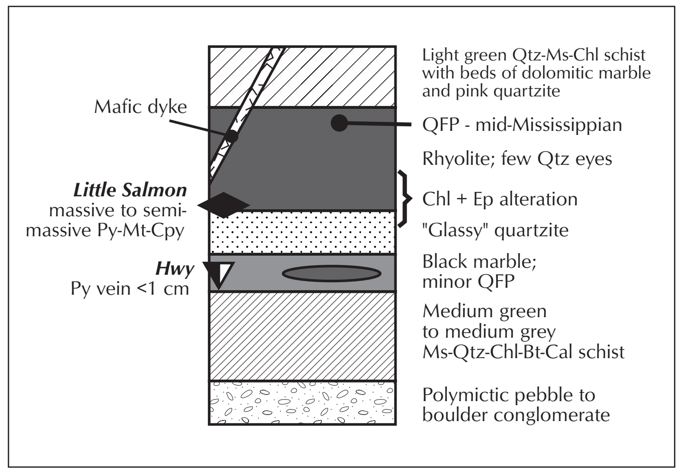

Figure 8. *Detailed stratigraphy of the base of Unit 3 near the Little Salmon occurrence, along the west flank of the Little Salmon volcanic sequence. Stratigraphic position of mineral occurrences are indicated. QFP = quartz-feldspar porphyry, Qtz = quartz, Ms = muscovite, Chl = chlorite, Ep = epidote, Bt = biotite, Cal = calcite, Py = pyrite, Mt = magnetite, Cpy = chalcopyrite.*

Figure 9. *Cobble conglomerate at the base of the Little Salmon volcanic sequence (Unit 3).*

conglomerate contains sub-angular to rounded clasts of quartz, K-feldspar, phyllite, dolomitic siltstone, dark grey marble, buff-weathering dolomitic marble, rhyolite, and granitoid; the matrix is calcareous, siliceous and/or carbonaceous. The conglomerate passes laterally into a mixture of buff-weathering dolomitic marble, light to dark grey quartzite and carbonaceous schist.

The conglomerate unit is overlain by light green quartz-chlorite-plagioclase-muscovite calcareous schist and light grey to light green quartzite (Fig. 2). The calcareous schist commonly contains 1-2 mm calcite porphyroblasts, and locally, 3-5-cm-thick beds of brown-weathering dolomitic marble. To the west, the quartzite is intercalated with dark grey to black carbonaceous phyllite. The quartzite is overlain by rhyolite and/or volcaniclastic rocks typical of the volcanic sequence (Figs. 2 and 8). The Little Salmon showing occurs at the contact between the quartzite and overlying rhyolite of Unit 3 (Fig. 8).

UNIT 4

The Little Salmon volcanic sequence is structurally overlain by an allochthonous sheet of distinct dark grey siliceous phyllite and light grey graded sandstone (Unit 4; Figs. 2 and 3). This unit likely represents a turbidite sequence of unknown age and origin. It locally contains dark grey marble and carbonate cobble conglomerate.

The occurrence of sheared serpentinite at the contact between Units 3 and 4 (Figs. 3 and 10) suggests that rocks of Unit 4 originated in an oceanic realm. The larger ultramafic bodies locally preserve relict cumulate textures.

INTRUSIVE ROCKS

Rocks of Yukon-Tanana Terrane are intruded by a wide range of granitoid rocks. Near the east end of Little Salmon Lake, arkosic grits of Unit 1 are intruded by the Drury Pluton (Fig. 3). It

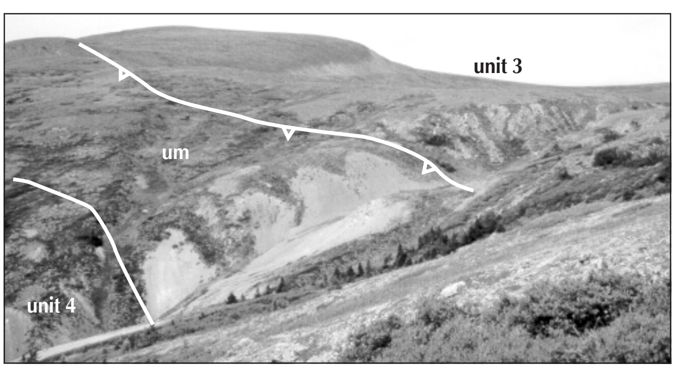

Figure 10. *Looking north at the eastern contact of the Unit 4 thrust sheet. Light grey scree slopes are serpentinite (um) that delineate the base of the thrust sheet. Volcanic rocks (Unit 3) in the footwall of the thrust are mylonitic. Dark grey phyllite of Unit 4 are in lower left corner.*

consists of variably foliated, fine- to medium-grained, equigranular biotite ± hornblende granodiorite. The Drury Pluton is typically uniform in composition. It is locally K-feldspar porphyritic and rarely more felsic (tonalitic) than average. At one locality, along the Robert Campbell Highway, it is a coarse-grained diorite with cumulate texture. The Drury Pluton was dated at 353 ± 1.4 Ma by U-Pb zircon (Oliver and Mortensen, 1998).

Unit 2 contains the widest variety of intrusive rocks. They occur as foliation-parallel, 1- to 10-m-thick, discontinuous lenses. Only locally do they form mappable bodies at the scale of 1:50 000 (50- to 100 m-thick). The igneous rocks vary from mafic (meta-gabbro) to intermediate (meta-diorite) in composition, and most likely belong to more than one magmatic suite. They are typically strongly foliated and commonly gneissic. These intrusions are currently interpreted to be of Mississippian age.

The base of Unit 3, along the west flank of the synclinorium, is locally intruded by a distinct, very coarse-grained (pegmatitic ?) hornblende diorite. It occurs as two ~50-m-wide bodies which are discordant with layering in the country rocks. The diorite is almost exclusively composed of plagioclase and hornblende, with hornblende commonly occurring as crystals up to several centimetres long. It is only weakly foliated and currently undated.

A medium-grained, equigranular hornblende leucogabbro intrudes the contact between the marble marker and volcaniclastic rocks (Unit 3) north of Bearfeed Creek. This rock is unfoliated and may therefore be somewhat younger than other igneous bodies in the area.

Finally, a post-tectonic, medium-grained, equigranular biotite granite (Snowcap Pluton; Fig. 3) intrudes rocks of Unit 2 near the west end of Little Salmon Lake. This pluton extends southward to the base of Snowcap Mountain south of Little Salmon Lake (Campbell, 1967). K-feldspar from the Snowcap Pluton yielded a $^{40}Ar/^{39}Ar$ integrated age of 85 Ma (Oliver, 1996). For this reason, we have assigned a Cretaceous age to this pluton. However, because K-feldspar typically has a very low closure temperature to argon diffusion (~150-200°C), this age assignment must be accepted with caution. The Snowcap Pluton may be much older.

STRUCTURE AND METAMORPHISM

Oliver (1996) described Yukon-Tanana Terrane rocks along Little Salmon Lake as strongly foliated and lineated tectonites of mylonitic character with little or no preservation of primary features with which to interpret protolith or relationships. Although all Yukon-Tanana Terrane rocks are penetratively deformed, we have found little evidence of the degree of deformation implied by Oliver (1996). Primary sedimentary and volcanic features such as fossils, graded beds, pillows, vesicles, etc., are common throughout the sequence and marker beds permit the definition and tracing of a stratigraphic succession.

The structure of the area is dominated by a broad synclinorium which is cored by volcanic rocks of Unit 3 and a thrust sheet of Unit 4 (Fig. 11). Axial planes of tight to isoclinal folds are defined by either a pressure-solution cleavage (in the east and in Unit 4), a penetrative schistosity (most widespread), or a strong transposition foliation and metamorphic segragation (in the west). The attitude of the dominant foliation varies across the area defining a structural fan with an axis that coincides with the core of the synclinorium (Fig. 11). Lineations are most commonly intersection and/or crenulation lineations. A mineral elongation lineation (quartz rodding, mica streaking) is locally developed, most typically at lower structural level in the western part of the area.

Mylonitic rocks are restricted to the footwall of the thrust fault at the base of the allochthonous rocks of Unit 4. At one locality, mylonitic volcanic rocks contain hornblende porphyroclasts with top-to-the-east asymmetry.

Evidence for an older phase of deformation is developed locally. Along the east side of the study area, isoclinal folds deformed by the dominant regional structures are locally outlined by pelitic horizons in grits of Unit 1. To the west, rocks of Unit 2 more typically contain an early schistosity folded by the dominant folds.

The dominant foliation is deformed by younger, gently plunging open folds with a northwest-striking axial planar crenulation cleavage. These structures appear to be related to the large antiform of the dominant foliation in the western part of the area, as previously suggested by Oliver (1996; his western antiform). However, Oliver's eastern synform (our synclinorium) doesn't appear to be of the same generation of structures; the dominant foliation fans across the synclorium rather than being folded by it (as implied by Oliver). We prefer to interpret the synclinorium as being linked to the dominant phase of deformation.

Another younger set of folds is restricted to the eastern part of the area (Unit 1 only). These have shallow, north-striking axial planar crenulation cleavage and typically deform the dominant foliation in tight east-verging folds. The relationship between these folds and open folds found to the west is unknown.

All rocks of Yukon-Tanana Terrane in Little Salmon Range are characterized by stable metamorphic mineral assemblages typical of greenschist facies. In the northeastern and northern parts of the area, the rocks are at chlorite grade. Elsewhere, the rocks contain biotite grade mineral assemblages. In the southwestern part of the area, rocks of Unit 2 have evidently experienced a more complex metamorphic history than the rest

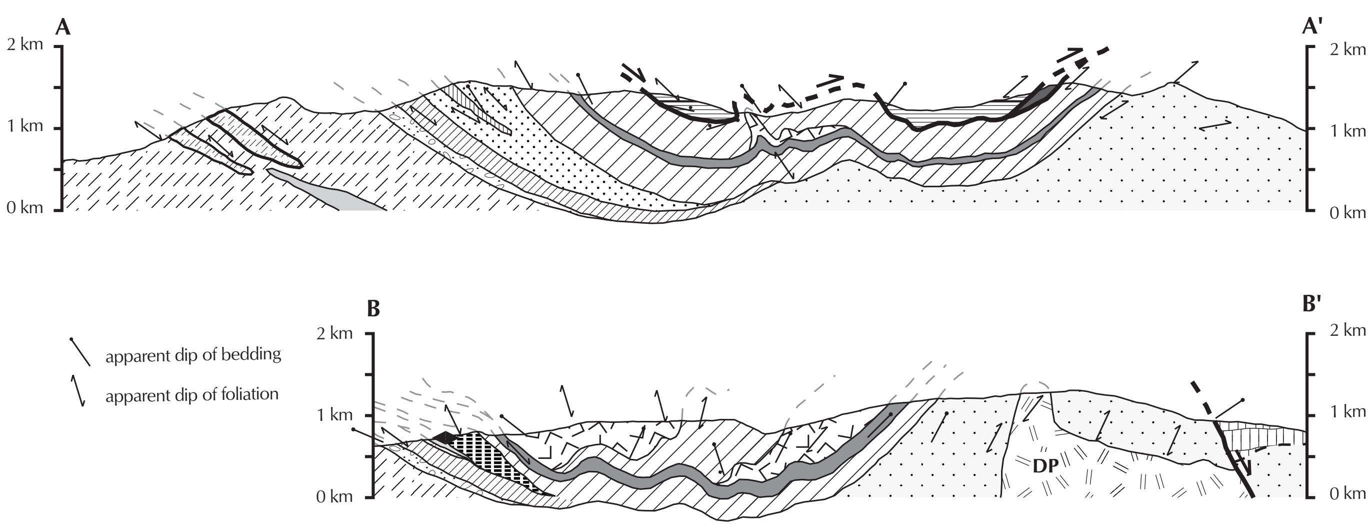

Figure 11. *Vertical cross-sections for Little Salmon Range. Line of sections and legend are located on Figure 2. Black diamond indicates location of Little Salmon massive sulphide occurrence.*

Figure 12. *Chlorite pseudomorphs after garnet in psammitic schist of Unit 2, along Robert Campbell Highway (field trip stop 8, Appendix 1).*

of Yukon-Tanana rocks in Little Salmon Range. The psammitic schist of Unit 2 commonly contains partially to completely retrograded syn- to post-tectonic garnet porphyroblasts (Fig. 12) and, locally, rectangular aggregates of muscovite which are probably pseudomorphs after an aluminosilicate phase. The significance of this earlier, higher grade metamorphism in rocks of Unit 2 has yet to be resolved.

$^{40}Ar/^{39}Ar$ dating of white micas along Little Salmon Lake yielded consistent integrated ages in the range of 180 to 193 Ma, with plateau ages tightly clustered at ca. 192 Ma (Oliver, 1996). This indicates that greenschist facies metamorphism most likely occurred in Early Jurassic time.

POTENTIAL FOR VOLCANIC-HOSTED MASSIVE SULPHIDE DEPOSITS

The discovery of a massive pyrite-magnetite-chalcopyrite occurrence along Robert Campbell Highway in 1998 (Colpron, 1999a) attests to the high mineral potential of the area. Lateral continuity of the volcanic host sequence (Unit 3) for over 20 km and the presence of manganiferous chert of possible exhalitive origin also underscores the prospectivity of this largely unexplored region.

Detailed mapping in the vicinity of the Little Salmon occurrence (Fig. 13) shows that the massive sulphide occurrence is located at the contact between a quartzite and felsic metavolcanic rocks (Fig. 8). Our mapping indicates that the felsic metavolcanic unit thins to the northwest, whereas the quartzite gets thicker. No new sulphide occurrences were located along this contact to the northwest, although this contact is covered for much of the area shown on Figure 3.

Small veins of pyrite, generally less than 1 cm wide, abound in an outcrop of black marble and felsic schist approximately 200 m to the west of the Little Salmon occurrence (Hwy. occurrence, Figs. 3 and 13). A pyrite vein returned anomalous concentrations of Cu, Pb, As and Au (Table 1). These veins may be related to sulphide concentrations at the main showing to the east.

An important new exploration vector within the Little Salmon volcanic sequence consists of the numerous manganiferous chert horizons that are present north of Bearfeed Creek (Fig. 14). These chert horizons occur as light to dark pink layers less than a metre thick within felsic volcanic rocks (rhyolite) of Unit 3. They contain up to 5% piedmontite (Mn epidote) and are probably of exhalative origin. The encasing rhyolite locally contains quartz lenses which may represent flattened amygdules; a possible near-vent facies. Grab samples from a discordant copper-bearing (bornite-malachite-tetrahedrite?) quartz vein within this sequence contain up to 5% Cu (Table 1). Similar veins may be present at the nearby Drury occurrence (Yukon Minfile, 1997, 105L 014; Fig. 3) where rumours of tetrahedrite have been reported. These veins may form part of a stockwork system. Further work is required to confirm this interpretation.

Another occurrence of a copper-bearing (malachite-bornite) quartz-carbonate vein is located at the contact between the volcanic sequence and arkosic grits of Unit 1 (Jaspy occurrence; Fig. 3). A grab sample from this occurrence contained anomalous concentrations in Cu, Pb, Zn, Ag and Ba (Table 1).

ADDITIONAL MINERAL OCCURRENCES

Other mineral occurrences include diopside-epidote-pyrite (± garnet) skarn in the aureole of Early Mississippian intrusions (Yukon Minfile, 1997, 105L 008 and 011; Fig. 3). The two occurrences that we visited only contained disseminated pyrite, with trace amounts of pyrrhotite at the Ulrike occurrence (Yukon Minfile, 1997, 105L 008). Samples from both occurrences were barren (Table 1).

Finally, an extensive zone of gossan with up to 2% disseminated pyrite occurs in arkosic grit (Unit 1) southwest of Drury Lake (southeast of the Jaspy occurrence). Although the one sample we have assayed was barren (Table 1), the extent of this zone warrants further work.

SUMMARY AND SPECULATIONS

Detailed mapping of Little Salmon Range has outlined a coherent stratigraphic succession from rocks which were previously described as strongly foliated and lineated (L-S) tectonites. The remarkable preservation of primary textures alone, in rocks of Units 1, 3 and 4, is inconsistent with the degree of deformation implied by previous studies (see Figs. 5, 6, 7 for examples).

The overall stratigraphic succession in the eastern part of the area is generally similar to that described by Oliver and

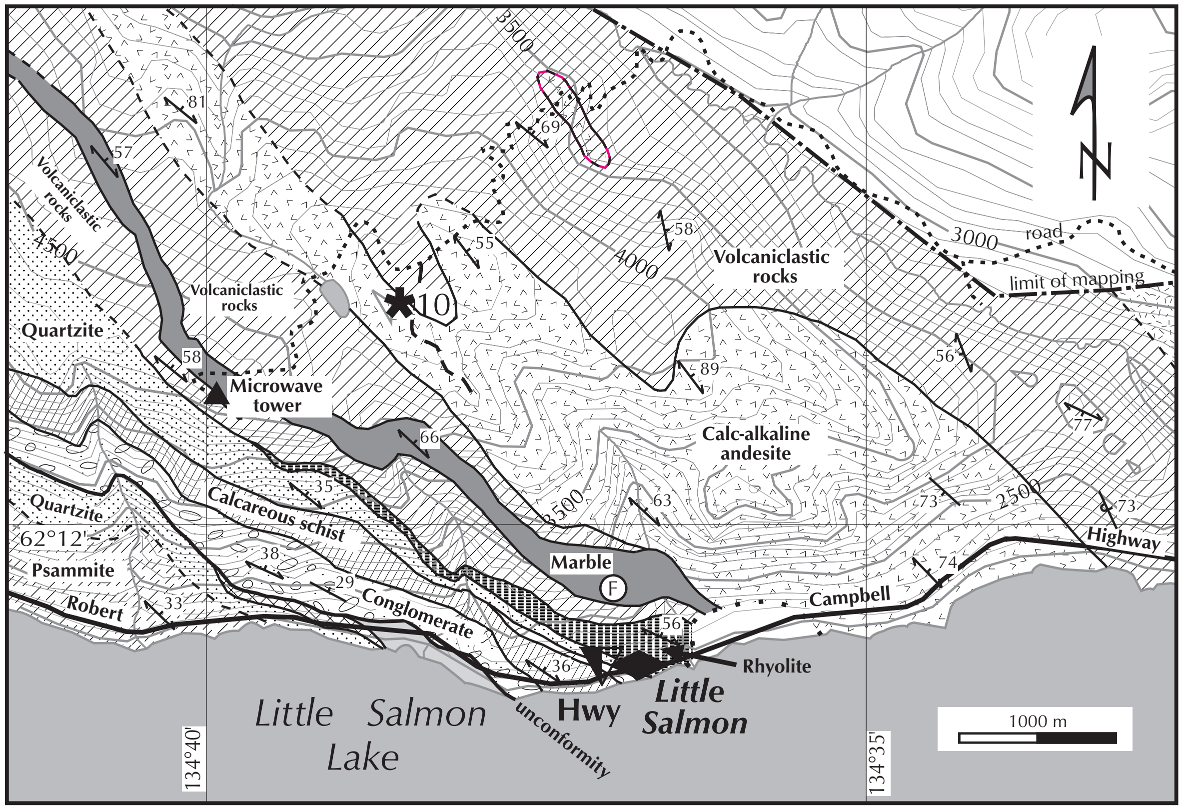

Figure 13. *Detailed geological map of the area of the Little Salmon occurrence. Legend located on Figure 2. Location of coral specimens shown in Figure 7 is indicated by circled F.*

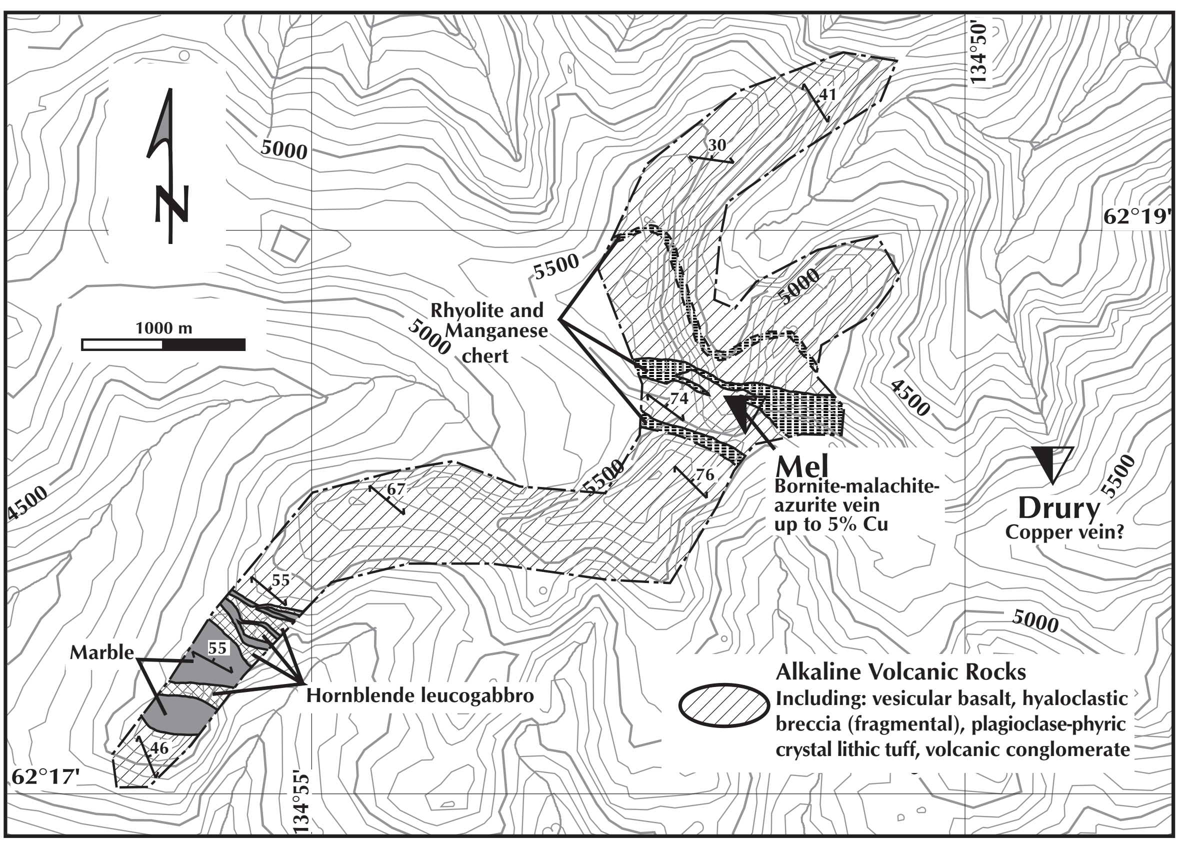

Figure 14. *Detailed geological map of a transect north of Bearfeed Creek. Legend located on Figure 3.*

Table 1. *Selected assay results from Little Salmon Range area.*

ELEMENT SAMPLES	Occurrence	Yukon Minfile	UTM-E Zone 8, NAD27	UTM-N	Mo ppm	Cu ppm	Pb ppm	Zn ppm	Ag ppm	Ni ppm	Co ppm	Mn ppm	Fe %	As ppm	Cd ppm	Bi ppm	Ba ppm	Hg ppm	Au ppb
99MC002	Hwy		520106	6895429	11	764	230	15	8.4	96	104	202	11.84	91	1	51	17	<1	96
99MC033	Ulrike	105L 008	526600	6896300	1	169	4	92	<.3	18	8	1240	2.31	5	1	<3	12	1	<2
99MC076	Fu in carbonate		516362	6897438	1	2	<3	18	<.3	355	47	2675	4.21	626	2.6	<3	21	<1	2
99MC143	Unit 1 gossan		519160	6904664	2	8	5	9	<.3	16	25	155	2.85	6	0.7	<3	27	<1	6
99MC151	Jaspy		517497	6905592	3	1874	180	134	76	9	1	348	0.49	166	16.6	<3	2137	23	8
99MC198-A	Stud	105L 011	512436	6896854	6	138	8	3	0.7	24	28	154	1.42	40	<.2	<3	67	<1	33
99MC198-B	Stud	105L 011	512436	6896854	6	260	5	4	0.4	18	22	256	1.29	27	<.2	<3	352	2	16
99MRT021-1	Mel		507277	6908273	<1	50,814	<3	143	4.3	164	40	285	4.7	2	2.1	<3	208	2	46
99MRT021-2	Mel		507277	6908273	4	232	<3	31	<.3	9	3	1657	0.81	7	<.2	<3	143	1	<2
99MRT021-3	Mel		507277	6908273	<1	17,463	<3	192	3.2	217	56	397	6.42	2	2.6	<3	1091	1	46

Notes: Analyses completed by Acme Analytical Laboratories Ltd., Vancouver, B.C. Au by fire assay/ICP; all other elements by ICP. Fu: fuchsite.

Mortensen (1998; our Units 1 and 3). This succession has been mapped for ~20 km to the northwest and may well extend for another 20 km to the north-northwest (Campbell, 1967). A key element of this stratigraphic succession is the Little Salmon volcanic sequence (Unit 3) which hosts a massive sulphide occurrence and probable exhalative horizons. If this sequence can indeed be mapped for more than 40 km, then it would greatly increase the area of prospective stratigraphy for hosting volcanogenic massive sulphide deposits.

As described by Oliver and Mortensen (1998), rocks in the western part of the area (our Unit 2) are more heterogeneous and marker beds are more difficult to define. These rocks have evidently experienced a metamorphic history which is distinct from other stratigraphic assemblages in the area. Further work is required in order to establish the origin and tectonic significance of this earlier amphibolite facies metamorphism.

We have suggested that both Units 1 and 2 are unconformably overlain by the Little Salmon volcanic sequence (Unit 3). If this is correct, then what is the relationship between Units 1 and 2? Unit 1 has apparently not experienced the higher grade metamorphic event recorded in Unit 2. One hypothesis would be that Units 1 and 2 were tectonically juxtaposed prior to deposition of the Little Salmon volcanic sequence (Unit 3). If that is the case, then perhaps the structure bounding Units 1 and 2 served as conduit for the emplacement of volcanic rocks of Unit 3.

Finally, the identification of an allochthonous sheet of distal turbidite (Unit 4) raises another problem of regional significance: what is the origin of this allochthon? The presence of serpentinized ultramafic rocks along the basal thrust suggests that an ocean basin separated the turbidite sequence from rocks of the Little Salmon sequence. Additional work is required in order to resolve the depositional and kinematic history of this enigmatic sequence.

ACKNOWLEDGEMENTS

This report has benefited from discussions and comments by Don Murphy (Yukon Geology Program), Steve Piercey (University of British Columbia), Jim Mortensen (UBC), and the participants of the 1999 Ancient Pacific Margin NATMAP field trip, from which the guidebook in Appendix 1 was derived. Additional field assistance was provided by Kaori Torigai and Annie Daigle. Field visits by Steve Piercey (UBC), Steve Johnston (University of Victoria) and Don Murphy (YGP) were greatly appreciated. Thanks to Al Carlos, of Whitehorse, for sharing his knowledge of the area and for pointing out areas where the bush was particularly bad; we should have listened to you Al! Helicopter services were provided by Brian Parsons (Carmacks) and Grant Shannon (Ross River) of TransNorth Helicopters. Editorial comments by Don Murphy, Leyla T.D. Weston and Diane Emond have greatly improved this manuscript. Camp safety was provided by Jasper W.P. Colpron.

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APPENDIX 1

A FIELD GUIDE TO THE GEOLOGY OF YUKON-TANANA TERRANE ALONG ROBERT CAMBELL HIGHWAY (LITTLE SALMON LAKE), CENTRAL YUKON

The field trip starts at the old service area and highway maintenance station near Drury Creek, at the east end of Little Salmon Lake. The transect is covered by NTS maps 105L/1 (Truitt Creek) and 105L/2 (Snowcap Mountain) and preliminary geological map Open File 1999-2 (Colpron, 1999b). Field trip stops are located on Figure 3.

0.0 km Drury Creek highway station.

0.8 km Outcrop of coarse-grained arkosic grit (Unit 1).

1.2 km Eastern contact between Drury Pluton and grit unit (Unit 1).

3.0 km STOP 1: Park at access road to gravel pit on north side of the road.

Drury Pluton: Exposure of biotite ± hornblende granodiorite dated at 353 ± 1.4 Ma (U-Pb, zircon; Oliver and Mortensen, 1998). This pluton is relatively uniform in composition. It is typically fine- to medium-grained and equigranular, although locally, it contains K-feldspar phenocrysts. Here, the granodiorite is only weakly foliated (foliation dips moderately to the southwest); it is typically more strongly foliated near its margins. The Drury Pluton intrudes the arkosic grit (Unit 1) exposed at the next stop.

4.8 km Western contact of Drury Pluton.

5.4 km STOP 2: Park in front of outcrop on north side of the road (km 474).

Light grey, fine- to medium-grained arkosic grit/ sandstone intercalated with medium to dark grey quartz-muscovite-biotite schist. This outcrop (and the next one – approximately 700 m to the west – STOP 2b) is typical of rocks that comprise Unit 1 which underlie the eastern part of Little Salmon Range. In addition, the structural relationships along the east side of the cleavage fan are well displayed here. Early isoclinal folds are prominantly displayed on the south side of the highway. There, two crenulation cleavages are superposed; the earliest one is believed to be equivalent to dominant regional fabric that we will observe farther west. The second cleavage (shallower) does not appear to have a regional equivalent in the western part of this transect.

Rocks at the western end of the outcrop are more calcareous, and for the most part, extensively replaced by garnet-diopside-epidote-calcite skarn. The skarn contains trace sulphides (pyrite). A 1.5-m-wide gossan, containing 5- to 10 cm-wide quartz veins with disseminated pyrite-pyrhotite ± chalcopyrite, is present at the east end of the outcrop. From here, walk along road to STOP 2b, approximately 700 m west.

5.9 km Parking area for STOP 2b is on the north side of the road.

6.1 km STOP 2b

Coarse-grained, thickly bedded (10-50 cm) and poorly sorted arkosic grit interbedded with rare, dark grey carbonaceous phyllite horizons (1-2 m). The grit consist of <10% feldspar granules; the majority of clasts are smokey, white and blue quartz granules; a few clasts of light grey siltstone are locally present. The grit passes westward into a >50 m section of carbonaceous phyllite with minor sandstone beds. Foliation here dips moderately to the west.

6.8 km STOP 3: Park at the start of outcrop (before curve).

This outcrop consists of dark grey carbonaceous phyllite which passes gradually westward into a sequence of interbedded (5-10 cm) light grey phyllitic marble and black calcareous phyllite. The marble beds consist of poorly sorted carbonate granule to pebble conglomerate – a strong indication of the detrital origin of the carbonate. This appears to be the case for all carbonate units in the area. Although there is lack of sedimentary structures supporting this interpretation, the rhythmic nature of this sequence suggests deposition as limestone turbidites. A 1-2-m-thick horizon of light green siltstone is intercalated with the carbonate rhythmites.

The carbonate rhythmite sequence is overlain by thickly bedded (50 cm to 2 m), medium grey, coarsely crystalline marble. The large (~0.5 to 1 cm) calcite spar which characterizes this marble are most likely recrystallized echinoderm fragments; such fragments are locally well preserved in this outcrop. A sample from this outcrop yielded Ordovician (?) conodonts (Poulton et al., 1999). However, this age determination is inconsistent with other age constraints discussed above. The massive marble is overlain to the west by a finer grained, dark grey to black cherty marble. This, in turn, is overlain by another coarsely crystalline, poorly bedded (>2 m) marble.

These massive marble beds are strongly boudinaged at the scale of the outcrop, between less competent, more phyllitic horizons. At a first glance, this apparent strain partitioning may suggest that the more massive marbles are fault bounded. However, a closer examination reveals that this is most likely a coherent section of lithologies with varying competencies. The west end of the outcrop displays a large northeastverging fold; this fold is associated with the dominant regional phase of deformation.

7.5 km Outcrop of greenstone (Unit 3).

8.2 km STOP 4: Park near small borrow pit.

Volcaniclastic rocks (Unit 3): This outcrop, and the next one down the road, consist of rhythmically interbedded light grey to light green sandstone, carbonaceous phyllite, and brown-weathering calcareous schist. Exposures on the floor of the borrow pit exhibit convincing graded beds that indicate stratigraphic top to the west (see Fig. 5).

In the main roadcut to the west, the sandstone beds are generally thicker (~1.5 m) and coarser grained, and interbedded with dark grey and olive-green phyllite. The sandstone becomes more thinly bedded (~3-10 cm) upsection; dark grey phyllite is less abundant and the sandstone is typically more green in colour. One exposure of this unit, approximately 1.3 km to the northwest, contains well-preserved pumice fragments in a light green sandstone matrix. This is a good indication of the volcanic origin of the clastic rocks.

Here, the foliation dips moderately to steeply to the east, indicating that we have now crossed the axis of the cleavage fan.

10.2 km STOP 5: Park just before outcrop.

Intermediate volcanic rocks (Unit 3): This outcrop consists of intermediate to mafic metavolcanic rocks (medium green, massive chlorite-plagioclase-epdiote-biotite schist) which are locally intercalated with minor light green, banded calcareous schist, dark grey carbonaceous schist and marble. The abundance of plagioclase in this unit suggests an intermediate composition (andesitic). Outcrops of this greenstone up the hill display well-preserved (although strained) pillow structures and a mafic dyke swarm. At this locality, the greenstone commonly contains magnetite and is more chlorite-rich than exposures along the road, suggesting that it is in part of a more mafic composition.

On our way to the next stop, we will be passing a covered interval which conceals an important stratigraphic marker – a distinctive marble unit which occurs between a light green quartzite and phyllite unit to the east and a light to medium green calcareous schist unit to the west. One outcrop of this marble contains solitary and colonial corals which suggest a probable late Mississippian to mid-Pennsylvanian age of this unit. The colonial corals occur in discrete beds 10-20 cm thick, suggesting a detrital origin. Similarly, the solitary corals are randomly oriented, also suggesting transport. This marble unit constitutes the most important stratigraphic marker in this part of Yukon-Tanana Terrane. It is considered equivalent to the carbonate rhythmite sequence that occurs at STOP 3.

11.7 km Park here for STOP 6 – located 300 m down the road.

12.0 km STOP 6: Little Salmon showing (Cu).

This outcrop consists of meta-rhyolite and contains the massive sulphide occurrence discovered by Don Murphy in 1998 and for which a preliminary description is given by Colpron (1999a).

The east end of the outcrop consists of quartz-feldspar meta-porphyry which grades to the west into more massive meta-rhyolite with fewer quartz-eyes. As the sulphide-rich zone is approached, the meta-rhyolite is altered to chlorite + epidote and locally contains magnetite veins. The sulphide zone itself, which is approximately 3 m wide, consists of semi-massive pyrite-magnetite-chalcopyrite horizons in a chlorite + quartz matrix. Another zone of non-magnetic massive sulphides, less than 1 m wide, occurs in a small isolated outcrop just to the west of the main roadcut. Assays from this occurrence returned Cu values of ~600 ppm and background values for other metals (Colpron, 1999a). The extensive chloritic alteration and anomalous Cu concentrations of the mineralized zone suggest that it may have formed in a sub-seafloor hydrothermal system.

The meta-rhyolite thins to the northwest, where it has been traced for approximately 3 km. It occurs at the contact between (1) a calcareous schist unit consisting of light to medium green quartz-muscovite-chlorite schist intercalated with ~10-cm-thick, buff-weathering dolomitic marble and minor pink calcareous quartzite (structurally above the meta-rhyolite); and (2) a light grey to light green quartzite (structurally below the meta-rhyolite; see Fig. 8). Near the road, the quartzite is generally coarse-grained and glassy. It is underlain (structurally) by a sequence of black marble and felsic schist which gradually passes into schistose marble and pebble to cobble conglomerate with a psammitic matrix.

Preliminary U-Pb zircon date indicates a mid-Mississippian age for the meta-porphyry (Mortensen, pers. comm., 1999).

13.3 km STOP 7

The first outcrop consists of a pebble conglomerate where clasts of quartz, K-feldspar, phyllite, dolomitic siltstone, dark grey marble and felsic metavolcanic rocks (?) are hosted in a fine-grained quartzite matrix. To the west, the rock becomes more schistose and darker in colour with only rare clasts. It is for the most part a carbonaceous schist with few horizons (<10 cm) of dark grey quartzite and buff-weathering dolomitic marble. A few metres above the road, outcrops in the bush reveal excellent exposures of a cobble to boulder, matrix-supported polymictic conglomerate (see Fig. 9). The clasts are sub-angular to rounded; the matrix consists of carbonaceous and calcareous schist.

14.9 km STOP 8: Park immediately after outcrop

This outcrop, and the next one to the west, are characteristic of the heterogeneous sequence of rocks which is exposed along the western half of the transect. It consists of light to medium grey quartzite and psammitic schist, medium and dark grey carbonaceous muscovite-quartz schist, and light green chloritic schist and quartzite. These rocks are commonly calcareous; thin horizons of marble are locally present (but not in these roadcuts). Another important feature of this lithologic package is the abundance of orthogneiss bodies within it. These are commonly only a few metres thick (i.e. not mappable) and usually discontinuous. Examples of orthogneiss lithologies will be seen at STOP 9 and 12.

The foliation in the first outcrop is locally of mylonitic character. Exposures above the road show lenticular distribution of these lithologies – could this be a fault zone? The next outcrop to the west displays 3 tectonic fabrics: an early schistosity is defined by alignment of micas in microlithons of the dominant, penetrative schistosity. The dominant fabric is in turn deformed by a northwest-striking crenulation cleavage. Small isoclinal folds of calcareous horizons are present in this outcrop – these have the dominant foliation in their axial plane. Both senses of asymmetry are recorded by these minor folds.

The rocks in these outcrops (like most of the rocks along the western part of the transect) have a different metamorphic history than those to the east. These roadcuts show evidence for an amphibolite grade metamorphic event now retrograded to greenschist facies. This is best shown by the occurrence of partially to totally retrograded garnet porphyroblasts. These porphyroblasts are syn- to post-tectonic. Calcareous rocks commonly have randomly oriented actinolite clusters. More evidence for this higher grade metamorphic event will be observed at STOP 11, farther west.

19.9 km STOP 9

This outcrop consists of light to medium green quartz-biotite-chlorite psammitic schist, medium green quartz-plagioclase-chlorite-biotite ± epidote ± muscovite calcareous schist, light grey quartz grit and white marble. At the west end of the outcrop, the marble is silicified and partially replaced by epidote ± diopside. This calc-silicate alteration is similar to that observed at the Stud occurrence (Yukon Minfile, 1997, 105L 011), a few hundred metres to the northwest, where disseminated pyrite occurs with the calc-silicate minerals. This calc-silicate alteration is interpreted as skarn in the aureole of a probable Mississippian intrusion (similar to that observed at Stop 2). The next two outcrops to the west (~300 m) consist of foliated quartz-plagioclase-chlorite-muscovite ± epidote orthogneiss (quartz diorite).

25.7 km STOP 10

Snowcap Pluton: This outcrop consists of medium-grained, equigranular biotite granite typical of the Snowcap Pluton. A Cretaceous age is assigned to this granite based on a K-feldspar $^{40}Ar/^{39}Ar$ integrated age of 85 Ma (Oliver, 1996).

28.2 km STOP 11

This stop presents further indications for an earlier amphibolite facies metamorphic event in rocks of Unit 2. The outcrop consists of a fine-grained, quartz-plagioclase-muscovite-biotite ± chlorite schist which contains randomly oriented, rectangular clusters of silvery muscovite. These rectangular clusters are interpreted to be muscovite pseudomorphs after an aluminosilicate phase. The eastern portion of the outcrop contains abundant chlorite pseudomorphs of garnet, similar to those observed at Stop 9 and shown in Figure 12.

29.6 km STOP 12

This outcrop consists of fine- to medium-grained, dark green, chlorite-epidote-plagioclase ± muscovite ± hornblende ± biotite mafic orthogneiss, intercalated with thin (5-10 cm) quartzite layers. The orthogneiss locally contains pyrrhotite ± magnetite. It becomes more mica-rich (muscovite ± biotite) to the east, where quartzite is more abundant. This outcrop is part of a larger body of mafic orthogneiss; the quartzite probably represents xenoliths of country rock with mica enrichment indicating partial assimilation of the sedimentary rocks.

Preliminary geology north of Mount Mye, Anvil District (105K/6, 105K/7), central Yukon

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Pigage, L.C., 2000. Preliminary geology north of Mount Mye, Anvil District (105K/6, 105K/7), central Yukon. *In:* Yukon Exploration and Geology 1999. D.S. Emond and L.H. Weston (eds.), Exploration and Geological Services Division, Yukon, Indian and Northern Affairs Canada, p. 101-114.

ABSTRACT

The northeast Anvil area, 15 km north of Mount Mye (NTS 105K/6, 105K/7), is underlain by a conformable Cambrian-Devonian volcanic and sedimentary package with an aggregate thickness of greater than 1600 m. The lowest unit, with an exposed thickness of 120 m, consists of calcareous phyllites of the Cambrian-Ordovician Vangorda formation. Conformably overlying the phyllites is a ≥ 900-m-thick Ordovician-Silurian sequence of submarine basalt flows and volcaniclastic sedimentary rocks of the Menzie Creek formation. Volcaniclastic sediments are dominantly coarse, proximal, fragmental breccias with lesser conglomerates, sandstones, and siltstones. Carbonaceous shales with lesser siltstones, limestones, dolostones, and quartzites of the Ordovician-Devonian Road River Group (≥ 450 m) are intercalated with and overlying the basalt flows.

The east margin of the map area is a depositional edge of basalt volcanism with only scattered thin flows occurring further to the east. This depositional edge is considered to be a north-trending, west-side-down, Ordovician-Silurian syndepositional, normal fault forming the east margin of a sedimentary sub-basin infilled with volcanic rocks. Hornfelsing on the east margin of the map area indicates a large, shallowly buried, northwest extension of the mid-Cretaceous Orchay Batholith.

RÉSUMÉ

La partie nord-est de la région d'Anvil, à 15 km au nord du mont Mye (SNRC 105K/6, 105K/7), est sous-tendue par un ensemble de roches volcaniques et sédimentaires conformes d'âge Cambrien à Dévonien, dont l'épaisseur totale dépasse 1 600 m. L'unité inférieure, d'une épaisseur apparente de 120 m, consiste des phyllades calcaires de la Formation de Vangorda, d'âge Cambrien à Ordovicien. Ces phyllades sont recouvertes par une séquence conforme, de plus de 900 m d'épaisseur, de coulées de basalte sous-marines et de roches sédimentaires volcanoclastiques de la Formation de Menzie Creek, d'âge Ordovicien à Silurien. Les roches sédimentaires volcanoclastiques sont surtout des brèches grossières à blocs, de faciès proximal, avec une quantité moindre de conglomérats, de grès et de siltstones. Des shales carbonés contenant des petites quantités de siltstones, de roches calcaires, de dolomies et de quartzites du Groupe de Road River (plus de 450 m), d'âge Ordovicien à Dévonien, sont à la fois intercalés et susjacents aux coulées de basalte.

La bordure orientale de la région cartographiée constitue une limite dépositionnelle du volcanisme basaltique et il n'y a que de minces coulées éparses plus à l'est. Cette limite dépositionnelle est interprétée comme étant une faille normale syndépositionnelle d'âge Ordovicien à Silurien, orientée vers le nord, et dont le bloc ouest s'est affaissé. Cette faille définie la limite orientale d'un sous-bassin sédimentaire rempli de roches volcaniques. Des indices de métamorphisme de contact à la bordure orientale de la région cartographiée indiquent la présence, à faible profondeur, d'une extension volumineuse du batholite d'Orchay, d'âge Crétacé moyen.

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INTRODUCTION

The Anvil District (Figs. 1, 2), in central Yukon, contains the only lead-zinc mines developed in the Selwyn Basin, a major lead-zinc provenance in western Canada. The District contains five known pyritic massive sulphide deposits with a total pre-mining mineral inventory of 120.1 million tonnes averaging 9.3% combined lead and zinc (Jennings and Jilson, 1986). Exploration potential for additional massive sulphide deposits within Anvil District remains high.

The Yukon Geology Program initiated an integrated multi-disciplinary geoscience study in 1998 to provide a unified geology framework for the area to assist future exploration. Projects within this integrated study included bedrock geology mapping and compilation (Pigage, 1999a, b, c, d, this report), surficial geology mapping and basal till sampling (Bond, 1999a, b, c, d, e, f; Lipovsky and Bond, 1999), and detailed lithogeochemistry of the immediate host rocks to the massive sulphide deposits. The goal of the bedrock mapping and geological compilation project within the District is to harmonize the property geology mapping completed by exploration companies with the regional geology mapping completed by the Geological Survey of Canada. Bedrock geology will be presented on a series of 1:25 000 scale maps.

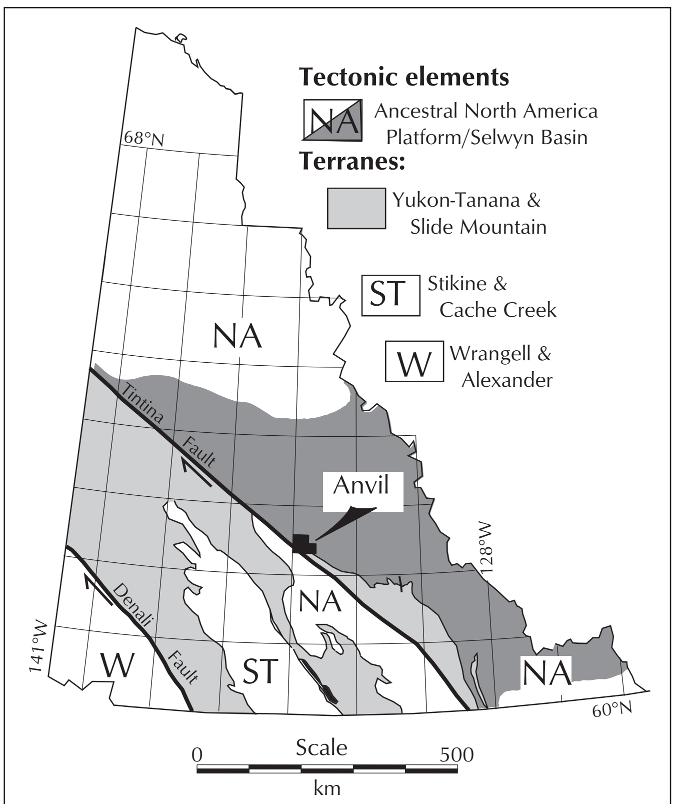

Figure 1. *Location of Anvil District in Yukon. Terrane assemblages modified from Wheeler and McFeely (1987).*

Three weeks of bedrock geology mapping was completed (Fig. 2) during the 1998 and 1999 field seasons in the northeast Anvil area, north of the Anvil Batholith. This report summarizes the bedrock geology encountered in the map area. All descriptions are based on hand sample and outcrop descriptions. Petrographic work is ongoing.

LOCATION AND ACCESS

Anvil District is located immediately northeast of the town of Faro, which is situated in Tintina Trench, a major northwest-trending physiographic feature. The northeast Anvil map area is situated 30 km northeast of the town of Faro and 15 km north of Mount Mye in NTS map sheets 105K/6 and 105K/7. Elevations in the area range from 4300 feet above sea level (a.s.l.) (1310 m) to 6600 feet a.s.l. (2010 m). Tree line occurs at the approximate elevation of 4500 feet a.s.l. (1370 m). Much of the area is above tree line, with broad, open U-shaped, grass-covered valleys separating steep ridges. Outcrop is extensive on ridge crests, especially on north-facing slopes. Within the broad valleys, outcrop is generally restricted to stream cuts. Valley bottoms are typically covered with thin to thick glacial till and glacial outwash sediments.

Partly overgrown exploration roads passable by ATV vehicles provide limited access to the southwest edge of the northeast Anvil area. These roads head north from the Faro mine road near the freshwater reservoir. Access to the area is most readily accomplished by helicopter. During 1998 and 1999, camps were placed using contract helicopter services based in Ross River.

PREVIOUS WORK

Regional geology for Tay River map area (105K) was completed at 1:253 440 scale by Roddick and Green (1961), and at 1:250 000 scale by Gordey and Irwin (1987). Tempelman-Kluit (1972) and Gordey (1990a, b) completed more detailed geology studies at scales of 1:125 000 and 1:50 000, respectively, in response to the interest generated by the discovery of the massive sulphide deposits in the Anvil District.

Exploration efforts in the northeast Anvil area were centred over the metasedimentary and metavolcanic rocks on the northeast flank of the Anvil Batholith (Fig. 2). Most exploration activity in the area occurred from the mid-1960s through the late-1970s. Jennings and Jilson (1986) provide an exploration overview of the geology in relation to the Anvil massive sulphide deposits. The only mineralized showing encountered to date is the KD prospect located just west of the northeast Anvil area. The KD prospect (Yukon Minfile, 1997, 105K083) consists of semi-massive to stockwork pyritic sulphide mineralization within metavolcanic rocks and has been classified as volcanogenic-massive-sulphide-type mineralization.

REGIONAL GEOLOGY

Anvil District represents the most westerly offshelf facies of the Cordilleran miogeocline, a prism of sedimentary rocks of Precambrian to Jurassic age deposited along the relatively stable continental margin of western North America. Cordilleran miogeocline stratigraphy is presented in Abbott et al. (1986). More detailed discussion of the stratigraphy and structure of the Anvil District is given in Jennings and Jilson (1986).

Anvil District (Fig. 1) is immediately east of the Yukon-Tanana Terrane (Coney, et al., 1980), the easternmost of the accreted 'suspect' terranes. The Yukon-Tanana Terrane is juxtaposed against Anvil District along the Vangorda fault (Jennings and Jilson, 1986) which Mortensen and Jilson (1985) have interpreted as a transpressive suture. Deformation and metamorphism associated with accretion of the suspect terranes was initiated during the Jurassic and culminated in the Cretaceous period (Tempelman-Kluit, 1979). More recently, strike-slip faulting along the Tintina Fault zone resulted in approximately 450 km of right-lateral strike-slip displacement during Late Cretaceous-Early Tertiary time (Tempelman-Kluit, 1970).

Tempelman-Kluit (1972) mapped a sedimentary and volcanic sequence ranging in age from Cambrian through Permian in the northeast Anvil area. A prominent basaltic volcanic package in the area was correlated with Permian (?) Anvil Range Group basalts on Rose Mountain. These volcanic rocks were considered to unconformably overlie all Cambrian through Mississippian metasedimentary rocks in the area.

More recently, Gordey (1983) showed that the basaltic volcanic rocks in the northeast Anvil map area were Cambro-Ordovician in age and could not be correlated with the Rose Mountain Anvil Range Group basalts. The northeast Anvil volcanic rocks were described further and informally named the Menzie Creek formation by Jennings and Jilson (1986).

Gordey (1983) interpreted the Menzie Creek formation in the northeast Anvil area as occurring in the hanging wall of a major subhorizontal thrust fault which separated it from the metasedimentary rocks. This fault was termed the Faro thrust and was considered to have a northeast-directed overlap of 9 km and a minimum strike-length of 18 km. Jennings and Jilson (1986) suggested that this fault might be a large gravity slide caused by uplift related to the intrusion of the mid-Cretaceous Anvil Batholith.

Detailed 1:25 000 scale geological mapping in the northeast Anvil area during 1998 and 1999 suggests that the Menzie Creek formation is part of a conformable sequence of stratigraphic units, and the Faro thrust represents intercalated volcanic and sedimentary rocks near a depositional margin to Menzie Creek volcanism.

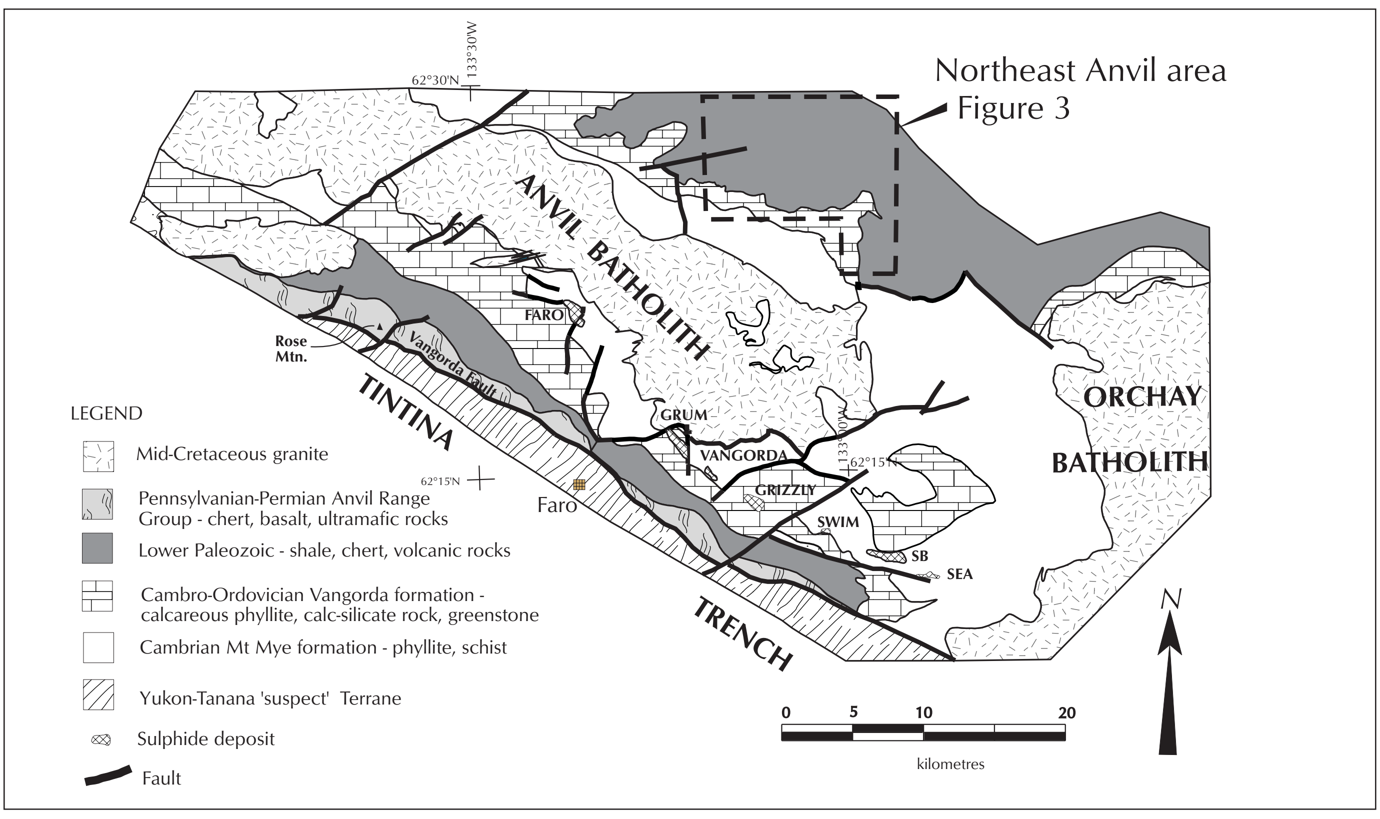

Figure 2. *Schematic geology of Anvil District, Yukon, showing the northeast Anvil map area (Fig. 3). Modified from Jennings and Jilson (1986).*

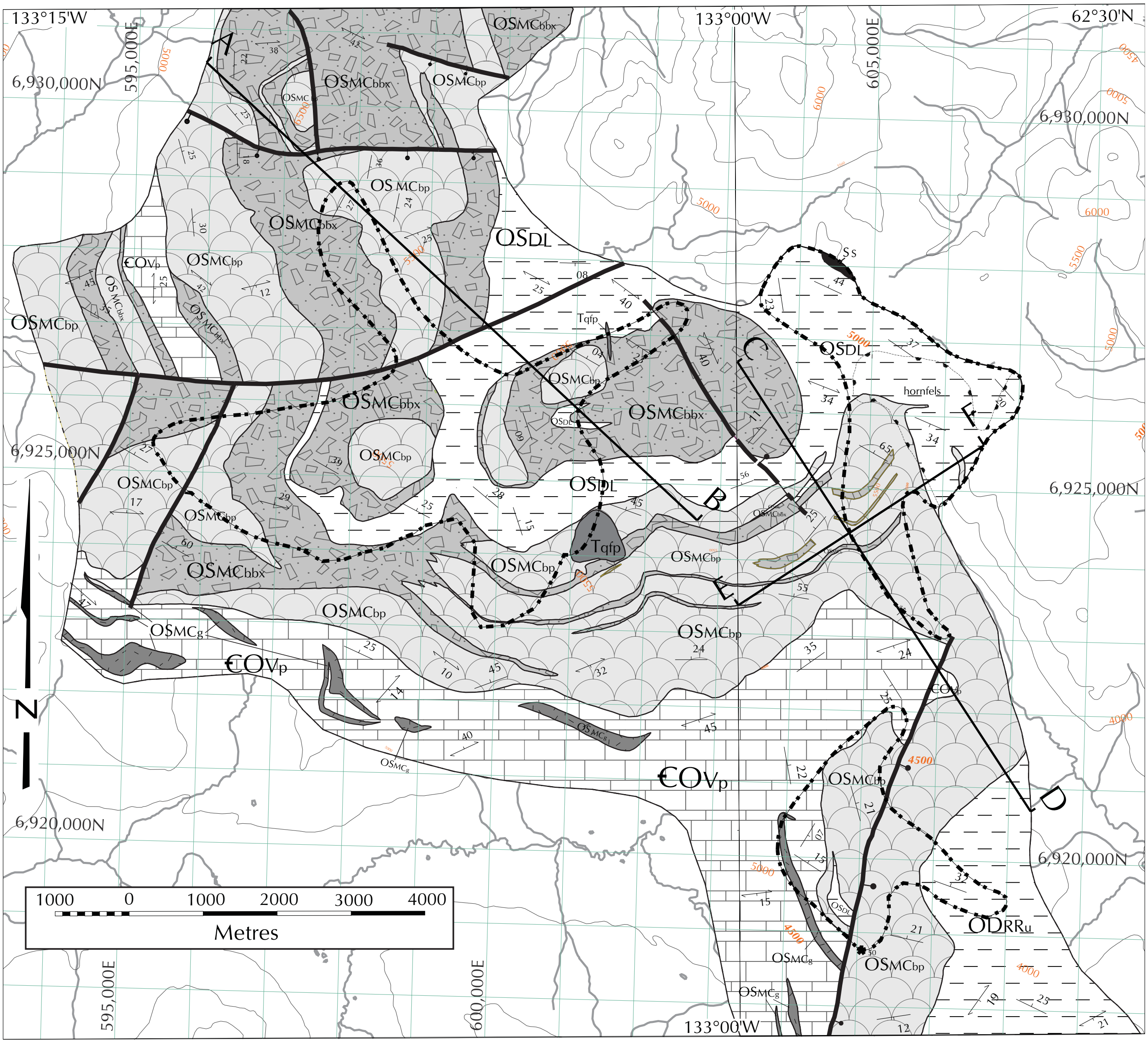

Figure 3. *Geology of northeast Anvil map area. Legend on next page.*

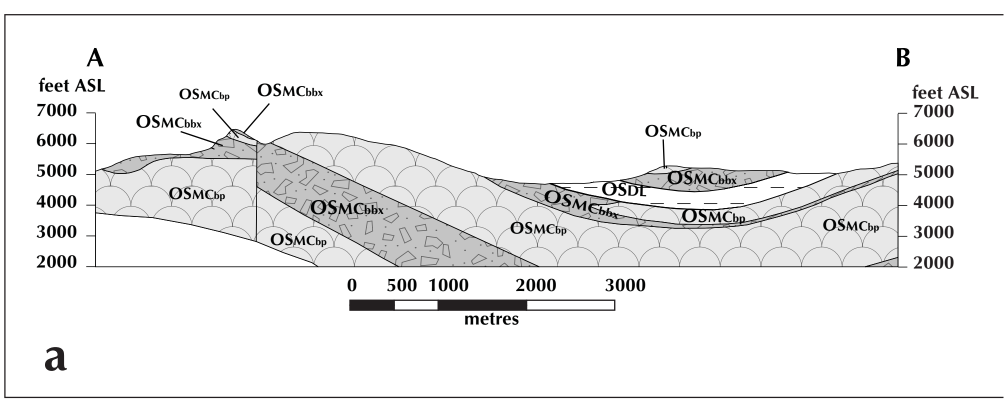

Figure 4. *Vertical cross-sections for Figure 3. Legend in Figure 3.*

ROCK UNITS

TERTIARY

Tqfp — White-weathering, aphanitic to fine-grained, flow-banded, rhyolitic quartz-feldspar porphyry.

ORDOVICIAN-DEVONIAN

UNDIVIDED ROAD RIVER GROUP

ODRRu — Dark grey to black argillite, with thin beds of medium to pale grey siltstone and fine sandstone, medium grey limestone, and basalt flows. Upper part of unit locally contains Devonian macrofossils. Includes Duo Lake Formation (OSDL) and unnamed Devonian sedimentary rocks. Steel Formation is not present.

ORDOVICIAN-SILURIAN

ROAD RIVER GROUP

STEEL FORMATION

SS — Tan- to orange-weathering, dolomitic, bioturbated, silty mudstone.

DUO LAKE FORMATION

OSDL — Dark grey to black, graptolitic argillite. Contains thin beds of medium to pale grey siltstone and fine sandstone, medium grey limestone, and basalt flows.

MENZIE CREEK FORMATION

OSMCb — Dark grey-green basalt. Undivided. Includes massive and pillowed flows, monolithic breccias, and volcaniclastic sandstones and siltstones. Interbedded with undivided Road River Group (ODRRu), Duo Lake Formation (OSDL), and Vangorda formation (COVp).

OSMCbp — Dark grey-green basalt. Includes massive and pillowed flows with minor monolithic breccias and volcaniclastic interbeds. Basalt flows locally contain white calcite amygdules. Interbedded with undivided Road River Group (ODRRu), Duo Lake Formation (OSDL), and Vangorda formation (COVp).

OSMCbbx — Dark grey-green basalt breccia. Monolithic breccias with lesser volcaniclastics and sandstone, siltstone and tuff interbeds. Minor massive and pillowed flows. Interbedded with undivided Road River Group (ODRRu), Duo Lake Formation (OSDL), and Vangorda formation (COVp).

OSMCg — Dark green, massive to foliated gabbro. Ranges from coarse-grained to fine-grained. Locally magnetic. Forms subvolcanic dykes and sills to Menzie Creek basalts.

CAMBRIAN-ORDOVICIAN

VANGORDA FORMATION

€OVp — Soft, silvery grey, calcareous phyllite with bands of medium crystalline grey marble, dark grey to black phyllite, and dark green gabbro sills and dykes (OSMCg). Greenschist facies equivalent of calc-silicate (COVcs). Regionally correlated with Rabbitkettle Formation.

€OVcs — Pale green and dark purplish brown, thinly banded calc-silicate rock with lesser bands of marble, black schist, and dark green gabbro sills and dykes. Amphibolite facies equivalent of calcareous phyllite (COVp). Regionally correlated with Rabbitkettle Formation.

SYMBOLS

Geological contact..

Faults..

Normal fault (dot on downthrown side)........

Metamorphic boundary (symbol on higher grade side)..... hornfels

Line of cross-section... A B

Bedding... 15

S_1 slaty cleavage.. 15

Area of detailed mapping................................

Figure 3. *continued*

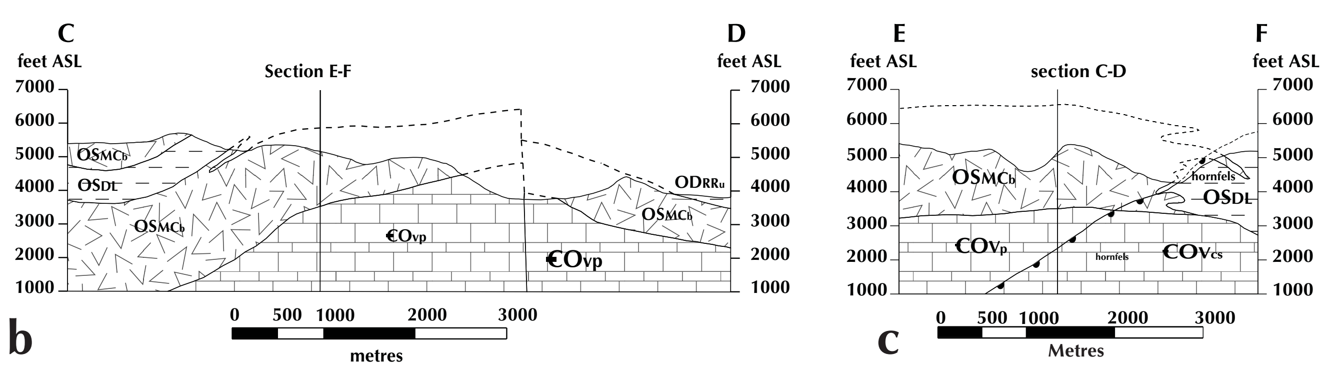

Figure 4. *continued*

NORTHEAST ANVIL GEOLOGY

INTRODUCTION

Volcanic and sedimentary units in the northeast Anvil area form a succession with a composite thickness of greater than 1600 m. Basaltic volcanic rocks of the Menzie Creek formation underlie most of the area. Fieldwork was directed towards looking at contacts between the Menzie Creek formation and underlying and overlying sedimentary units as well as documenting internal lithology variations within the Menzie Creek volcanic rocks.

Figure 3 shows the geology for the northeast Anvil area. Irregular outlines display the areas of geological mapping completed during the 1998-1999 field seasons. Geology outside the outlines is based on geological mapping completed by Jilson (1977). Figure 4a, b and c are vertical cross-section drawings interpreted from the geology map.

All units contain a single deformation foliation (S_1) consisting of a slaty cleavage. The S_1 slaty cleavage is moderately to well developed in the pelites, and poorly to moderately developed within the volcanic rocks. It most commonly dips moderately to the south and southwest, although local east to northeast dips are present. S_0 bedding and S_1 foliation intersections have a general north to northeast vergence. The entire sequence is interpreted to be structurally upright, based on rare stratigraphic top indicators and comparison to regional stratigraphy. Stratigraphic thicknesses are a minimum because of the pervasive S_1 foliation. The timing of development of the S_1 foliation is loosely constrained to be post Upper Paleozoic (Jennings and Jilson, 1986). Locally, pelitic rocks contain later deformation fabrics with weak development of a crenulation cleavage associated with small chevron-style folds. These later cleavages are rarely developed, do not give consistent orientations, and may be related to more than one period of compressive stress deformation.

The northeast Anvil area is generally within the subgreenschist facies of metamorphism. Low-pressure hornfelsing occurs along the east margin of the map area and will be discussed further.

STRATIGRAPHY

VANGORDA FORMATION (COV_P)

The Vangorda formation (Jennings and Jilson, 1986) is the lowermost unit exposed in the northeast Anvil area. Pale silvery grey, calcareous phyllite weathers recessively, forming scree slopes with abundant soft, silvery grey chips in the southeast part of the area. Cliffs commonly have a drusy, opaque white surface coating consisting of calcite. Phyllites are thinly laminated on a 1-2 mm scale with laminae being marked by dark grey striping within a light grey matrix. Discontinuous, 1-15-cm-thick beds of quartzose siltstone or fine limestone (Fig. 5) constitute 10-30% of the phyllite and are directly responsible for its calcareous nature.

Rare 1-2-m-beds of dark grey to black phyllite are present locally. A 50-m-thick bed of dark grey- to tan-weathering, finely laminated, dolomitic, siltstone occurs in the upper part of the formation. The formation also contains poorly foliated, fine- to medium-grained, dark green gabbro sills ranging up to 15 m in thickness. The medium-grained sills display a relict igneous texture consisting of white feldspar phenocrysts in a dark green chloritic matrix. They are interpreted as subvolcanic equivalents of the overlying Menzie Creek formation.

The lower contact of the Vangorda formation is not exposed in the northeast Anvil area. Mapping immediately to the southwest indicates it is conformably underlain by purplish brown-weathering, noncalcareous phyllites and schists of the Mount Mye formation (Jennings and Jilson, 1986). The upper contact with the overlying the Menzie Creek formation is conformable with local interbedding of volcanic rocks and phyllites over a 10- to 30-m interval.

Figure 5. *Thin limestone beds in phyllite, Vangorda formation. S_1 slaty cleavage is subhorizontal.*

The exposed thickness of the Vangorda formation in the map area is 120 m. The overall map pattern indicates a minimum thickness of 210 m. Jennings and Jilson (1986) suggest a possible thickness of 1000 m based on mapping in the entire Anvil District. The fine-grained nature of the phyllites and the thinly interbedded siltstones and limestones suggest deposition in relatively deep water with a regular influx of limestone and siltstone material by turbidity currents (Jennings and Jilson, 1986).

The Vangorda formation forms a widespread unit within the Anvil District. The Anvil District massive sulphide deposits straddle the lower contact of the Vangorda formation with the Mount Mye formation (Jennings and Jilson, 1986). This unit was mapped by Tempelman-Kluit (1972) as the upper member of Unit 3. Gordey (1990a, b) mapped it as the Rabbitkettle Formation (Gabrielse, et al., 1973). Jennings and Jilson (1986) correlate the Vangorda formation with the Rabbitkettle Formation but note that the Vangorda phyllites are more argillaceous than typical Rabbitkettle.

The Vangorda formation within the Anvil District is unfossiliferous. Fossils collected from the overlying the Menzie Creek formation (Tempelman-Kluit, 1972; Gordey, 1983, 1990a) in the northeast Anvil area range from Tremadoc (lower Early Ordovician) through Llandoverian (lower Early Silurian). The Rabbitkettle Formation in Nahanni map sheet 105I, 200 km east of the northeast Anvil area, ranges in age from probable Late Cambrian to late Middle Ordovician (Gordey and Anderson, 1993). The local fossils and regional correlation indicate a Late Cambrian through lower Early Ordovician age for the Vangorda formation.

MENZIE CREEK FORMATION (OSMCb)

Conformably overlying the Vangorda formation is a thick, resistant, grey-weathering basaltic volcanic unit informally named the Menzie Creek formation (Jennings and Jilson, 1986). The Menzie Creek formation forms the major unit encountered in the northeast Anvil area. Massive and pillowed, locally amygdaloidal flows are interbedded with volcaniclastic sedimentary rocks consisting dominantly of monolithic basalt breccia with lesser conglomerate, sandstone, and siltstone. These different lithologies laterally vary dramatically in thickness and amount within the map area. Minor intercalated black phyllite, bedded black chert, limestone, and dolostone occur locally throughout the unit.

Menzie Creek massive and pillowed flows form cliff outcrops consisting of black, dark brownish green, bluish green, or bluish olive-green, aphanitic to porphyritic basalt. Porphyritic varieties contain minor fine white feldspar and/or dark green mafic phenocrysts up to 5 mm across; typically the mafic phenocrysts are altered to fine, dark green chlorite. Many of the basalts are amygdaloidal, with amygdules up to 1 cm across infilled with white calcite, dark green chlorite, or white calcite rimmed by chlorite. Individual flows are not readily visible in outcrop. The

Figure 6. *Pillow basalt flow, Menzie Creek formation. Note rock hammer for scale.*

Figure 7. *Isolated pillows in chloritic matrix, pillow basalt flow, Menzie Creek formation. Note rock hammer for scale.*

S_1 slaty cleavage is poorly developed to absent within the massive and pillowed flow units.

Pillow lavas contain varying proportions of pillows, ranging from flows consisting dominantly of pillows (Fig. 6) to those with isolated pillows in a dark green chloritic matrix (Fig. 7). Pillows range up to 1.5 m across although diameters less than 0.5 m are more common. Rarely reddish chert occurs irregularly in the matrix. Commonly amygdules within the pillows are radiating and may form pipes. Pale green rinds up to 2 cm thick are locally visible on the pillow margins.

Massive and pillow basalt flows occur throughout the northeast Anvil area. Units consisting dominantly of flows range from a few metres thick to tens of metres thick. These flow units constitute the dominant lithology in the east part of the map area.

Monolithic basalt breccias (Fig. 8) consist of angular basalt fragments typically up to 50 cm across within a dark green chloritic matrix. Some fragments display pillow-margin rinds. Locally, the breccias contain a small proportion of nearly complete pillows among the clasts (Fig. 9). Breccias are generally nonstratified and do not display primary bedding. Typically the S_1 slaty cleavage is moderately to well developed within the chloritic matrix of the breccia units.

Monolithic breccias occur as rare thin beds in the east part of the map area. In the north and western parts of the area, they constitute the dominant lithology and form prominent cliff outcrops. In one locality, the breccias form an unstratified unit over 200 m thick.

Locally, basalt flows and monolithic breccia units are strongly quartz-carbonate altered with rare pale green mariposite grains in a bright orange- to tan-weathering quartz-carbonate matrix. In some instances alteration is spatially associated with late steep faults. In other locations timing of alteration relative to deformation is uncertain. On the eastern edge of the map area, hornfelsing of the Menzie Creek basalts is delineated by the

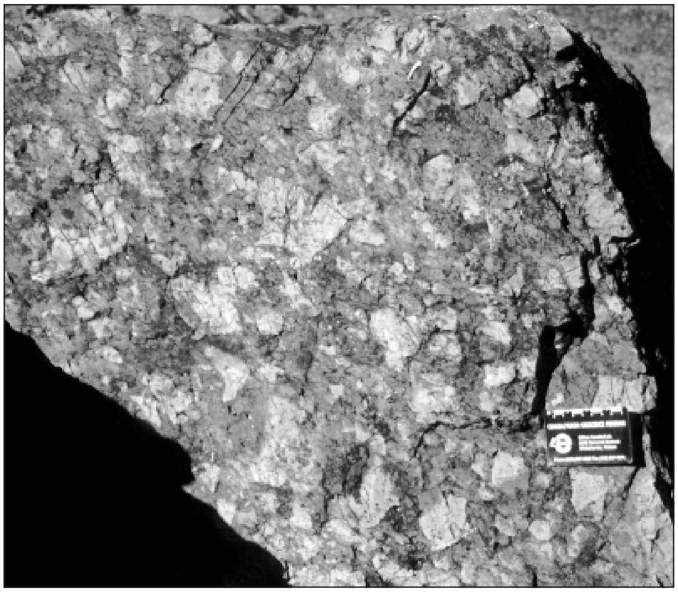

Figure 8. *Monolithic basalt breccia, Menzie Creek formation.*

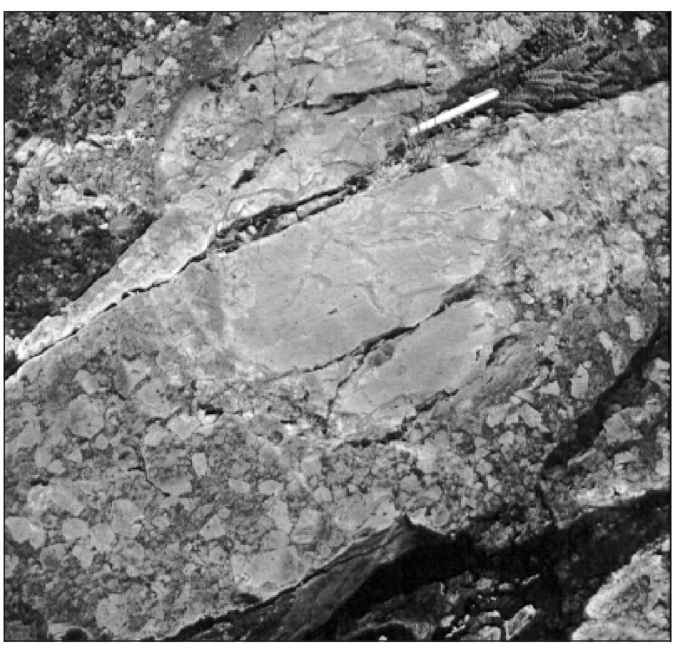

Figure 9. *Isolated pillow in monolithic basalt breccia, Menzie Creek formation. Pencil magnet in upper right corner of outcrop is 12.5 cm long.*

Figure 10. *Epiclastic volcanic sandstone bed, Menzie Creek formation.*

extensive development of fine disseminated purplish brown biotite (see Fig. 3).

Epiclastic volcanic conglomerates, sandstones, and siltstones are locally interbedded with basalt flows and monolithic breccias in minor amounts. These lithologies (Fig. 10) are generally only a few metres thick although rarely they range up to 20 m in thickness. Occasional graded beds give a stratigraphic top upright structural orientation. Coarse clasts are predominantly volcanic rock fragments. Rare dark grey to black, noncalcareous, silty phyllite, black bedded chert, pale grey limestone, and tan- to orange-weathering dolostone occur as 1-10-m beds at different stratigraphic levels within the volcanic sequence.

The Menzie Creek formation has a total thickness of approximately 900 m in the east edge of the northeast Anvil area. Aggregate thickness of the unit increases to the north and west. The lower contact with the Vangorda formation is conformable with interbedding of basalt and calcareous phyllite over a 10-30-m-interval. The upper contact with overlying carbonaceous phyllites of the undivided Road River Group in the southeast part of the map area has interbanding of basalt and phyllite over a 10-m-interval. Menzie Creek volcanic rocks are intercalated with black phyllites of the Duo Lake Formation (lower Road River Group) along the east margin of the map area. Gordey (1983) interpreted these relations as structural contacts with Menzie Creek volcanic rocks being thrust over the black phyllites along the Faro fault. In this report, the author suggests that these contacts are stratigraphically conformable, and the east side of the notheast Anvil area contains the depositional margin to Menzie Creek volcanism. These stratigraphic relations will be discussed in more detail in a separate section below.

Primary depositional textures within the flow units indicate submarine volcanism. Epiclastic volcanic sedimentary rocks and intercalated shales, limestones, and dolostones also delineate a subaqueous depositional environment. Jennings and Jilson (1986) suggested that lithologies in the upper part of the formation might be interpreted as indicating shoaling of the volcanic pile with time. The predominance of flow units on the east part of the map area indicates that submarine vent(s) for the Menzie Creek formation were preferentially located along the east margin of the northeast Anvil area.

Figure 11 displays discriminant diagrams prepared using NEWPET (Clarke, 1993) of volcanic flow and breccia units at different stratigraphic levels within the Menzie Creek formation. In all diagrams, the samples form tight clusters indicating alkali basalt compositions from a within-plate tectonic setting. Fossils from intercalated phyllites and limestones in the map area (Tempelman-Kluit, 1972; Gordey, 1983) range in age from lower Early Ordovician (Tremadoc) through early Lower Silurian (Llandoverian).

Menzie Creek volcanism therefore extends through this time interval. Basaltic volcanic rocks ranging in age from Cambrian to

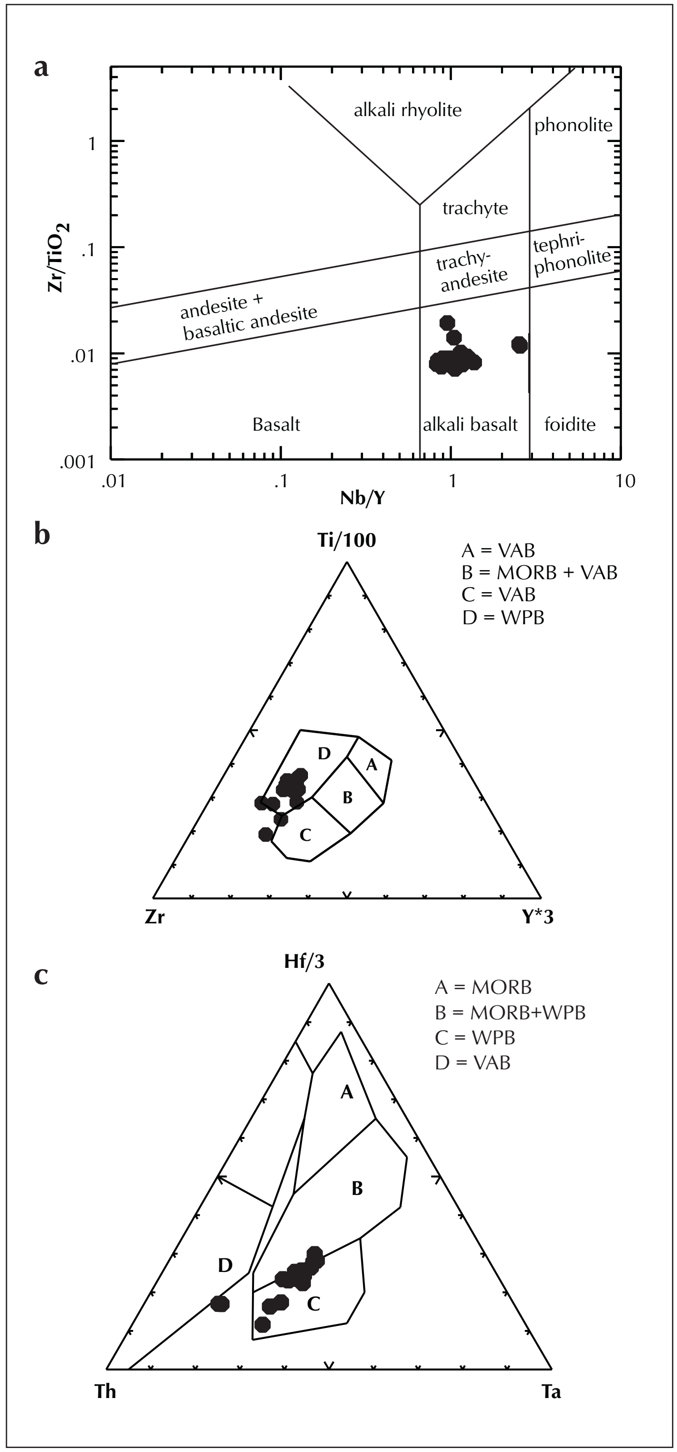

Figure 11. *Discriminant diagrams for representative basalt samples from Menzie Creek formation. a) Composition diagram using Zr/Tio$_2$ vs Nb/Y from Winchester and Floyd (1977, Fig. 6) as revised by Pearce (1996). b) Tectonic setting diagram using Ti-Zr-Y from Pearce and Cann (1973). c) Tectonic setting diagram using Hf-Th-Ta from Wood (1980, Fig. 1a); VAB=volcanic-arc basalt, MORB=mid-ocean ridge basalt, WPB=within-plate basalt.*

Middle Devonian with similar compositions and tectonic setting have been described in several localities in the northern Cordillera (Goodfellow at al., 1995). The lower Paleozoic volcanic rocks are consistent with interpretation of Selwyn Basin as a passive continental rift that underwent episodic extension and associated volcanism.

ROAD RIVER GROUP

The eastern margin of the northeast Anvil area is underlain by dark grey to black, noncalcareous phyllite, tan-weathering, bioturbated, dolomitic siltstone, and lesser massive to argillaceous limestone, and massive quartz sandstone and dolostone. The carbonaceous phyllites can be traced laterally westward into the central part of the map area where they are intercalated with Menzie Creek volcanic rocks. Regionally, these units (Gordey, 1990a, b; Jennings and Jilson, 1986) are correlated with the Road River Group (Gordey and Anderson, 1993). In the northern part of the map area, Road River Group can be subdivided into two formations, the lower Duo Lake Formation (Cecile, 1982) and the upper Steel Formation (Gordey and Anderson, 1993). In the extreme southeast part of the area, the Steel Formation is missing, and the sequence of carbonaceous siltstones and phyllites forming the undivided Road River Group includes interbedded limestones and dolostones of probable mid-Devonian age (Tempelman-Kluit, 1972). Stratigraphic descriptions of these three units are presented below.

DUO LAKE FORMATION (OSDL)

Dark grey to black, noncalcareous, siliceous phyllite to siltstone of the Duo Lake Formation (Cecile, 1982) is the dominant lithology on the northeast margin of the map area. The phyllites weather pale grey, commonly with faint pinkish to reddish hues. The unit mostly forms rounded scree slopes of medium grey phyllite chips which often display a strong pencil rodding resulting from intersection of S_0 bedding with the S_1 slightly irregular slaty cleavage. In the central part of the map area, the phyllites are interbedded with volcanic rocks of the Menzie Creek formation.

On the east margin of the northeast Anvil area, the dark phyllites are intercalated with lesser amounts of coarsely recrystallized, medium grey to off white, massive and argillaceous limestone, black bedded chert, and medium grey, noncalcareous, finely laminated, pinstriped siltstone. These lithologies locally are up to 6 m thick. A massive, grey to white quartz sandstone bed up to 15 m thick containing lenses of grey- to tan-weathering dolostone occurs within the carbonaceous phyllites in the central part of the map area. The sandstone rarely forms prominent cliffs on ridge tops; more commonly it occurs as rubble resting in phyllite chip scree.

On the east edge of the map area, outcrops of the Duo Lake Formation are strongly hornfelsed. Phyllites are strongly rust-brown weathering and moderately magnetic from fine disseminated pyrrhotite. Fresh surfaces display a purplish tinge from fine biotite. Hornfelsed pinstriped siltstones commonly have a light grey to off white bleached appearance.

The Duo Lake Formation on the east edge of the area has a thickness of at least 700 m. The tongue of Duo Lake phyllites extending toward the west is about 300 m thick. Fossils from the tongue of black phyllite intercalated with the Menzie Creek volcanic rocks in the central part of the map area delineate an age range from Arenigian (upper Early Ordovician) to Llandoverian (lower Early Silurian; Tempelman-Kluit, 1972; Gordey, 1983). The massive quartz sandstone mapped in this immediate area occurs in close proximity to the fossil localities and would have the same approximate age. The Duo Lake Formation in the type area (Misty Creek Embayment) has an age range from earliest Early Ordovician to late Early Silurian (Cecile, 1982). Both upper and lower contacts in the type area are diachronous. In the Nahanni area, the Duo Lake Formation ranges in age from Arenigian (Early Ordovician) to mid-Wenlockian (early Late Silurian; Gordey and Anderson, 1993).

STEEL FORMATION (SS)

In the extreme northeast part of the map area, black phyllites, cherts, and pinstriped siltstones of the Duo Lake Formation are conformably overlain by massive, tan-weathering, pale grey, slightly dolomitic, bioturbated siltstones of the Steel Formation (Gordey and Anderson, 1993). In the map area, the Steel Formation siltstones consist of rubble of large angular blocks on a broad plateau. The upper contact of the unit occurs to the east and northeast of the map area. Mapping by Gordey (1990b) indicates the Steel Formation in this immediate area is less than 30 m thick.

The age of the Steel Formation in the type area (Gordey and Anderson, 1993) is poorly constrained to be of definite Ludlovian (mid-Late Silurian) age, but may range from late Wenlockian (Mid-Silurian) to Earliest Devonian. The unit has poor fossil control in the northeast Anvil area; it is younger than the underlying the Duo Lake Formation.

UNDIVIDED ROAD RIVER GROUP (ODRRu)

Undivided Road River Group overlying the Menzie Creek formation is mapped in the extreme southeast part of the northeast Anvil area. The dominant lithologies are carbonaceous silty phyllites identical to the phyllites described above for the Duo Lake Formation. The Steel Formation is not present in this area. The carbonaceous phyllites contain intercalated tan-weathering grey dolostone, white-weathering quartz sandstone, and light grey to white limestone units which are lithologically identical to the massive quartz sandstone, dolostone, and limestone beds described for the Duo Lake Formation.

The lower contact of the undivided Road River Group with the Menzie Creek formation appears conformable with interbanding of phyllite and basalt over a 5-m-thickness. The upper contact has been eroded and is therefore not exposed. A minimum thickness of 460 m is indicated from map patterns. A dolostone-quartzite unit within the carbonaceous phyllites immediately southeast of the map area contains macrofossils with a probable late Middle Devonian age (Tempelman-Kluit, 1972). This unit therefore has an upper age, which is younger than the Duo Lake and Steel formations.

Carbonaceous phyllites and cherts of the undivided Road River Group and Duo Lake Formation were deposited in a quiet, euxinic marine basin. Presence of burrowing organisms in the Steel Formation indicates the marine basin was oxygenated during the Steel Formation deposition.

INTRUSIVE ROCKS

RHYOLITIC QUARTZ-FELDSPAR PORPHYRY (Tqfp)

The east central part of the northeast Anvil area contains a crudely circular intrusive plug of aphanitic, quartz-feldspar porphyry with an approximate diameter of 700 m. Further north, thin, vertical, north-trending dykes of the same intrusive unit are present. Fresh surfaces are dark reddish purple, and weathered surfaces are pale grey. The porphyry contains scattered 1-2 mm phenocrysts of white feldspar, grey quartz, and magnetite. Delicate mm-scale flow banding within the intrusive plug is crudely parallel to the marginal contact. The intrusive weathers as coarse, blocky rubble. The porphyry has been dated using whole rock K-Ar with an intrusive cooling age of 54.3 ± 1.2 Ma (Hunt and Roddick, 1991).

STRUCTURE

The Menzie Creek formation consists dominantly of volcanic flow units in which it is extremely difficult to determine S_0 bedding. The Duo Lake Formation is recessive weathering and does not form outcrops with readily visible bedding. Mapping during the 1998-1999 field seasons was partly directed towards trying to determine S_0 bedding for the different units.

Figure 3 shows field S_0 bedding measurements within the Menzie Creek formation and the Duo Lake Formation. S_0 bedding overall dips moderately northwest in the eastern part of the area, and east or northeast in the western part of the area. In all cases the lower Menzie Creek formation dips uniformly beneath the mapped westward extending tongue of the Duo Lake Formation phyllite. Map patterns and S_0 bedding measurements define a broadly warped structural basin with the core of the basin being located northeast of the map area. Age ranges from fossil localities are consistent with the Menzie Creek formation and the Duo Lake Formation forming a conformable sequence with younger fossils being structurally higher than older fossils.

MENZIE CREEK–DUO LAKE STRATIGRAPHIC RELATIONS/GROWTH FAULT

The central portion of the northeast Anvil area contains a 300-m-thick tongue of the Duo Lake Formation intercalated within the Menzie Creek formation. Immediately east of the map area, the Menzie Creek formation is absent (Gordey, 1990b). A north-northwest-trending stream valley at the east edge of the map area (Fig. 3) contains detailed stratigraphic relations between basalt and carbonaceous phyllite which have a bearing on interpretation of the Duo Lake-Menzie Creek stratigraphic relations in this area.

Outcrops on the ridge west of the valley define a 300-m-thick section of Menzie Creek volcanic rocks with S_0 bedding dipping shallowly to moderately northwest. Outcrop and subcrop at higher elevations consist dominantly of massive and pillow basalt flows with only minor interbedded volcaniclastic sedimentary rocks. Outcrops near the valley bottom consist of massive and pillow basalt flows with black phyllite and chert constituting roughly 20-30% of the exposures.

In contrast, the ridge on the east side of the stream valley consists dominantly of Duo Lake phyllites, cherts, and siltstones, defining a 275-m-thick section. The phyllites contain at least three thin beds of massive to pillowed Menzie Creek basalt typically ranging up to 10 m in thickness. The basalt beds have carbonaceous shales both overlying and underlying them. Figure 12 illustrates the basal contact of one of the basalt horizons; the contact is not sheared and the S_1 slaty cleavage passes from the phyllite to the basalt with only slight refraction. These structural and stratigraphic relations strongly suggest the contact between the Menzie Creek basalts and the Duo Lake phyllites is conformable.

Basalt units on both the east and west sides of the valley were sampled for lithogeochemistry. All analyses from this area plotted as part of the cluster of the Menzie Creek formation compositions illustrated in Figure 11. The thin basalt flows on the east side of the valley are definitely part of the same eruptive sequence as the thick volcanic pile further to the west.

These different observations indicate that this stream valley marks an east depositional margin to a thick Menzie Creek volcanic succession. Figure 4c is an east-west cross-section illustrating this interpretation. The Menzie Creek formation is laterally equivalent to the Duo Lake Formation with only thin tongues of Menzie Creek volcanic rocks extending east across the present stream valley. Similarly the Duo Lake phyllite within the Menzie Creek volcanic rocks in the central part of the northeast Anvil area represents a conformable depositional tongue of shale extending westward into the volcanic succession. This east Menzie Creek depositional margin also coincides with the predominance of Menzie Creek flow lithologies as opposed to epiclastic volcanic sedimentary rocks in the northeast Anvil area.

A reasonable paleogeography during Ordovician-Silurian time to explain the described stratigraphic variations would be a north-trending, syndepositional, west-side-down, normal fault along the east depositional edge of Menzie Creek volcanism. This syndepositional fault would correspond to the eastern limit of a depositional sub-basin containing the thick Menzie Creek volcanic pile and would provide a conduit for eruption of the Menzie Creek basalts. Similar syndepositional faults within Selwyn Basin during Devonian time have been verified through detailed geologic mapping (Abbott, 1982; Turner and Rhodes, 1990).

Figure 12. *Carbonaceous shale conformably overlain by pillow basalt.* S_0 *bedding dips gently to the left.* S_1 *slaty cleavage dips about 45 degrees to the left. Note rock hammer for scale.*

Gordey (1990a, b) documented a dramatic westward thickening of the Steel Formation from less than 30 m to greater than 900 m about 5 km north of the northeast Anvil area, in the northwest corner of map sheet NTS 105K/7 and the southeast corner of map sheet NTS 105K/10. This thickening is on trend with the interpreted Ordovician-Silurian growth fault and is consistent with a west-side-down active growth fault at the sea floor in early Silurian time.

METAMORPHISM – HORNFELSING

Biotite-bearing, hornfelsed phyllites of the Duo Lake Formation and basalts of the Menzie Creek formation outcrop along the east margin of the northeast Anvil area. Intrusive rocks do not outcrop in the immediate area of the hornfelsed units.

Gordey (1990a, b) has mapped a regionally extensive Cambro-Ordovician unit (CO_t) consisting dominantly of resistant, dark grey-weathering, massive to laminated, blocky, white to light grey, quartzose siltstone and chert extending southeast from the northeast Anvil area to the margins of the mid-Cretaceous Orchay Batholith (see Fig. 2). He considered this unit to be older than the Duo Lake Formation and stratigraphically equivalent to the Menzie Creek and Vangorda formations. The southwest margin of this unit corresponds to the hornfelsed sedimentary rocks of the Duo Lake Formation and volcanic rocks of the Menzie Creek formation on the east margin of the northeast Anvil area. The CO_t unit, as mapped, probably demarcates the aerial extent of hornfelsing northwest of the mid-Cretaceous Orchay Batholith and indicates a large shallowly buried northwest extension to the batholith.

SUMMARY AND CONCLUSIONS

Volcanic and sedimentary units in the northeast Anvil area form a Cambrian through Devonian succession with a composite thickness of greater than 1600 m. Oldest exposures in the area are calcareous phyllites of the Cambrian-Ordovician Vangorda formation. The Vangorda formation is conformably overlain by basaltic volcanic rocks of the Menzie Creek formation. Menzie Creek volcanic rocks are intercalated with and overlain by carbonaceous phyllites of the Road River Group. Basalts of the Menzie Creek formation underlie most of the map area.

Contact relations between the Menzie Creek formation and Road River Group are not readily visible because of the recessive nature of the Road River phyllites. Gordey (1983) suggested that the Menzie Creek formation consistently structurally overlies the Road River with the contact between them being a major subhorizontal thrust fault, which he called the Faro fault. Detailed mapping in northeast Anvil area during the 1998 and 1999 field seasons indicates that S_0 bedding in the Menzie Creek formation and the intercalated Road River Group has a consistent uniform orientation with contacts between basalt and phyllite being conformable stratigraphic contacts within a homoclinal interbedded sequence.

The east margin of the map area is a depositional edge of Menzie Creek basalt volcanism with only scattered thin flows occurring further to the east. This depositional edge is considered to be a north-trending, Ordovician-Silurian, west-side-down, syndepositional growth fault forming the east margin of a depositional sub-basin. The sub-basin is infilled with a thick sequence of Ordovician-Silurian alkali basalt flows and epiclastic volcanic sedimentary rocks with lesser intercalated carbonaceous shales.

Hornfelsing on the east margin of the northeast Anvil area delineates the aerial extent of a large, shallowly buried northwest extension of the mid-Cretaceous Orchay Batholith.

ACKNOWLEDGEMENTS

Jason Adams and Dylan MacGregor provided assistance in the field during the 1998 and 1999 seasons, respectively. Gregg Jilson kindly made available unpublished geology maps encompassing the northeast Anvil area. He also provided an interested audience for geology discussions pertaining to the area. This paper was reviewed by Diane Emond.

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Wolf Lake project: Revision mapping of Dorsey Terrane assemblages in the upper Swift River area, southern Yukon and northern B.C.[1]

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ABSTRACT

The northern half of the Jennings River (104O) and southern half of the Wolf Lake (105B) map areas include polydeformed and metamorphosed rocks of the eastern Big Salmon Complex (Yukon-Tanana Terrane) and a succession of mostly Paleozoic rock assemblages currently grouped in Dorsey Terrane.

On the northeast side of Dorsey Terrane, siliceous grits and mafic metavolcanic rocks of the Dorsey assemblage are thrust over the Ram Creek assemblage. Dorsey assemblage is in turn structurally overlain by thin mafic volcanic rocks and limestone (Klinkit (?) assemblage), and by dark phyllitic rocks and quartzites of the Swift River assemblage.

Extensive stratabound pyrrhotite-sphalerite mineralization occurs along a 6.5 km structural trend in calc-silicate rocks and rhyolite of the Ram Creek assemblage. Similar mineralization also occurs several kilometres southwest of that trend, within or adjacent to the Dorsey assemblage. Both assemblages contain quartz +/- feldspar -phyric layers with potential for volcanogenic massive sulphide showings.

RÉSUMÉ

La moitié nord de la région cartographique de Jennings River (SNRC 104-O) et la moitiée sud de celle de Wolf Lake (SNRC 105-B) sont sous-tendues par les roches métamorphiques de tectonisme polyphasé de la partie orientale du Complexe de Big Salmon (Terrane de Yukon-Tanana) ansi que par une succession de roches principalement Paléozöiques présentement attribuées au Terrane de Dorsey.

Au nord-est du Terrane de Dorsey, les roches siliceuses à granules et des roches métavolcaniques mafiques rapportées à l'assemblage de Dorsey chevauchent l'assemblage de Ram Creek. L'Assemblage de Dorsey est à son tour superposé tectoniquement par une mince succession de roches volcaniques mafiques et de calcaires (assemblages de Klinkit (?)), ainsi que par des lithologies phylliteuses sombres et des quartzites (assemblage de Swift River).

Les roches calco-silicatées et les rhyolites de l'assemblage de Ram Creek renferment de nombreux indices stratiformes minéralisés en phyrrotine et sphalérite. La minéralisation est répartie sur une distance de 6,5 km le long d'un axe tectonique. À quelques kilomètres au sud-ouest de cet axe, le mème type de minéralisation est retrouvé en bordure et dans l'assemblage de Dorsey. Les assemblages de Dorsey et Ram Creek renferment plusiers horizons siliceux à phénocristaux de quartz ± feldspath, ce qui suggère un potentiel pour la présence de sulfures massifs volcanogènes.

[1]*Contribution to the Ancient Pacific Margin NATMAP project. Geological Survey of Canada Contribution 199212.*

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INTRODUCTION

The region east of Teslin Lake to the continental divide (Fig. 1) includes poly-deformed, medium- to high-grade metamorphic rocks which range from older than Devonian to Triassic in age. The western third comprises the Big Salmon Complex which has similar lithostratigraphy to Yukon-Tanana Terrane; the eastern two thirds has been referred to as Dorsey Terrane (this term may become obsolete as the component rock units are attributed to other, better established, terranes). The study area is bounded to the east and northeast by the Cassiar Platform and intruded by Early Cretaceous Cassiar batholith. Revision mapping of the Swift River area by the Geological Survey of Canada (GSC) began in 1999, in concert with on-going projects of the British Columbia Geological Survey (BCGS; Nelson et al., 1998; Mihalynuk et al., 2000).

This work is part of the central component of the Ancient Pacific Margin NATMAP, a Cordillera-length forum for understanding the tectonic evolution, paleogeography and metallogeny of rock units that form the late Paleozoic and early Mesozoic western margin of ancestral North America. In addition to accelerated mapping and metallogenic studies by the GSC, the initiative involves programs of the BCGS and the Glenlyon and Finlayson projects of the Yukon Geology Program. The rock units, sometimes known as pericratonic terranes, are structurally complex and metamorphosed because they have taken the brunt of deformation and high-pressure metamorphism during collision of North America with arcs, oceanic crust and outboard terranes. The long-term NATMAP objective in the Swift River area is to produce a revised map covering northern Jennings River, B.C. (104O) and southern Wolf Lake, Yukon (105B) at 1:250 000 scale, in addition to open-file maps at 1:50 000 scale of selected areas.

Existing bedrock maps date from reconnaissance fieldwork in the fifties and early sixties (Mulligan, 1963; Poole et al., 1960; Aitken, 1959; and Gabrielse, 1969); these authors defined the major lithologic units with limited paleontological and geochronological control. Discovery of carbonate-hosted zinc-lead deposits (e.g., Midway, now called Silvertip) and intrusive-related tin tungsten and gold deposits (e.g., Logtung) led to mineral exploration booms and subsequent geological mapping (e.g., Abbott, 1981; Lowey and Lowey, 1986; Murphy, 1986; Nelson and Bradford, 1993), but the regional coverage has not been updated to reflect these advances. During a synthesis of tectonic assemblages of the Canadian Cordillera, the name ‘Dorsey Terrane’ was given to rocks that lay outboard of the Cassiar Platform but did not resemble the Yukon-Tanana or Slide Mountain terranes (Monger et al., 1991). Field mapping aimed at defining the Dorsey Terrane established a framework of five assemblages, Hazel, Ram Creek, Dorsey, Swift River and Klinkit, each with distinctive lithologic and structural characteristics (Harms and Stevens, 1996; Fig. 2).

In 1999, a joint BCGS-GSC one-month camp was established on Morley Lake with a shared contract helicopter to assist continued fieldwork in the Big Salmon Complex (Mihalynuk et al., 1998, in press) and southeast Dorsey Terrane (Nelson et al., 1998, this volume), as well as to permit traverses across key geological exposures of the above-mentioned assemblages in southern Yukon. Mapping in 1999 showed that Hazel Ridge, a broad upland east of Morley Lake, is a direct continuation of the Big Salmon Complex (Roots et al., 2000), hence the term ‘Hazel assemblage’ should be retired. The remainder of this paper describes exposures in the Swift River headwaters area which are among the most accessible in Dorsey Terrane. The authors focus upon the relationships between the component assemblages, and intend to date these rocks and perform provenance studies, which will likely modify their interpretation.

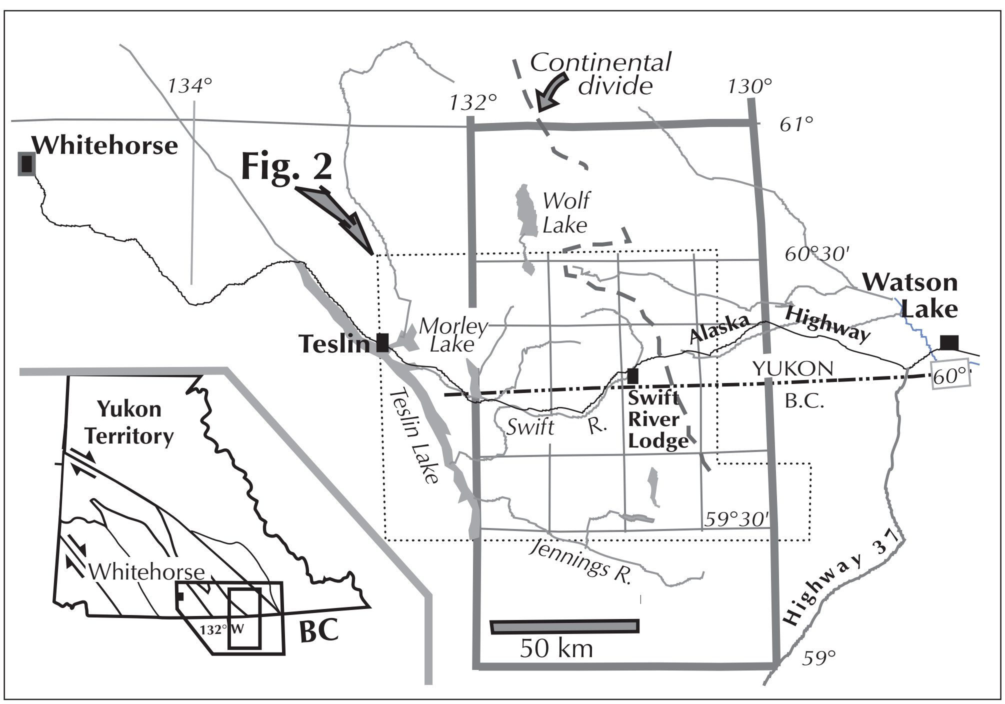

Figure 1. Wolf Lake and Jennings River map areas (thick outline) straddle the BC-Yukon border. Thin lines delineate the 1:50 000-scale map areas.

GEOLOGY OF THE UPPER SWIFT RIVER AREA

Four-wheel drive exploration roads and bulldozer trails extend about 30 km northwest from the Pine Lake airstrip near the continental divide, and require fording the river about 10 km from the Alaska Highway. The Bar mineral occurrence (generally known as the Dan showing; Yukon Minfile, 1997, 105B 027) is located below treeline (Fig. 3) and is owned by First Yukon Silver Resources. The showing includes a 200-m-long trenched and washed exposure with abundant stratabound sphalerite, magnetite-pyrrhotite and galena known locally as 'the Window.' Mineralization is discontinuously exposed along structural grain to the northwest for 6.5 km, principally at the Lucy, Gossan and Crescent (Yukon Minfile, 1997, 105B 026) showings. The area was under option to Cominco in 1993 (Indian and Northern Affairs Canada, 1994, p. 4) and Birch Mountain Resources in 1997 (Burke, 1999). Numerous assessment and other reports describe the geology;

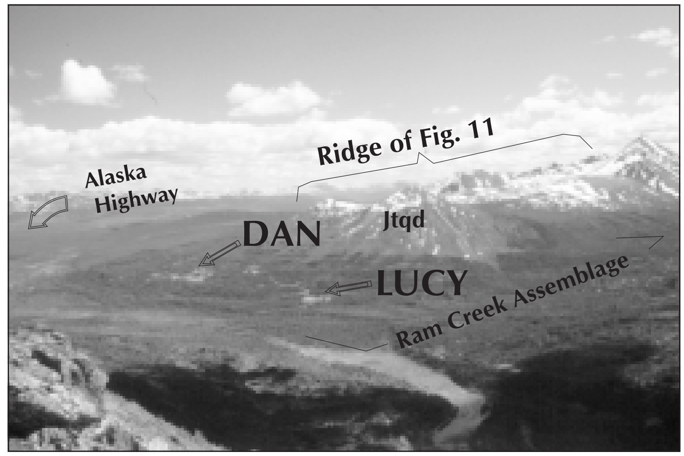

Figure 3. *View southeast of upper Swift River valley, showing some mineral occurrences and units mentioned in text.*

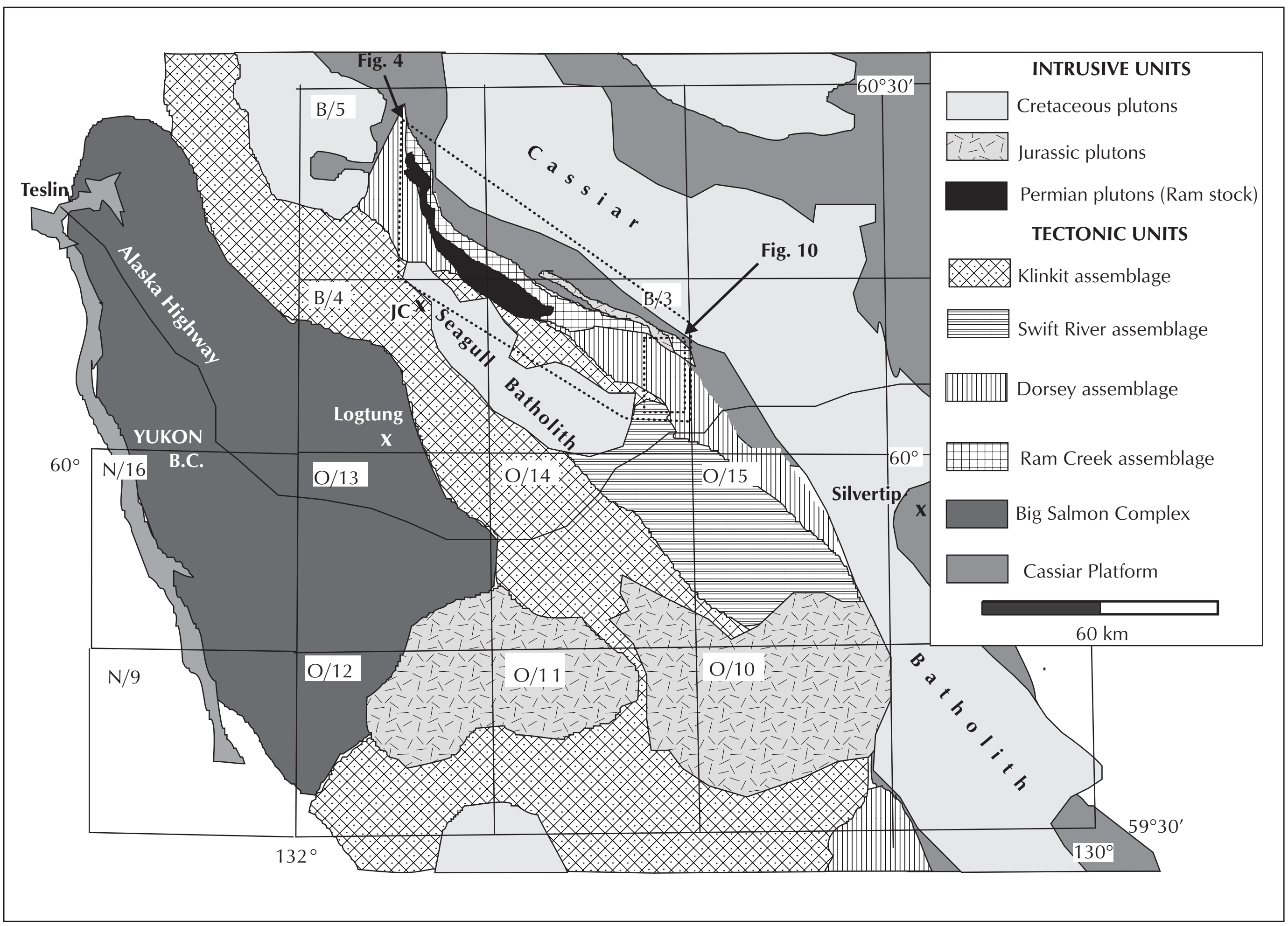

Figure 2. *Tectonic units of southern Yukon and northern British Columbia, modified from Nelson et al. (1998) and unpublished data.*

this work is summarized in Indian and Northern Affairs Canada, (1981, p. 144; 1993, p. 2) and by Bremner and Liverton (1991, a, b). These showings will likely be the focus of a metallogenic study by Suzanne Paradis (Mineral Deposits Division, GSC) and detailed structure by Luis José Homen D'el-Rey Silva (Instituto de Geosciencias, Universidade de Brasilia, Brasil) under the aegis of the Ancient Pacific Margins NATMAP.

The above-mentioned showings lie within a mixed lithologic package called the Ram Creek assemblage. This narrow belt trends 45 km in a northwesterly direction between the Cassiar Platform to the northeast, and the Dorsey assemblage to the southwest (Fig. 4).

RAM CREEK ASSEMBLAGE

This assemblage comprises mafic to intermediate metavolcanic rocks with discontinuous bodies of quartzite, marble and meta-plutonic rocks (Harms and Stevens, 1996). We observed these rocks in the vicinity of the Dan showing, and south of Ram Creek at the northwest end of the belt. At the former, bulldozer scraping and trenching have exposed predominantly calc-silicate rock with interfolded metavolcanic and marble layers (Fig. 5). The calc-silicate unit comprises metamorphosed clastic and volcanic sediments, chloritic schist and amphibolite. Visible minerals include diopside, plagioclase, garnet and calcite; in places pyroxene and garnet are replaced by actinolite and chlorite. The retrograde metamorphic assemblage is spatially associated with the massive sphalerite and pyrrhotite-magnetite (Bremner and Liverton, 1990b).

The calc-silicate unit includes meta-rhyolite, a greenish, finely banded rock with visible quartz and rare plagioclase phenocrysts (Fig. 6). Intense shearing and stretching has obliterated most primary structures. In pockets, however, evidence of igneous origin remains and includes beta-quartz phenocryst morphology and rare primary flow textures. The millimetre scale layering which can be traced several tens of metres at the Window is the product of very localized strain.

The origin of the mineralization is debatable. The stratabound nature of mineralization and presence of rhyolite imply nearby volcanism. The mineralogy is clearly that of a hydrothermal skarn deposit, and it postdates metamorphic layering. It has been argued that the sulphides have been remobilized from a pre-existing syngenetic deposit, but the coincidence that mineralization is concentrated within the superimposed thermal aureoles of three plutonic bodies, is unlikely.

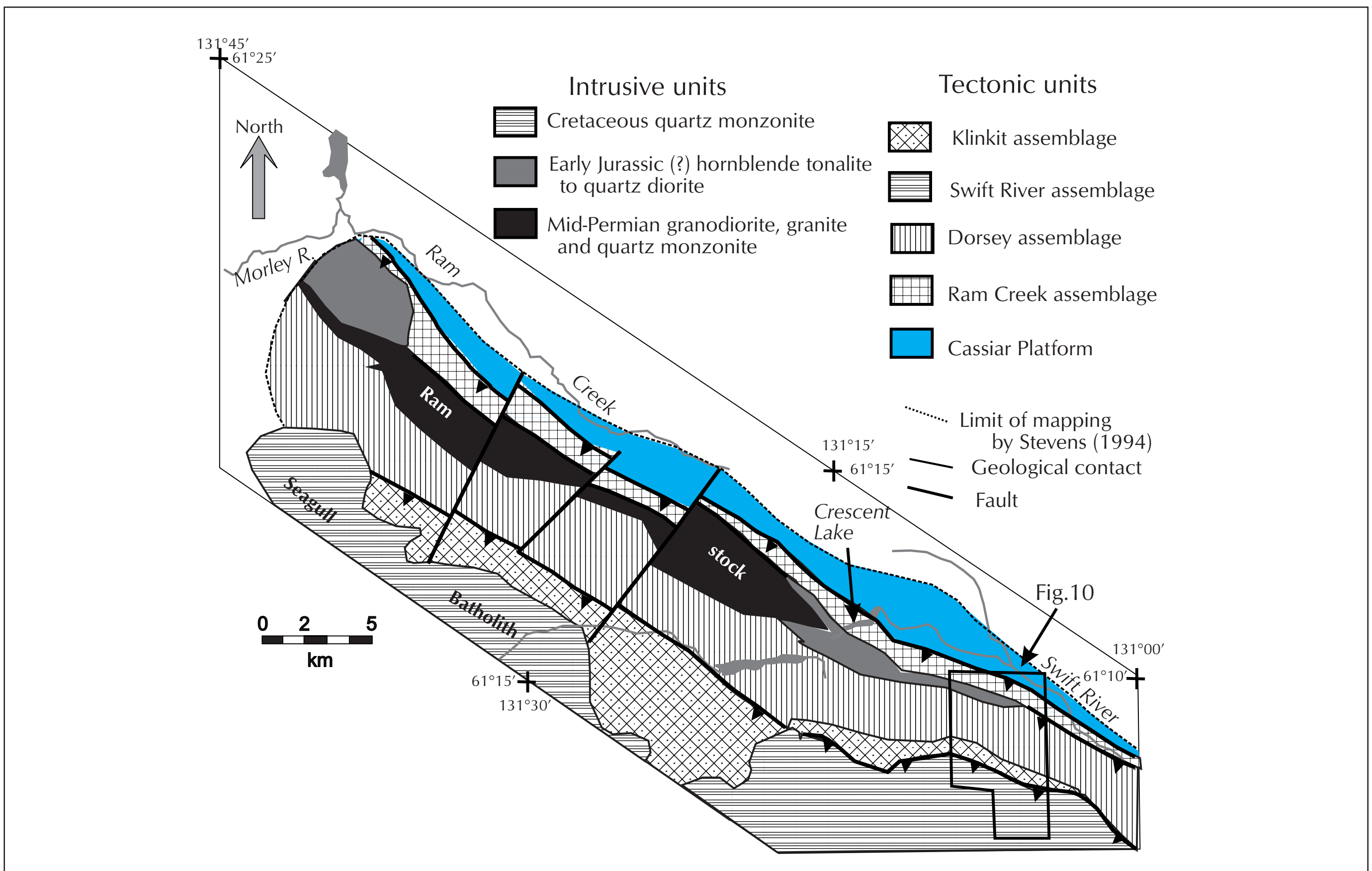

Figure 4. *Map of northern Dorsey assemblage, modified from Stevens (1996).*

The authors also examined the Ram Creek assemblage at the northwest end of the belt. There it consists of chloritic metavolcanic schist interbedded (at metre scale) with black phyllitic argillite. Locally, the green rock reveals compositional layering (Fig. 7); the authors interpret it to represent mafic flows. The calc-silicate rock and mineralization are absent from the three spur ridges examined at the northwest end of the Ram Creek assemblage.

Contacts and comment

The northeast boundary of the Ram Creek assemblage is everywhere covered, but is likely a fault because the metamorphic grade and structural style differ markedly from the (structurally) underlying Cassiar Platform. The southwest side of the Ram Creek assemblage south of the Dan showing is a weakly deformed tonalite to diorite body parallel to the regional grain and is likely a sill of Jurassic age. The contact is reported to be slightly sheared.

At the northwest end of the Ram Creek assemblage, the southwest (structurally upper) contact is reported to be a mylonitic shear or strongly foliated zone 10-20 m wide, that grades upward into massive granodiorite of the Ram stock (Stevens and Harms, 1995). The nature of this contact should be regionally re-examined because at least one ridge spur exposes a sharp contact. Near this contact xenoliths of metavolcanic rock lie within the granite. Further fieldwork is also needed because the nature of the contact has important implications for timing of the deformation.

The Ram stock, elongated parallel to the northwest structural trend, has been dated by U-Pb zircon geochronology at

Figure 5. *The 'Window' exposure at the Dan occurrence. The white marble bodies lie within rusty-weathering calc-silicate rock; sphalerite-magnetite mineralization occurs near the contact (dark zone between T. Liverton and M. de Keijzer).*

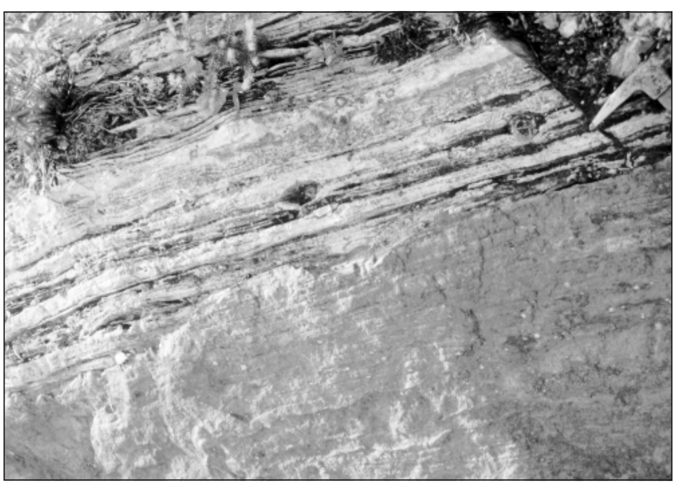

Figure 6. *Fine banding of chlorite-plagioclase-quartz in the calc silicate rock immediately south of the Dan mineralization. These layers are metamorphic and contacts between layers are entirely sheared (UTM 382650E, 6671550N).*

Figure 7. *Chloritic schist (mafic flow rock) of the Ram Creek assemblage near the northwest end of the belt (UTM 59250E, 6686750N).*

259 ± 2 Ma (J. Mortensen, pers comm., 1996; Stevens, 1996). If the contact with the Ram Creek assemblage is everywhere a shear zone, then its deformation may post-date the Permian intrusion, which could have later been thrust over the Ram Creek assemblage. The presence of mafic volcanic-looking clasts along the northeast side of the Ram stock, however, indicate that either the volcanic component of Ram Creek assemblage, or another volcanic unit, was adjacent to the intrusion in pre-Permian time.

Based upon initial observations, there is some doubt that the Ram Creek assemblage is a robust term. It does not appear to show lateral continuity in lithology, but appears to be structurally interleaved slices. Abbott (1981) interpreted this unit as fault-bounded slivers of Cassiar Platform strata and Yukon Cataclastic Complex (an obsolete term superseded by Yukon-Tanana Terrane in this region). Similarly, Stevens and Harms (1995) initially referred to the belt as the 'Imbricate assemblage.' We favour both Abbott's and Stevens' earlier interpretations, pending quantitative data on the age, or provenance of its constituents.

In east-central Jennings map area of northern B.C., a similarly situated belt (between Cassiar Platform and Dorsey assemblage) is also referred to as Ram Creek assemblage (Nelson et al., this volume). This belt is more cohesive, however, consisting of mafic to rhyolitic tuffs, with local limestone and chert. They are overthrust by the Dorsey assemblage on a mid-Permian thrust (Nelson et al., 1998). The rhyolitic tuffs are Mississippian in age, coeval with those in the Big Salmon Complex (Nelson et al., this volume). Given this evidence we suspect that 'Ram Creek assemblage' is a composite of rock units that are part of other terranes, including the Yukon-Tanana Terrane, and the term should eventually be retired.

DORSEY ASSEMBLAGE

In the Swift River area, mafic gneiss with interleaved siliceous schist and quartzite, is structurally overlain by muscovite ± biotite ± plagioclase ± tourmaline schist, quartzite and minor marble (Stevens, 1996). Where mapped south of the Dan showing, chlorite-muscovite-feldspar-quartz schist predominates (Fig. 8), but siliceous rock and orthogneiss are important constituents. Some compositional layers contain relict quartz granules and are probably metasedimentary. Yellowish calc-silicate layers reveal brown retrograde garnets about 1 mm across. At least three quartz-feldspar-phyric, white to pale yellow meta-rhyolitic layers (Fig. 9) were noted on spurs at approximately the same distance below the top of the Dorsey assemblage. On the north-facing slope, medium- to coarse-grained granitic orthogneiss is exposed. Its upper contact is slightly discordant with the overlying quartz-muscovite schist and is interpreted it as a sill. Orthogneiss of similar appearance is common in the Big Salmon Complex on Hazel Ridge and yielded a mid-Mississippian date (Mihalynuk et al., 1998). The orthogneiss on the ridge south of the Dan occurrence is expected to be of similar age.

The Dorsey assemblage to the northwest is intruded by the Ram stock, as indicated by abundant apophyses and inclusions. Because deformed clasts of the Dorsey assemblage are included within this Permian granite, the medium- to high-pressure metamorphism of that assemblage (Stevens, 1996) must be older than mid-Permian age.

KLINKIT (?) ASSEMBLAGE

Between the known Dorsey assemblage and the first layers of tan and black siliceous phyllite of the Swift River assemblage to the south (Fig. 10), is an approximately 250-m-thick section of mafic metavolcanic rocks, white marble and dark epiclastic

Figure 8. *Hinge of folded calc-silicate and quartz-feldspar augen schist of the Dorsey assemblage south of the Dan occurrence. This view is westerly, down moderately plunging stretching lineation parallel to the fold hinge (UTM 380850E, 6670240N).*

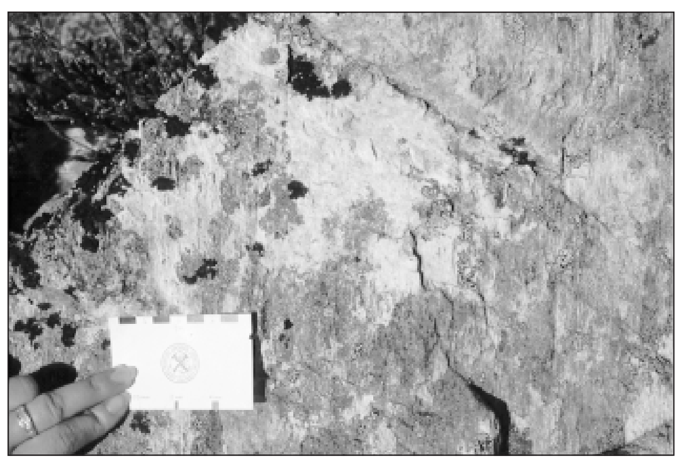

Figure 9. *Quartz-eye felsic schist (meta-rhyolite?) in the Dorsey assemblage, 2 km south of the Dan showing (UTM 381060E, 6670240N).*

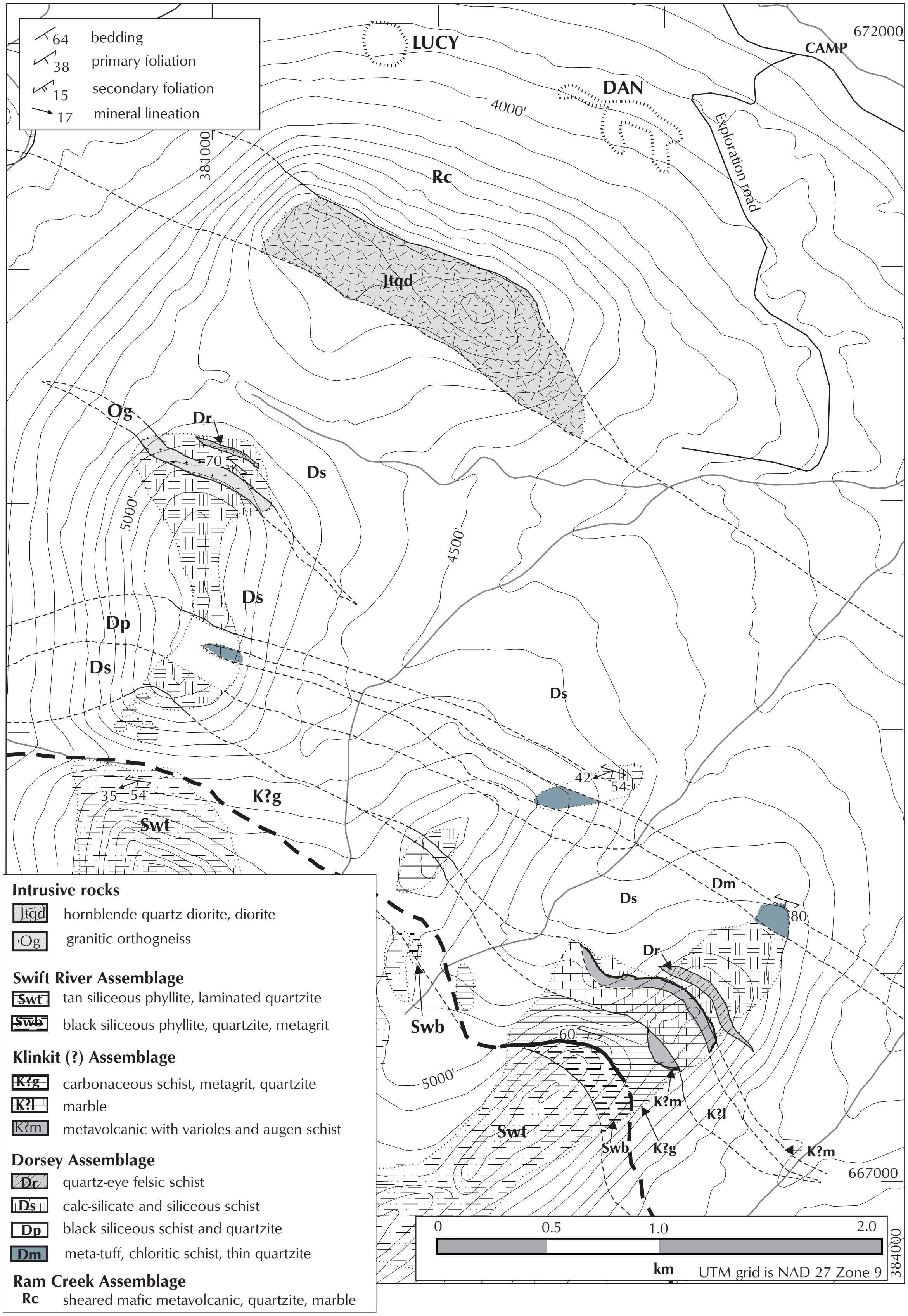

Figure 10. *Bedrock geology of the Swift River headwaters area. Contacts north of the Jurassic sill (unit Jtqd) are modified from Stevens and Harms (1995).*

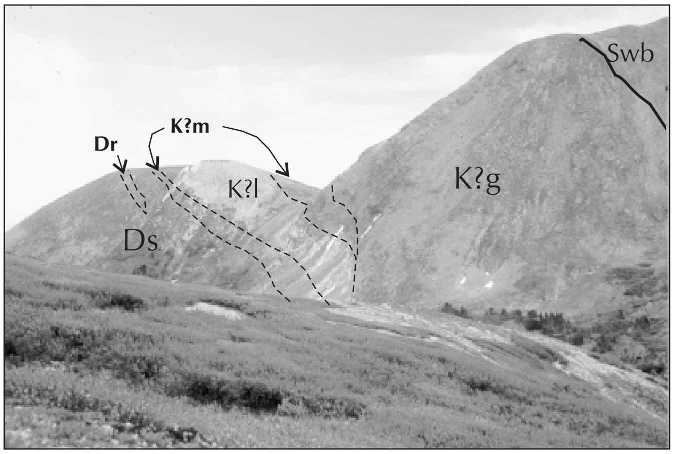

Figure 11. *View southeast of the northeast spur. Note the 40 m thick marble (K?l), with mafic metavolcanic (Klinkit (?) assemblage) on either side. See Figure 10 for unit abbreviations.*

Figure 13. *Dark, foliated metavolcanic rock conformably overlain by massive marble on the eastern-most spur ridge (see Fig. 10). View south at 381900E, 6667740N.*

rocks (Fig. 11). This section was included within the Dorsey assemblage by Stevens and Harms (1995; middle of their section A1-A2). The contacts are indicated on Figure 12.

On the northeast spur, a dark weathering metavolcanic layer a few metres wide structurally underlies the limestone (Fig. 13). The metavolcanic layer is mottled green and maroon, with ovoid light coloured patches several centimetres across which resemble varioles in altered basalt. The light grey-weathering marble forms a prominent band 20-50 m wide across two spur ridges (Fig. 11). Its base consists of waxy green carbonate blocks in a darker weathering phyllitic matrix. Structurally above the limestone is about 150 m of brown, green and black mottled mafic metavolcanic rock containing black quartzite with white streaks. Locally, the metavolcanic rock has a rippled, lumpy texture caused by abundant quartz lenticles distributed on foliation planes. It is likely a meta-tuff since it shows compositional layering. The tuff beds are separated by 1-3 cm separations of green and yellow chert, as well as epidotized and silicified layers. One layer of medium to coarse greenish grit resembles a strongly sheared plutonic rock.

Comment

The rocks in this succession are lithologically unlike those of the neighbouring Dorsey and Swift River assemblages. The mafic volcanic and massive carbonate is reminiscent of Klinkit assemblage 25 km to the southwest in the Logtung area, however their age is unknown. Layers containing quartz-feldspar augen are being tested for primary datable minerals. Contacts are parallel to compositional layering and the foliation of enclosing units, with no discernible difference in structural character.

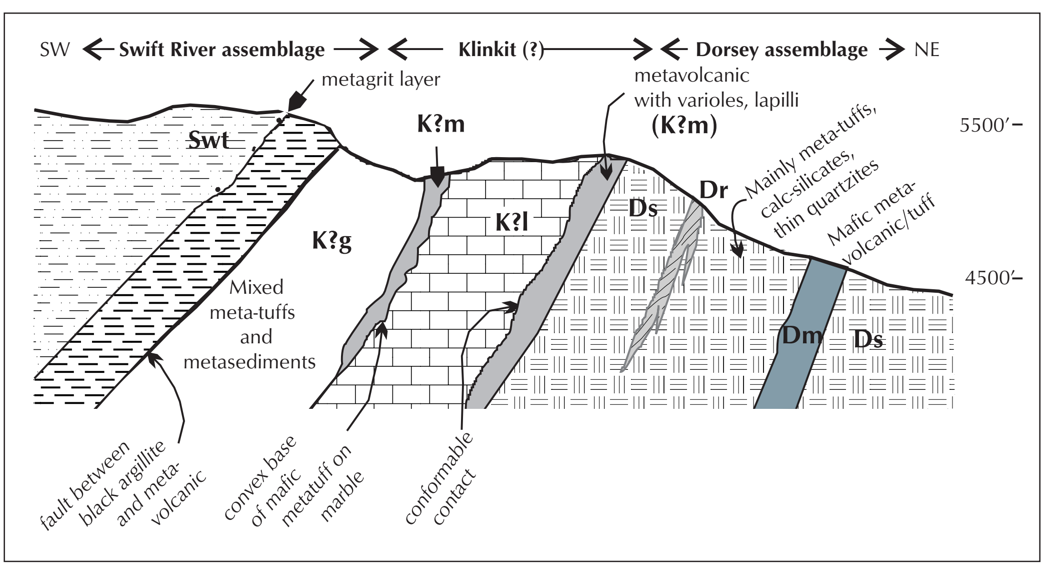

Figure 12. *Schematic section of the northeast spur with notes on contacts between Dorsey, Klinkit (?) and Swift River assemblages. Unit abbreviations correspond with those of Figure 10.*

SWIFT RIVER ASSEMBLAGE

The base of the Swift River assemblage is defined by an abrupt change from dark coloured volcaniclastic rock below (Klinkit (?) assemblage), to brown-weathering phyllite (meta-siltstone) with abundant black argillite partings above (Fig. 14). The metasiltstone is about 50 m thick, structurally overlain by dark meta-sandstone with manganese oxide coating, and interspersed with metre-thick, streaky grey quartzite and mafic layers. The Swift River assemblage continues south at least 10 km to the Alaska Highway near the Swift River Lodge.

STRUCTURAL NOTES

Transposition of compositional layering in these rocks is evident, although most primary sedimentary features, including way-up indicators, have been obliterated. Dorsey assemblage rocks display a moderately southwest-dipping penetrative foliation defined principally by oriented muscovite and biotite flakes. A mineral lineation plunges moderately towards 270°-290° and is typically sub-parallel to hinges of tight to isoclinal folds.

In the structurally overlying Swift River assemblage, the amount of finite strain appears to be, at least locally, less than that experienced by the Dorsey assemblage rocks. Rarely, patches of fine metasedimentary laminae are preserved. Minor fold axes and crenulation lineations plunge moderately west, showing structural continuity and their common transposition history with the Dorsey rocks.

No minor structures were observed that indicate the nature of the original contact between the Dorsey, Klinkit (?) and Swift River assemblages. Are they syn-orogenic (ductile or brittle) thrust, or sedimentary contacts? If the middle section is indeed a sliver of Klinkit assemblage, it is younger than the structurally overlying Swift River assemblage (see Nelson et al., this volume), thus the upper contact is a thrust. Nevertheless, the contact has undergone later shearing (Fig. 13) such that no small-scale motion indicators remain. Mesoscopic top-to-the-south and –southwest ductile and brittle–ductile shear bands (Fig. 15) and brittle normal faults postdate the penetrative foliation. Normal faults, both mesoscopic and macroscopic, with probable normal displacements of up to 100 m, have been recognized throughout the area. In some cases, these faults occur at the contact of the two assemblages, thus obscuring original contact relationships. In the northwestern Dorsey Range, about 34 km northwest of the area described here, the contact between the Dorsey and Klinkit assemblages is also a late-stage, steeply south-dipping normal fault, and abundant mesoscopic down-to-the-southwest normal faults occur in Dorsey assemblage.

MINERALIZATION

About 2.5 km east along the structural grain from where the Dorsey-Swift River boundary was examined lies the Mod showing and several others where magnetite-pyrrhotite, sphalerite and galena, with minor chalcopyrite and pyrite form bands 0.5 cm to 1 cm in thickness. Although the ore and gangue mineralogy is similar to that of the Dan-Crescent trend, this mineralization is at least 1 km higher in the structural succession. Three marble outcrops are exposed within the same structural grain as the 40-m-wide marble described here as part of the Klinkit (?) assemblage. As with the Dan, it is unclear whether these are epigenetic skarns, or skarnified syngenetic (possibly volcanic-associated) occurrences. The presence of quartz ± feldspar-phyric rock layers within the Dorsey and possibly Klinkit assemblages strengthens the case for volcanogenic massive sulphide mineralization.

Figure 14. *Southeast view of discrete, strained contact between foliated metavolcanic rock (Klinkit (?) assemblage) and structurally overlying black clastic rock of the Swift River assemblage (UTM 382750E, 6667530N).*

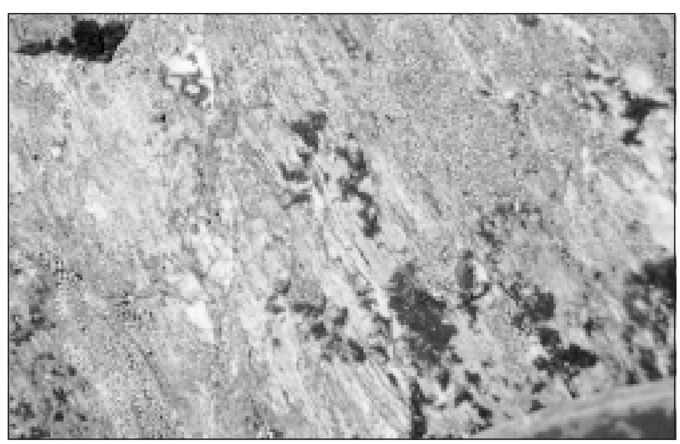

Figure 15. *View southeast of brittle-ductile shears, hammer head at lower right of photo. These small-scale structures are top-to-southwest shear bands common in northern Dorsey Terrane.*

ACKNOWLEDGEMENTS

This varied and wide-ranging field season would not have been possible without a strong show of support from the mineral industry and the cooperation of both the Yukon Geology Program and the BC Geological Survey. We benefited from astute observations by assistants Tom Gleeson and Kim Wahl, associates Steve Gordey (GSC), Rich Friedman (University of British Columbia) and Tekla Harms (Amherst College), as well as prompt, professional service by Andy Page (helicopter pilot) and Beth Hunt (cook). Dan Breeden and his family at Morley River Lodge cheerfully assisted with complicated logistics and communications. The H.S. Bostock Core Library, run by Mike Burke of Indian and Northern Affairs Canada graciously provided storage space. Dean Polard kindly assisted with camp construction. We thank Ed Balon and Wojtek Jakubowski (Fairfield Minerals), Geoff Bradshaw, James Smith and Terry Tucker (Brett Resources), as well as both Hardy Hibbing and Tim Liverton of Watson Lake for sharing geological information and permitting us to visit their mineral interests. This report includes maps originally drafted by Melanie Reinecke and editorial suggestions by Steve Gordey, Don Murphy and Grant Abbott.

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‘Alpine-type’ ultramafic rocks of the Kluane metamorphic assemblage, southwest Yukon: Oceanic crust fragments of a late Mesozoic back-arc basin along the northern Coast Belt

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Mezger, J.E., 2000. ‘Alpine-type’ ultramafic rocks of the Kluane metamorphic assemblage, southwest Yukon: Oceanic crust fragments of a late Mesozoic back-arc basin along the northern Coast Belt. *In:* Yukon Exploration and Geology 1999, D.S. Emond and L.H. Weston (eds.), Exploration and Geological Services Division, Yukon, Indian and Northern Affairs Canada, p. 127-138.

ABSTRACT

Mica-quartz schist and olivine serpentinites form the Kluane metamorphic assemblage, a 150-km-long belt that is wedged between the Yukon-Tanana Terrane and the Insular Superterrane in the northern Coast Belt. The olivine serpentinites are serpentinized dunites that occur as lens-shaped bodies, interlayered along strike, with the mica-quartz schist. The larger ultramafic bodies developed a foliation and shear sense that is similarly oriented to those in the adjacent schist, suggesting ‘Alpine-type’ emplacement. Tectonic juxtaposition of schist and ultramafic rocks occurred during collapse and subduction of a back-arc basin underneath the North American continental margin in the Late Cretaceous. Oxygen isotope analyses point to values similar to known ophiolitic serpentinites. The ultramafic rocks are interpreted to be part of an oceanic crust that formed topographic highs during subduction and were subsequently sheared off and tectonically interleaved with metasedimentary rocks during the accretionary process.

RÉSUMÉ

Des schistes à mica-quartz et des serpentinites à olivine forment l’assemblage métamorphique de Kluane; une ceinture de 150 km de long que l’on retrouve entre le terrane de Yukon-Tanana et le superterrane Insulaire, dans la partie septentrionale de la chaîne Côtière. Les serpentinites à olivine sont des dunites serpentinizées qui se présentent sous forme de lentilles qui sont intercalées, le long de l’affleurement, avec les schistes à mica-quartz. Les plus gros amas ultramafiques ont développés une foliation et une direction de cisaillement d’orientation similaire à celle du schiste adjacent, suggérant un emplacement de ‘type alpin’. La juxtaposition tectonique du schiste et des roches ultramafique s’est formée durant l’effondrement et la subduction d’un bassin d’arrière-arc sous la marge continentale nord americaine au Crétacé supérieur. Les analyses des isotopes d’oxygène ont enregistrées des valeur similaires aux serpentinites ophiolitiques connues. Les roches ultramafiques sont interprétées commes faisant partie d’une croûte océanique qui formait des reliefs topographiques durant la subduction et qui a été successivement cisaillée et tectoniquement intercalée avec des roches métasédimentaires durant le processus d’accrétion.

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INTRODUCTION

Ultramafic rocks are minor, but common constituents of accreted terranes in the northern Cordillera. Two types of ultramafic rocks, 'Alpine-type' and 'Alaskan-type,' are distinguished by their genetic origin. Alpine-type ultramafic rocks are generally fault-bounded, internally deformed and serpentinized. They are interpreted as segments of oceanic crust and/or mantle that were tectonically emplaced into their present position (Hall, 1987). A common feature of Alpine-type ultramafic rocks is the occurrence along tectonic zones, e.g., faults, shear zones and terrane boundaries. Slivers of serpentinite, serpentinized dunite and peridotite, associated with flysch deposits and mica schists, occur along the Denali Fault zone in the central and eastern Alaska Range. These ultramafic rocks may be the remnants of an ocean basin, possibly the basement of Wrangellia that collapsed during subsequent accretion in the Late Mesozoic (Nokleberg et al., 1985, Patton et al., 1994). Alaskan-type ultramafic rocks, found along a 560-km-long belt west of the Coast Plutonic Complex in southeastern Alaska, are concentrically zoned bodies with a dunite core and pyroxenite shells, generally associated with gabbro intrusions (Taylor, 1967; Himmelberg et al., 1985; Patton et al., 1994). They are interpreted as fractionated ultramafic intrusions (Taylor, 1967).

In the Coast Belt of southwestern Yukon, ultramafic rocks occur within the Kluane metamorphic assemblage (KMA). The KMA is a tectonically thickened package of graphitic mica schist and gneiss that is wedged between rocks of North American affinity (Yukon-Tanana Terrane) to the east and accreted terranes of the Insular Superterrane (Alexander Terrane) to the west. The KMA is separated from the Yukon-Tanana Terrane by the Paleocene-Eocene granodiorite of the Ruby Range Batholith, and from the Alexander Terrane by the Denali Fault zone (Fig. 1). The KMA does not appear to be correlated with any other sedimentary or metamorphic rock assemblage of the northern Cordillera. Its tectonic affinity remains enigmatic. On the most recent tectonic assemblage map of the Canadian Cordillera, the KMA is shown as "metamorphic rocks undivided" (Wheeler and McFeely, 1991).

The schist and gneiss of the KMA are characterized by north- to northeast-dipping regional foliation and a shallowly east-west-plunging mineral lineation (Mezger, 1997). The regional foliation overprints two earlier foliations that are preserved as graphitic inclusions in plagioclase porphyroclasts. Lacking original sedimentary structures, this regional foliation is referred to as S_{n+2}. At lower structural levels, the schists are mylonitic with a distinct fabric asymmetry, defined by shear bands and rotated porphyroclasts that indicate top-to-the-west sense of shear. At higher structural levels these fabrics are overprinted by contact metamorphism related to the Early Tertiary intrusion of the Ruby Range Batholith, the northern extension of the Coast Plutonic Complex (Mezger, 1997). The geochemical and Neodymium isotope character of the KMA is intermediate between juvenile and evolved sources, which suggests a back-arc basin setting for the sedimentary protolith (Mezger, 1996, 1997; Mezger and Creaser, 1996).

The objective of this paper is to describe ultramafic rocks of the KMA, discuss their possible origin, mode of emplacement into the mica schist, and the implications on the tectonic evolution of the KMA and the northern Cordillera. In addition to petrological and structural observations, oxygen isotope data are presented. It will be shown that the ultramafic rocks of the KMA are fragments of an oceanic crust that were tectonically interleaved with metasedimentary rocks during underplating and accretion to the overriding North American plate in the Late Cretaceous.

ULTRAMAFIC ROCKS OF THE KMA

The KMA forms a 150-km-long, southeast-trending belt, underlying approximately 3000 km^2 of the Ruby and Dezadeash ranges northeast of the Shakwak Trench in southwestern Yukon. It extends from the mouth of Kluane River to Dezadeash Lake, covering the Kluane Lake (115 G&F), Aishihik Lake (115 H) and Dezadeash (115 A) map sheets (Fig. 1). Ultramafic rocks are only minor constituents, occurring as interleaved lenses within a 12-km-thick unit of schist and gneiss in the western part of the KMA. As a result, these ultramafic rocks have largely gone unnoticed by previous workers, and were not mapped as separate units. The metamorphic assemblage was originally termed "Kluane Schist" by McConnell (1905). The term "Kluane metamorphic assemblage" was introduced by Mezger (1995) to include the ultramafic rocks which have undergone the same tectono-metamorphic evolution as the mica-quartz schist ("Kluane Schist" *sensu strictu*).

The ultramafic rocks in the KMA form four distinct ultramafic bodies that occur for 60 km along strike in the Ruby Range, from Doghead Point, northeast of Burwash Landing, to northwest of Kloo Lake. Their sizes vary from a width and thickness of a few tens of metres (Erdmer, 1990) to 15 km with a structural thickness of more than 1000 m (Figs. 2, 3). The two larger bodies are recognized by distinct positive magnetic anomalies on aeromagnetic maps (GSC, 1967, 1968).

The ultramafic rocks are serpentinized dunites that consist of varying amounts of Mg-rich olivine (Fo=90, 10-80 vol.%), serpentine (15-60 vol.%), talc (0-40 vol.%), as well as iddingsite, magnetite, chromite and pentlandite (5-10 vol.% combined), with traces of calcite (Table 1). Olivine is preserved in rounded pods, up to one centimetre in diameter, and is characterized by mesh-like inclusions of chromite, overgrown by chromium-magnetite (Figs. 4, 5, 8). At some localities of the large Doghead Point ultramafic body, spinning of the compass needle can be observed. Iddingsite forms yellowish alteration rims around olivine. Abundant serpentine and talc give the rock a light greenish colour and a soapy touch.

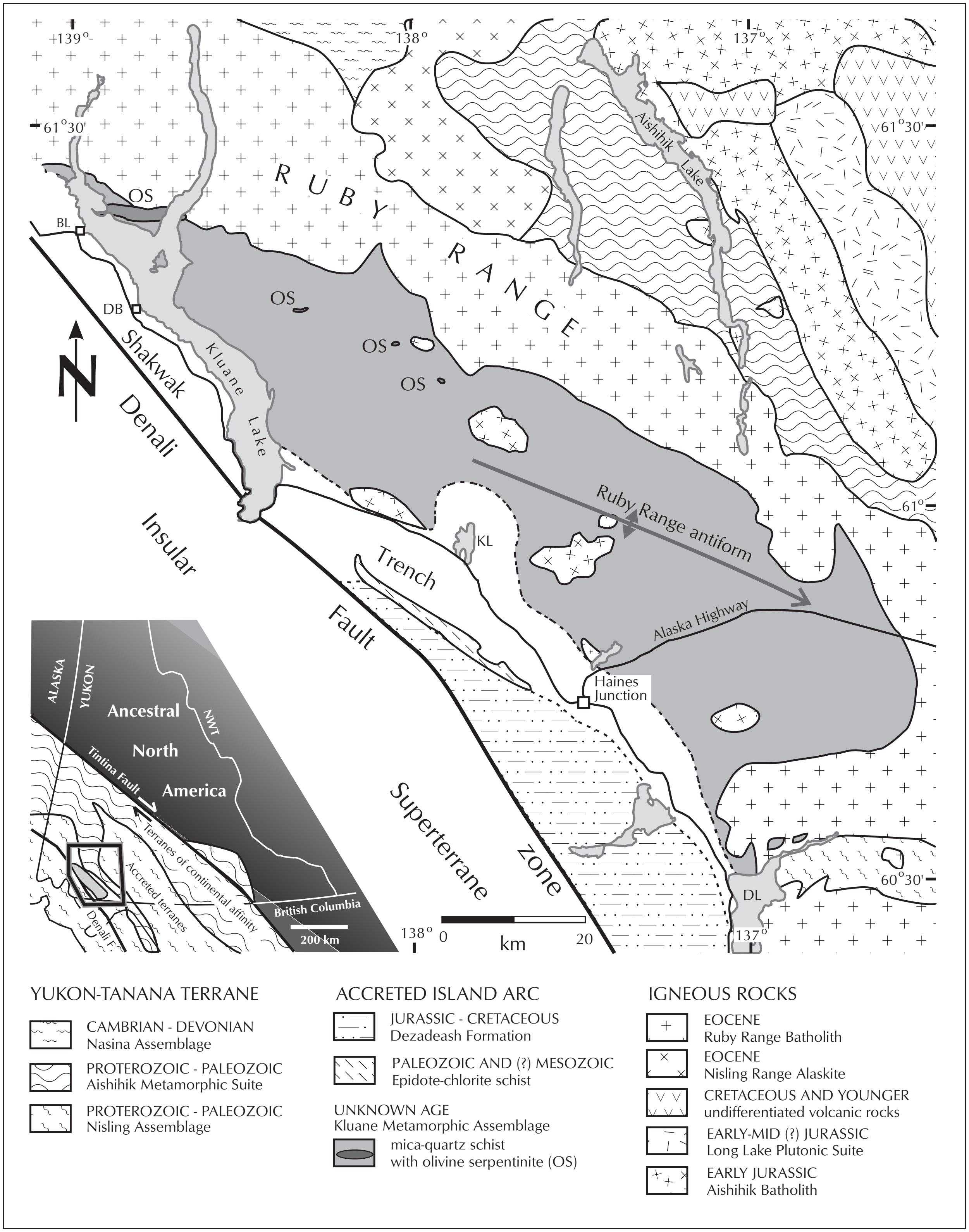

Figure 1. *Geological overview map of the Kluane metamorphic assemblage. Additional information from Kindle (1952), Muller (1967), Tempelman-Kluit (1974), Wheeler and McFeely (1991), Dodds and Campbell (1992) and Johnston and Erdmer (1995). BL: Burwash Landing; DB: Destruction Bay; DL: Dezadeash Lake; KL: Kloo Lake.*

DOGHEAD POINT ULTRAMAFIC

By far the largest ultramafic body is located near Doghead Point on the northern shore of Kluane Lake, opposite of Burwash Landing (Fig. 2). It forms a 1260-m-high east-trending ridge and can be traced for 9 km from the north end of an unnamed lake across Talbot Arm to the eastern lakeshore. The ultramafic body is in contact with muscovite-chlorite schist in the south, and tonalitic intrusions of the Ruby Range Batholith in the north. Aeromagnetic data suggest that it extends further west to Sandspit Point, resulting in a total length along strike of 15 km. However, there is no exposure in the low-relief wooded area. The ultramafic body has a minimum structural thickness of 1000 m. The extent of the body is outlined by the 57,400 nT total magnetic field isoline, which closely follows the observed geological contact in the field. A maximum magnetic intensity of 1700 nT above the average for the schist (57,300 nT) suggests a massive body. The subsurface extension of the ultramafic body is not known. However, a steep-dipping internal foliation at its northern margin, and the lack of a distinct magnetic low to the north suggest it has a wedge-like shape which does not extend much further into subsurface beyond its exposed northern contact (Fig. 3).

The Doghead Point olivine serpentinite has a strongly developed schistosity, which can be correlated with the major regional schistosity S_{n+2} in the adjacent mica schist. Schistosity is defined by the alignment of serpentine grains in the cleavage domains (Fig. 4). Olivine is preserved in the less-sheared microlithons (Figs. 4, 5). The strike of schistosity is parallel to that of the underlying schist, dipping moderately to steeply to the north-northeast (Fig. 2). In the western part of the ridge, steeply,

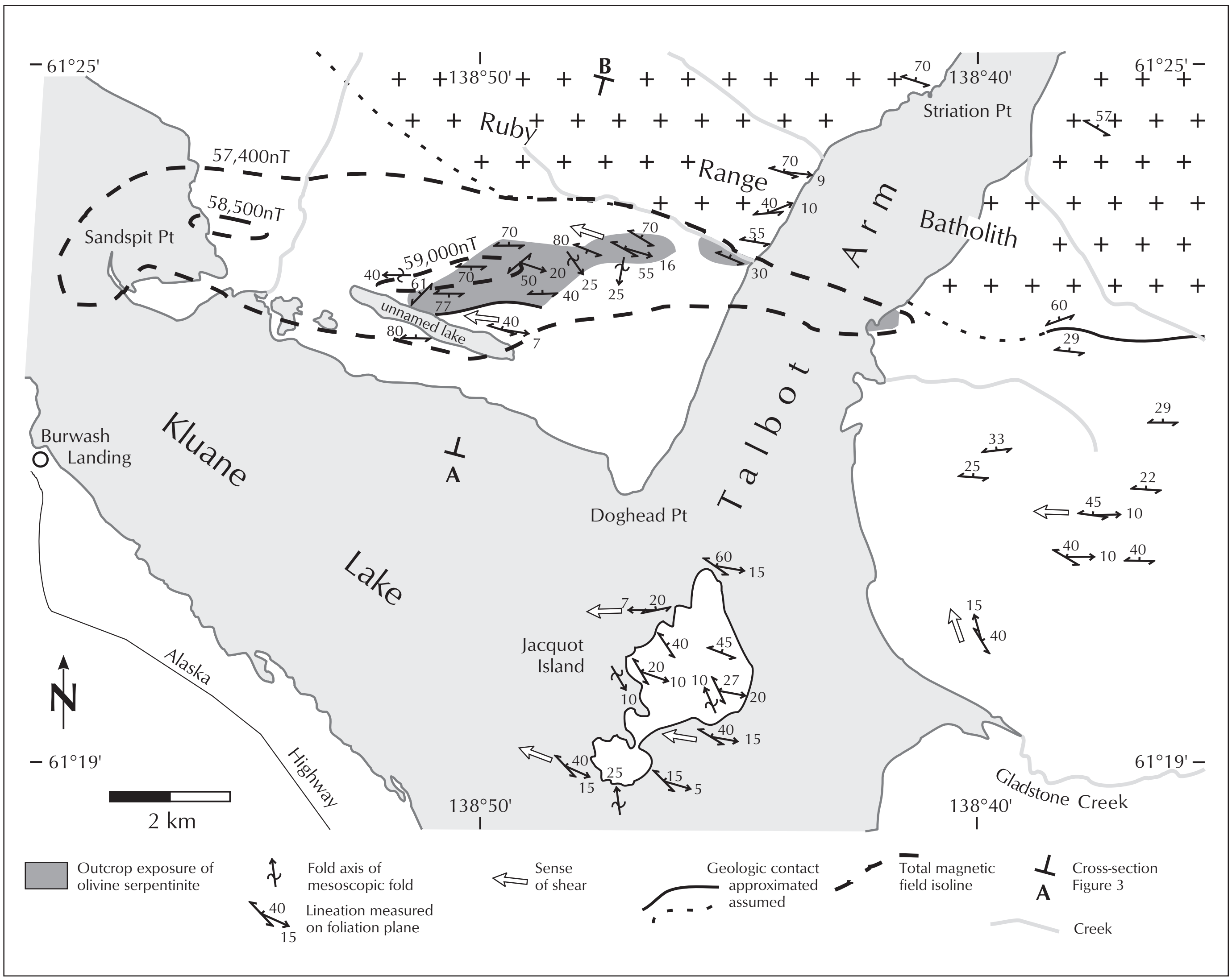

Figure 2. *The Doghead Point olivine serpentinite occurrence in the central Kluane Lake region. The surface exposure of the ultramafic body follows the 57,400 nT magnetic field isoline. Magnetic field data modified after GSC (1967).*

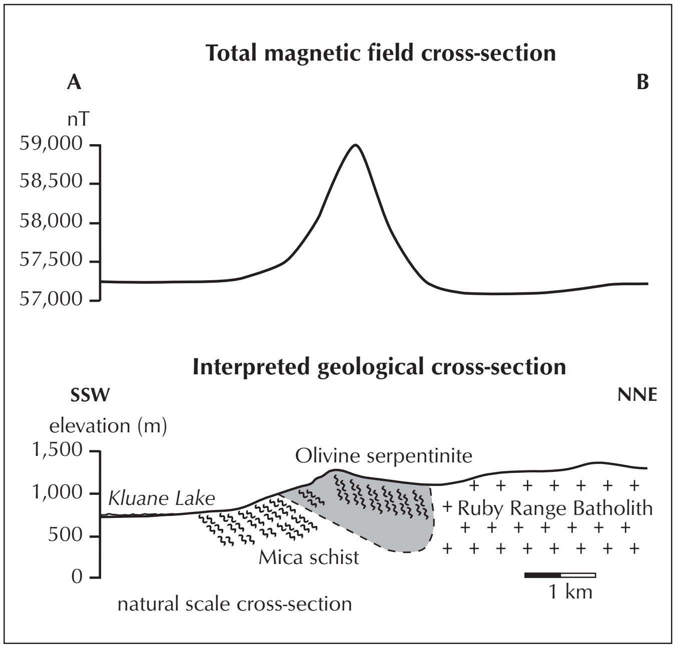

Figure 3. *Magnetic field cross-section and interpreted geological section through the Doghead Point ultramafic body. The subsurface extension of the serpentinite is speculative. See Figure 2 for location of section.*

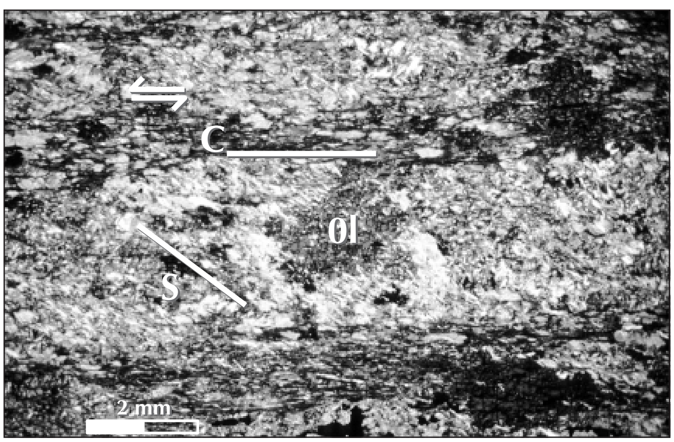

Figure 4. *Photomicrograph of the central Doghead Point olivine serpentinite with prominent asymmetrical fabric, interpreted as a c/s fabric of Berthé et al. (1979) and resembling fabrics described by Norrell et al. (1989) from serpentinites of the Josephine Ophiolite (compare with their Figure 6). Platy alignment of serpentine in the cleavage planes defines a schistosity c. S-planes are developed in 3-mm-wide microlithons between more intensely sheared cleavage planes. A top-to-the-left sense of shear can be deduced. Olivine porphyroclasts (Ol), preserved in the microlithons, display web-like alteration to chromite and magnetite. Scale bar: 2 mm. Crossed polarized light (XPL).*

southerly dipping schistosity can be observed. Less commonly, a mineral lineation defined by elongated serpentine flakes is developed in the serpentinite.

Locally, a secondary foliation S_{n+3}, axial planar, to northeast- to southwest-plunging, mesoscopic open F_{n+3} folds and millimetre-scale F_{n+3} crenulation folds, is developed in the olivine serpentinite (Fig. 6). S_{n+3} is restricted to the fold hinges, and as such does not form a penetrative foliation that can be mapped on a regional scale. F_{n+3} folds are also observed in the schist throughout the whole KMA, without development of an axial planar cleavage.

In places where a strong mineral lineation is developed, the serpentinite is mylonitic and displays an asymmetrical fabric. Narrow shear zones, 0.25-1 mm wide, parallel to the dominant foliation S_{n+2}, separate wider zones (1-3 mm) of oblique grain shape foliation defined by serpentine crystals (Fig. 4). The angle

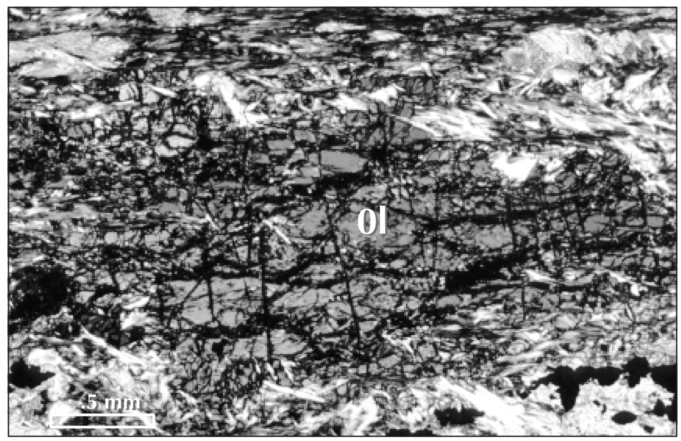

Figure 5. *Enlarged view of the lower right section of Figure 4 showing the web-like alteration of olivine. Scale bar: 0.5 mm. XPL.*

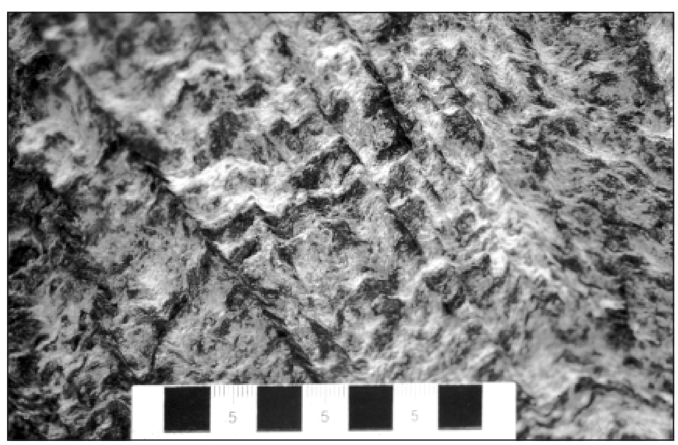

Figure 6. *Crenulation folding of the central Doghead Point olivine serpentinite. A 5-mm-spaced crenulation foliation S_{n+3} runs from upper left to lower right. Scale bar is in centimetres.*

between the foliation S_{n+2} and the oblique serpentine grains ranges between 35-45°. Similar fabrics have been described by Norrell et al. (1989) from partly serpentinized peridotites of the Josephine ophiolite of northern California. They interpret them as c/s fabrics after Berthé et al. (1979), synonymous to c-type shear bands of Passchier and Trouw (1996). The sense of shear deduced from the c/s fabrics is sinistral, top to the west, similar to that obtained from c′-type shear bands and rotated porphyroclasts in the adjacent muscovite-chlorite schist.

Locally, decimetre-sized boudins of altered gabbronorite aligned in layers parallel to the serpentinite schistosity can be observed (Fig. 7). Brownish orthopyroxene crystals are prominently weathered on the surface of the boudins (Fig. 8). Thin sections reveal that orthopyroxene in the gabbronorite is partly replaced by clinoamphibole (Fig. 9).

Schistosity orientation and shear sense indicators in the mica schists and olivine serpentinite are similar, suggesting a common deformation history. Along its northern contact with gneissic quartz diorite and tonalite of the Ruby Range Batholith, the ultramafic body appears more massive with less altered olivine crystals. This indicates recrystallization of olivine as a result of contact metamorphic overprinting by the batholith. Field observations suggest that the juxtaposition of ultramafic rock and mica schist occurred in the early stage of the major deformation phase D_{n+2}, and prior to the intrusion of the Ruby Range Batholith.

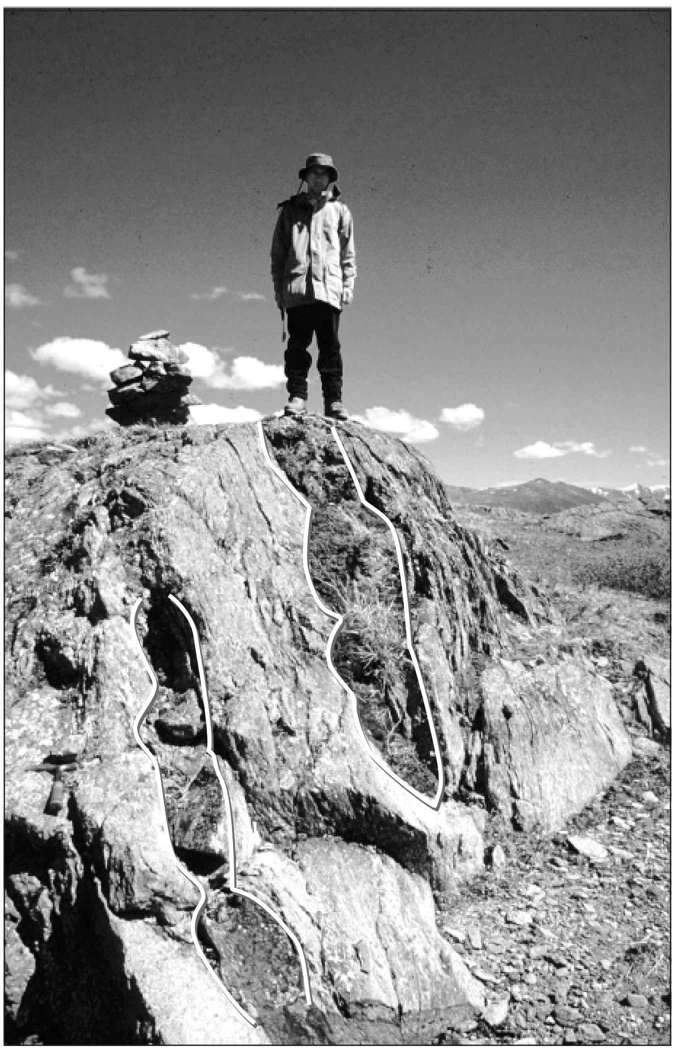

Figure 7: *Steeply dipping, foliated olivine serpentinite on the ridge north of Doghead Point. Two layers of boudinaged, altered gabbronorite are outlined. The layers have a thickness of 30-50 cm.*

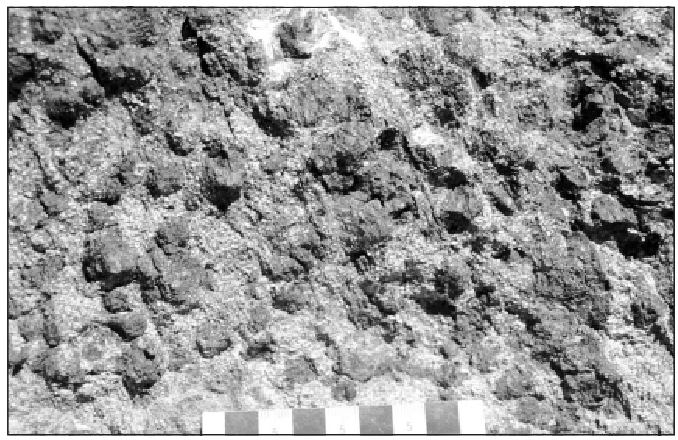

Figure 8. *Weathered surface of gabbronorite boudins showing brownish altered orthopyroxene phenocrysts. Scale bar is in centimetres.*

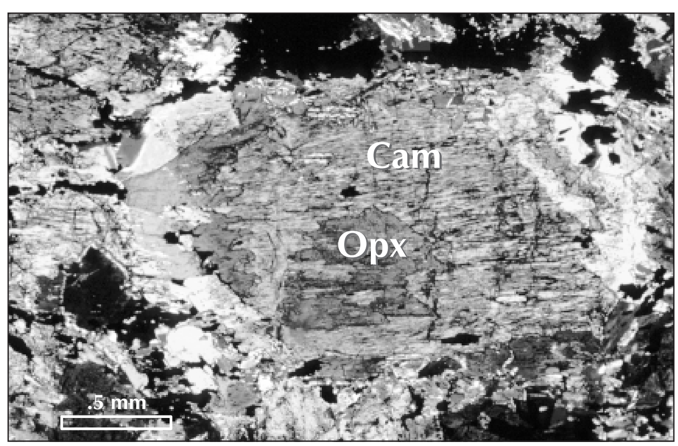

Figure 9. *Photomicrograph of gabbronorite. The original orthopyroxene (Opx) is almost completely replaced by clinoamphibole (Cam) and only preserved as a relic in the centre of the crystal. Scale bar: 0.5 mm. XPL.*

SWANSON CREEK ULTRAMAFIC

A smaller olivine serpentinite body is located on a ridge west of Swanson Creek (Fig. 10), and is recognized as a minor positive anomaly (+ 200 nT) on the aeromagnetic map (GSC, 1968). The body is wedge-shaped, less than a kilometre wide and approximately 150-200 m thick (Fig. 11). Its exposure is restricted to the ridge crest, tapering off downslope. The northerly dipping orientation of the wedge is parallel to the general attitude of the foliation in the surrounding schist. A penetrative foliation is developed close to the contact with the mica-quartz schist. The contact is fabric-parallel. Away from the contact, the ultramafic body is characterized by centimetre-scale cleavage zones anastomosing around decimetre-scale undeformed olivine serpentinite (Figs. 12, 13). Such structures are also described in less deformed, incohesive serpentinites of the Josephine Ophiolite (Norrell et al., 1989). The cleavage is moderately dipping towards north, similar to the orientation of the foliation in the adjacent schist, suggesting coeval development of cleavage and schistosity, similar to what is observed within the Doghead Point serpentinite locality.

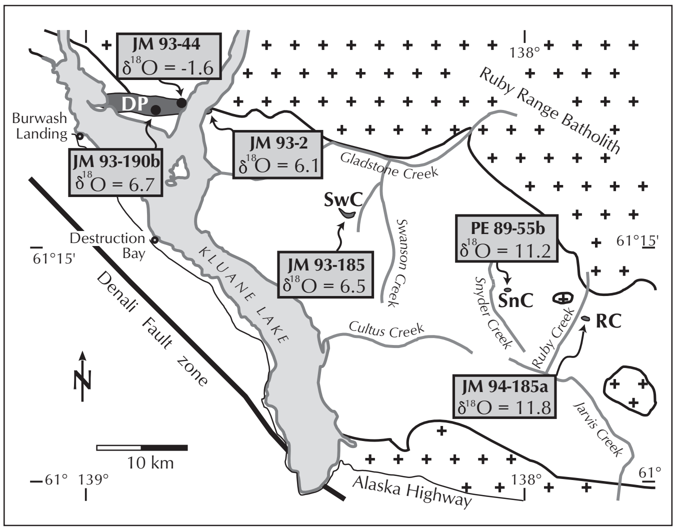

__Figure 10.__ Oxygen isotope data from the four known occurrences of olivine serpentinite (dark shaded areas) in the Kluane metamorphic assemblage. The data are listed as $\delta^{18}O$ SMOW. DP=Doghead Point; SwC=Swanson Creek; SnC=Synder Creek; RC=Ruby Creek.

__Figure 11.__ View from southeast onto the Swanson Creek ultramafic lens, outlined by white line. The lighter colour of the olivine serpentinite is in contrast to the dark grey of the mica-quartz schist. Note that the ultramafic body tapers off downslope. It does not extend towards the bottom of the valley. The exposure of the ultramafic along the ridge is approximately 200 m.

__Figure 12.__ The structural character of the Swanson Creek ultramafic body is different from that of the Doghead Point serpentinite. A penetrative foliation is restricted to the margins of the ultramafic body. More common is a foliation anastomosing around elongated, decimetre-scale, undeformed olivine serpentinites.

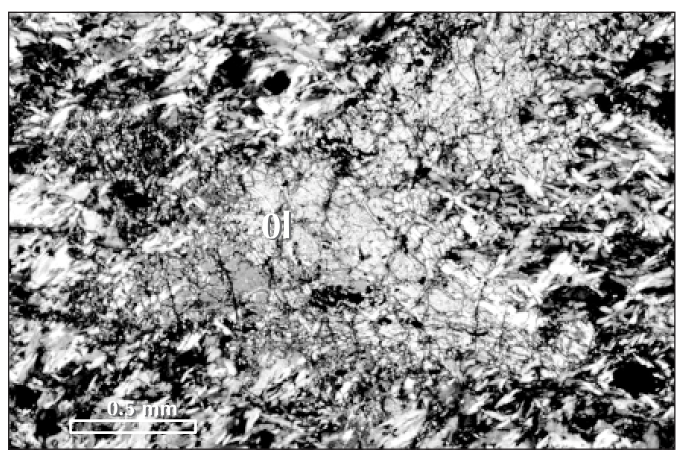

__Figure 13.__ Photomicrograph of an undeformed olivine (ol) serpentinite of the Swanson Creek lens. Serpentine and talc crystals are randomly oriented. Scale bar: 0.5 mm. XPL.

SNYDER CREEK (SNC) AND RUBY CREEK (RC) ULTRAMAFIC BODIES

The two eastern olivine serpentinite bodies are too small to be distinguished on aeromagnetic maps. The Ruby Creek exposure forms a resistant knoll in the order of tens of metres on a plateau east of Ruby Creek. The contact with the mica-quartz schist is exposed. On a ridge east of Snyder Creek, Erdmer (1990) observed two small bodies at the scale of tens of metres. At both localities, the serpentinites are massive and show no conspicuous signs of deformation.

OXYGEN ISOTOPE STUDIES

RESULTS

Six olivine serpentinite samples, three from the Doghead Point lens, and one each from the other localities, were selected for oxygen isotope analysis. The objective was to compare the oxygen isotope signature of the KMA ultramafic rocks with those of serpentinites of known ophiolites and mantle material, and to examine the effects of hydrothermal alteration. Fred Longstaff of the University of Western Ontario performed whole-rock ^{18}O analyses. The results are listed as deviation from Standard Mean Ocean Water ($\delta^{18}O$ SMOW) in Table 1 and are shown on Figure 10.

Table 1: *Location, mineral composition and d*^{18}*O values of olivine serpentinites of the Kluane metamorphic assemblage.*

Sample #	**Location**	**Field relationship**	**Mineral paragenesis[1] (vol. %)**	**Yield (µmoles/mg)**	**$\delta^{18}O$ SMOW[2] (‰)**
		Doghead Point ultramafic (DP)			
JM 93-2	eastern shore of Talbot Arm, Kluane Lake 138°41'40" W, 61°22'45" N	eastern margin contact not exposed	Ol, Srp, Mag, Chr	8.46	**6.1**
JM 93-44	western shore of Talbot Arm, Kluane Lake 138°44'40" W, 61°23'10" N	northern contact with Ruby Range Batholith	Ol (75), Srp (20), Mag, Chr (5)	10.09 (repeat) 9.88	**-1.1** (repeat) **-2.2**
JM 93-190b	southern slope of hill, north of Doghead Point 138°49'40" W, 61°23'05" N	central part of lens	Srp (70), Ol (10-15), Tlc (10), Idd (2-3), Pn, Chr, Mag (5)	13.65	**6.7**
		Swanson Creek ultramafic (SwC)			
JM 93-185	ridge west of Swanson Creek, Ruby Range 138°25'50" W, 61°15'20" N	central part of lens	Srp (65), Ol (30), Mag, Chr (5), Cc	11.74	**6.5**
		Snyder Creek ultramafic (SnC)			
PE 89-55b	ridge east of Snyder Creek, Ruby Range 138°03'00" W, 61°12'42" N	small outcrop	Tlc (50), Srp (35) Ol (15), Mag, Chr, C	12.08	**11.2**
		Ruby Creek ultramafic (RC)			
JM 94-185a	plateau east of Ruby Creek, Ruby Range 137°50'42" W, 61°10'42" N	small outcrop, in contact with mica schist	Tlc (50), Ol (25) Srp (20), Mag, Chr, Cr-En (5)	11.4	**11.8**

[1]Mineral composition estimated from thin section analysis. Cc: calcite; Chr: chromite; Cr-En: chrome-enstatite; Idd: iddingsite; Mag: magnetite; Ol: olivine; Srp: serpentine; Tlc: talc.

[2]Oxygen isotope analyses made by F. Longstaff, University of Western Ontario. Reproducibility of quartz standards ± 0.03‰.

The $\delta^{18}O$ SMOW values fall into three groups, -1.6‰, 6.5‰ and 11.5‰. Values from 6.1 to 6.7‰ were recorded from samples of the core zone (JM 93-190b) and the eastern margin (JM 93-2) of the Doghead Point ultramafic lens, and from the core of the Swanson Creek lens (JM 93-185; Fig. 10). These samples are characterized by a high serpentine content of 60-70 vol.% (Table 1). They are located at some distance (hundreds of metres) to the marginal zone of the ultramafic bodies. Higher $\delta^{18}O$ values, 11.2 and 11.8‰, are obtained from the samples of the two smaller talc-rich serpentinites in the east (PE 89-55b, JM 94-185). The lowest $\delta^{18}O$ value, -1.6‰, is measured in a sample (JM 93-44) from the northern margin of the Doghead Point ultramafic, close to the contact with the Ruby Range Batholith.

INTERPRETATION OF $\delta^{18}O$ DATA

The $\delta^{18}O$ values of 6-7‰ of the core zones of the larger bodies are similar to values reported from serpentinites of the Onverwacht Group ophiolites in South Africa (3-6‰, Hoffman et al., 1986) and intrusive rocks of the Bay of Islands ophiolite in Newfoundland (5.8‰, Muehlenbachs, 1986). These values deviate very little from pristine mantle values (Kyser, 1986), which implies that the water/rock ratio must have been small. This is the case regardless if serpentinization occurred *in situ* in an ocean floor setting, as a result of interaction with magmatic fluids (5-7‰) and sea water (0‰), or after obduction due to interaction with metamorphic (13-20‰) or meteoric waters (-20-0‰; Wenner and Taylor, 1973; Shepard, 1986). A similar small water/rock ratio can be inferred from serpentinization of an ultramafic intrusion within a sedimentary sequence (Alaskan-type), resulting from interaction with high $\delta^{18}O$ metamorphic fluids that were derived from pelitic sediments with $\delta^{18}O$ values of 13-20‰ (Taylor and Shepard, 1986). In all cases, a significantly large water/rock ratio would have changed the $\delta^{18}O$ values. To distinguish the source of serpentinization, further oxygen isotope studies of individual minerals and also δD (Deuterium) studies are necessary.

The high $\delta^{18}O$ values (11.2 and 11.8‰) and the high talc content (~50 vol.%) of the smaller ultramafic bodies indicate interaction with hydrothermal fluids derived from the mica-quartz schist (Deer et al., 1992). The existence of pristine olivine in these samples suggests that the water/rock ratio was not exceptionally high. The $\delta^{18}O$ values of pelitic sediments range from 13‰ to 20‰, and metamorphic fluids derived from dehydration of metasedimentary rocks during metamorphism record 3‰ to 20‰, at 300 to 600°C (Taylor and Shepard, 1986). This hydrothermal event could be caused by (a) fluids originating from dehydration of the sediment during initial metamorphism, (b) fluids driven out during the intrusion of the Ruby Range Batholith, or (c) post-intrusive localized fluids flowing through pervasive joints and fractures.

Present day meteoric waters of the North American Cordillera are relatively depleted in ^{18}O and can have $\delta^{18}O$ values of -20‰ and less (Shepard, 1986). The negative $\delta^{18}O$ value of -1.5‰ of sample 93-44 at the margin of the larger Doghead Point olivine serpentinite is most likely the result of localized alteration due to interaction with meteoric water during uplift of the KMA in post-Eocene time.

ORIGIN AND EMPLACEMENT OF THE KMA ULTRAMAFICS

The origin of the ultramafic rocks of the KMA cannot be unambiguously inferred from oxygen isotope data alone. Both intrusive and ophiolitic setting is possible. Their tectonic setting can be constrained when the ultramafic rocks are taken into context with the structural, geochemical and isotopic character of the surrounding mica schist. These metasedimentary rocks are remarkably homogeneous in their geochemical and isotopic composition. Their protolith was derived from more than one provenance region, and represents a mixing of evolved (continental) and juvenile (volcanic arc) sources (Mezger and Creaser, 1996; Mezger, 1997). The restricted occurrence of orthoamphibole gneiss with primitive isotopic signature and thin bands of actinolite fels suggest proximity to a volcanic arc, but not isolation from a continent. The most probable depositional setting for the sedimentary protolith of the KMA is a back-arc basin located between a volcanic arc (Insular Superterrane?) and the North American continental margin (Mezger et al., in review).

Graphitic inclusion trails are common features of plagioclase porphyroclasts of the KMA schist, and are indicative of two earlier foliations, an original lamination (?) and a slaty cleavage (Mezger, 1997). There is no compelling evidence for a penetrative ductile deformation predating the regional schistosity S_{n+2} that is developed in the mica schist and the olivine serpentinite. This implies that mica schist and ultramafic rocks were juxtaposed prior to, or in the early stage of D_{n+2} deformation.

Juxtaposition of the ultramafic rocks and schist could have resulted from (a) intrusion of ultramafic magma into the sedimentary protolith or mica schist of the KMA (Alaskan-type), or (b) by tectonic interleaving of disrupted lower portions of the oceanic crust/mantle (Alpine-type). Alaskan-type emplacement can be precluded due to absence of internal zoning of the ultramafic bodies, lack of intrusive relations with gabbros and no thermal overprinting of the schist at the contact. A foliation-parallel contact between schist and ultramafic rock, internal foliation of the larger ultramafic bodies, and location of the ultramafic rocks along strike of the regional foliation support an Alpine-type emplacement. It follows that mica schist and serpentinite were juxtaposed during accretion onto the Yukon-Tanana Terrane, after the back-arc basin had collapsed and subducted.

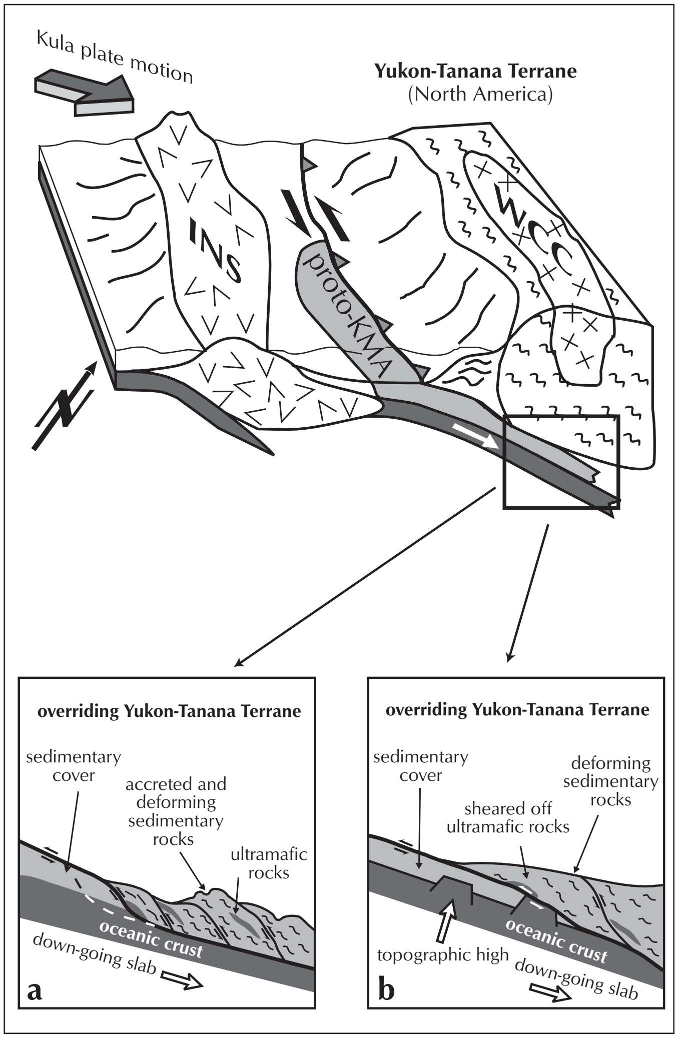

Figure 14. *Tectonic model of the accretion of the KMA onto the North American continental margin in the Late Cretaceous. The top block diagram shows the collapse of the back-arc basin into which the sedimentary protolith of the KMA was deposited. As the Kula plate changed motion towards the east at around 95 Ma (Engebretson et al., 1995), the Insular Superterrane (INS) was approaching the North American continental margin. This resulted in eastward oblique subduction of the KMA back-arc basin, and the development of a magmatic arc, possibly the Whitehorse Coffee Creek arc (WCC, J. Mortensen, pers. comm., 1999). The pair of black arrows indicates a sinistral strike-slip component. (a) Accretion of tectonically interleaved metasedimentary and ultramafic rocks by development of duplex structures (Platt, 1986). (b) Tectonic underplating by shearing off topographic highs of the oceanic crust and inter-foliating ultramafic with metasedimentary rocks along detachment zones (Karig and Sharman, 1975).*

The mode of tectonically interleaving ultramafic rocks with the schist is poorly understood. One model suggests that during underplating, detachment faults or shear zones could form (Fig. 14). These faults could cut through the sedimentary cover and oceanic crust of the down-going plate, resulting in duplex structures being accreted to the overriding plate (Fig. 14a; Platt, 1986). Alternatively, Karig and Sharman (1975) proposed that the ultramafic rocks represented topographic highs, such as horst structures or seamounts, that were sheared off and subsequently tectonically interleaved and deformed with the scraped off sedimentary rocks (Fig. 14b).

During the underplating process, the sedimentary rocks were ductilely deformed and metamorphosed to become mylonitic mica schist. Geobarometry on garnet cores indicate that this process took place at depths of 20-25 km (Mezger et al., in review). The direction of underplating or underthrusting can be deduced from the orientation of mineral lineation and sense of shear derived from rotated plagioclase porphyroclasts and c′-type shear bands in mylonitic schist. These indicate uniform eastward underthrusting of the KMA underneath the Yukon-Tanana Terrane. The oblique angle of underplating, implying a sinistral strike-slip component, could explain the presence of the ultramafic bodies along strike of the regional foliation. The four ultramafic lenses could be fragments of one large body that became disrupted during oblique underplating. Tectonic underplating of the KMA occurred in the Late Cretaceous. It is constrained by the change of motion of the Kula plate towards an easterly direction relative to North America, at around 95 Ma (Engebretson et al., 1995), and by intrusion of late deformational mafic dykes into the KMA at 72 Ma (Mezger et al., in review).

The tectonic setting of the KMA serpentinites is comparable to similar ultramafic bodies in the central and eastern Alaska Range, which are also located near the Denali Fault zone, and are interpreted to be Alpine-type (Nokleberg et al., 1985; Patton et al., 1994). With the exception of the Chulitna Terrane of central Alaska (Jones et al., 1980), serpentinites in Alaska and the Yukon are not correlated to any ophiolitic sequence. In absence of ophiolitic sequences, Alpine-type ultramafic rocks may be considered fragments of subcontinental mantle or oceanic crust or mantle. Bucher-Nurminen (1991) interpreted peridotites of the Scandinavian Caledonides interleaved with predominantly continental-derived metamorphic rocks, including quartzite and quartz-rich mica schist, as fragmented subcontinental mantle material. However, in eastern Alaska and the Yukon, the ultramafic rocks are generally associated with marine sedimentary, as well as other sedimentary rocks that are partly derived from juvenile island arcs. The sediments were most likely deposited in an oceanic back-arc basin, so that the ultramafic rocks associated with them probably represent fragments of oceanic crust or mantle.

CONCLUSIONS

Inter-foliation with mica schist, similar ductile fabrics in schist and ultramafic rocks, lack of internal zoning, and lack of intrusive relations with gabbro, suggest that the serpentinites of the KMA are Alpine-type ultramafic rocks. Though oxygen isotope studies cannot unequivocally prove ophiolitic origin of the olivine serpentinites, they record $\delta^{18}O$ values that are comparable to known ophiolitic serpentinites. It is concluded that the ultramafic rocks of the KMA represent remnants of an oceanic crust associated with a Mesozoic back-arc basin onto which the sediments of the proto-KMA were deposited. The basin collapsed in the Late Mesozoic. Fragments of it, the ultramafic and metasedimentary rocks of the KMA, were accreted onto the overriding North American plate. During accretion, the metasedimentary rocks and the serpentinites were strongly deformed and tectonically interleaved prior to the Early Tertiary intrusion of the Ruby Range Batholith. The KMA and similar metamorphic assemblages containing Alpine-type ultramafic rocks are located along the Denali Fault zone. This suggests that the Denali Fault zone is the location of a major suture zone or terrane boundary resulting from the collapse of a large oceanic basin or back-arc basin, which extended from central Alaska to southern Yukon.

ACKNOWLEDGEMENTS

I am indebted to Philippe Erdmer who introduced me to the Yukon and its geology. This paper is the result of a Ph.D. thesis under his supervision. Discussions with Karlis Muehlenbachs of the University of Alberta helped to clarify the oxygen isotope data. Financial support was provided by grants to the author from the University of Alberta, the Canadian Circumpolar Institute (CCI) and the Geological Society of America, and through Philippe Erdmer by NSERC. The logistical support of the Yukon Geology Program during the initial field work in 1993-95 and helicopter sharing is gratefully acknowledged. Rob Brown, Kevin Brett and Brys Francis provided excellent field assistance. Kluane Helicopters of Haines Junction is thanked for safe and on-time services. Thanks to Paul Bons and Sandra Piazolo for critical reviews of the first draft. Moa Zahid and Jacques Morel provided the French translation.

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Age, geochemistry, paleotectonic setting and metallogeny of Late Triassic-Early Jurassic intrusions in the Yukon and eastern Alaska: A preliminary report

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Mortensen, J.K., Emon, K., Johnston, S.T. and Hart, C.J.R., 2000. Age, geochemistry, paleotectonic setting and metallogeny of Late Triassic-Early Jurassic intrusions in the Yukon and eastern Alaska: A preliminary report. *In:* Yukon Exploration and Geology 1999, D.S. Emond and L.H. Weston (eds.), Exploration and Geological Services Division, Yukon, Indian and Northern Affairs Canada, p. 139-144.

ABSTRACT

Late Triassic to Early Jurassic age (~220-185 Ma) intrusions comprise one of the most widespread and volumetrically significant plutonic suites in central and western Yukon, and eastern Alaska, but have received very limited study thus far. A new research project has been initiated that will examine the temporal, geochemical and petrotectonic evolution of this magmatic event, and the nature and origin of associated Cu, Au and PGE mineralization. The intrusions are mainly hornblende- and biotite-bearing granodiorites and quartz monzonites, although granitic phases and rare ultramafic phases (as at Pyroxene Mountain) are also present. Several bodies of coarse-grained muscovite granite that are included within the suite have been recognized in southwestern Dawson, and central and western Stewart River map areas. Most intrusions give preliminary U-Pb zircon and titanite ages of ~195 Ma to ~185 Ma, although scattered bodies give ages up to 218 Ma. Geochemical studies completed thus far indicate that most intrusions are metaluminous and formed in a volcanic arc environment, although some of the muscovite-granite phases in western Yukon are peraluminous and trend into the anorogenic (within-plate) granite field on various tectonic discriminant plots. Dating studies at Minto and Williams Creek indicate that copper-gold mineralization in both areas is hosted in part by deformed intrusions dated at ~194 Ma and is crosscut by massive, post-mineralization Granite Mountain batholith dated at ~190 Ma. The mineralization is therefore intimately associated with the Triassic-Jurassic magmatism, and we tentatively interpret the deposits as deformed copper-gold porphyries.

RÉSUMÉ

Les intrusions du Trias supérieur au Jurassique inférieur (~220 à 185 Ma) sont une des suites plutoniques les plus répandues et les plus volumineuses du centre et de l'ouest du Yukon et de l'est de l'Alaska, mais elles n'ont pas encore fait l'objet d'une étude détaillée. On a entrepris un nouveau projet de recherche dans le cadre duquel on examinera l'évolution temporelle, géochimique et pétrotectonique de cet événement magmatique ainsi que la nature et l'origine de la minéralisation en Cu, Au et EGP qui lui est associée. Les intrusions sont surtout constituées de granodiorites et de monzonites quartzifères à hornblende et à biotite, bien qu'on retrouve également des phases granitiques et de rares phases ultramafiques (comme le mont Pyroxène). Plusieurs masses de granite à muscovite à grain grossier sont incluses dans la suite et on été identifiées dans le sud-ouest et le centre de la région de Dawson ainsi que les parties centrales et occidentales de la région de Stewart River. La datation au U-Pb du zircon et de la titanite de la plupart des plutons fournit des âges préliminaires entre ~ 195 Ma et ~185 Ma, bien que pour quelques plutons épars on obtient des âges allant jusqu'à 218 Ma. Les études géochimiques complétées jusqu'à maintenant indiquent que la plupart des plutons sont méta-alumineux et ont été formés dans un environnement d'arc volcanique insulaire, quoi que certaines des phases de granite à muscovite de l'ouest du Yukon soient hyperalumineuses et aient une affinité qui tend vers le champ anorogénique (intraplaque) sur divers graphiques de discrimination tectonique. Les études de datation à Minto et à Williams Creek indiquent que la minéralisation en cuivre-or dans ces deux régions est en partie encaissée dans des intrusions déformées qui ont été datées à ~ 194 Ma et qu'elle est recoupée par le batholite massif post minéralisation de Granite Mountain qui a été daté à ~ 190 Ma. La minéralisation est donc intimement associée avec le magmatisme du Trias-Jurassique et l'interprétation proposée est que les gisements représentent des gisements de porphyres à cuivre-or déformés.

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INTRODUCTION

Intrusions of Late Triassic to Early Jurassic age (~220-185 Ma) are widespread throughout central and western Yukon, and eastern Alaska; however, the age, lithogeochemistry, paleotectonic evolution and metallogenic significance of this magmatism have received very limited study thus far. In view of the current high level of industry interest in intrusion-related mineralization in this region, and the recognition that several important mineral deposits and occurrences are spatially and genetically associated with the Triassic-Jurassic intrusions, more detailed study of this magmatic event is clearly required. A new research project has been initiated that will include geological mapping, U-Pb and Ar-Ar dating, and petrochemical studies of the intrusions, as well as several of the mineral deposits and occurrences that are thought to be temporally and genetically related to them. In this paper we present a synthesis of our present understanding of the Triassic-Jurassic magmatism, and report new geochemical results for some of the main intrusions in the suite.

REGIONAL FRAMEWORK FOR THE MAGMATISM

Late Triassic and Early Jurassic plutonic rocks in the Yukon (Fig. 1) have been assigned to various plutonic suites, including the Klotassin, Long Lake and Aishihik suites (e.g., Woodsworth et al., 1991; Johnston et al., 1996). Many of the isotopic ages on which these subdivisions were based, however, have proven to be incorrect (e.g., Mortensen, 1999). A revised map showing the distribution of Late Triassic and Early Jurassic plutonic rocks presents a considerably different pattern of magmatism than appears on currently available compilations (e.g., Wheeler and McFeely, 1991). Several plutons that were previously thought to be Cretaceous or Paleozoic in age have now given Triassic or Jurassic U-Pb ages. At the same time, some large bodies (such as the large expanse of granitoids in the western Dawson Range) that were previously considered to be Triassic or Jurassic have given Early Cretaceous U-Pb ages. The available mapping and age database for these intrusions does not appear to be adequate to support a subdivision of the intrusions into individual suites as yet.

The revised map distribution of plutons of Late Triassic-Early Jurassic age in the Yukon and easternmost Alaska (Fig. 1) shows that the intrusions form two distinct, sub-parallel belts. Most plutons fall within a sinuous western belt that stretches from west of Whitehorse through the eastern Dawson Range in the Williams Creek and Minto areas, and across the Stewart River map area, before terminating in the south-central Eagle quadrangle in eastern Alaska. An eastern belt of smaller and more widely scattered intrusions extends from the Seagull area (Abbott, 1981) through the Thirtymile Range (Gordey et al., 1998), the Sawtooth Range (Stevens et al., 1993), to the Lokken batholith. It then crosses the future trace of the Tintina Fault, which, if reconstructed before dextral strike-slip displacement, would extend into the Simpson Lake and Finlayson Lake areas (now in southeast Yukon). It is uncertain whether this belt re-crosses the trace of the Tintina Fault back into the eastern Eagle quadrangle in Alaska. Intrusions in both belts appear to be mainly emplaced into metamorphic rocks of the Yukon-Tanana Terrane. Preliminary field observations indicate that these intrusions are broadly late syn- to post-tectonic with respect to the main ductile deformation that affected this region. This deformation is thought to be associated with final terrane amalgamation in the northern Cordillera, and an improved understanding of the Triassic-Jurassic magmatism may shed new light on processes of terrane accretion as they operated in this area.

LITHOLOGY

The Late Triassic-Early Jurassic intrusions are compositionally highly variable. Most bodies are broadly intermediate in composition, but mafic to ultramafic phases, including mafic syenite, hornblendite, dunite, troctolite and clinopyroxenite are also locally present. Granitic phases are well developed in the western plutonic belt in the Stewart River map area and Eagle quadrangle. There, they occur both as relatively large, discrete plutons such as at Jim Creek and Crag Mountain (Fig. 1), and as swarms of felsic dykes and sills, such as those along the Yukon River between the mouths of the Stewart and Sixtymile rivers. Intermediate composition bodies commonly display a weakly to moderately developed foliation, although this fabric generally appears to be a result of magmatic flow, rather than tectonic deformation. Intermediate composition phases typically also contain abundant coarse pink K-feldspar phenocrysts, with strong igneous zoning defined by bands of biotite inclusions.

AGE CONSTRAINTS ON THE MAGMATISM

Preliminary U-Pb and Ar-Ar dating studies of the intrusions indicate crystallization ages that are mainly in the range of 195 Ma to 185 Ma (Early Jurassic) in both the western and eastern plutonic belts (Fig. 1). Scattered intrusions in the western belt yield ages up to 220 Ma (Late Triassic; Johnston et al., 1996; Hart, 1995; Mortensen, this study). Available data are too scattered at present to indicate any spatial or temporal trends in the magmatism. U-Pb zircon systematics of the intrusions are typically very complex, and indicate the presence of abundant inherited zircon components with a wide variety of ages. U-Pb dating of titanite has proven to be very useful for determining crystallization ages. Most K-Ar ages for the intrusions reflect at least minor disturbance, and should be considered suspect unless confirmed by an independent dating method.

GEOCHEMISTRY OF LATE TRIASSIC-EARLY JURASSIC PLUTONIC ROCKS

Major, trace and rare-earth element (REE) analyses have been obtained for a number of plutons of known Late Triassic-Early Jurassic age. This includes several phases of the Jim Creek pluton, as well as the Granite Mountain pluton, and syndeformational biotite-granodiorite orthogneiss and K-feldspar-megacrystic granite at the Minto copper deposit, all in the western plutonic belt. It also includes several small porphyritic hornblende-biotite granodiorite bodies from the Simpson Lake area in the eastern plutonic belt (Fig. 1). Preliminary interpretations of these data are presented here, together with data from the Aishihik batholith and Long Lake suite in the western plutonic belt (Johnston, unpublished data).

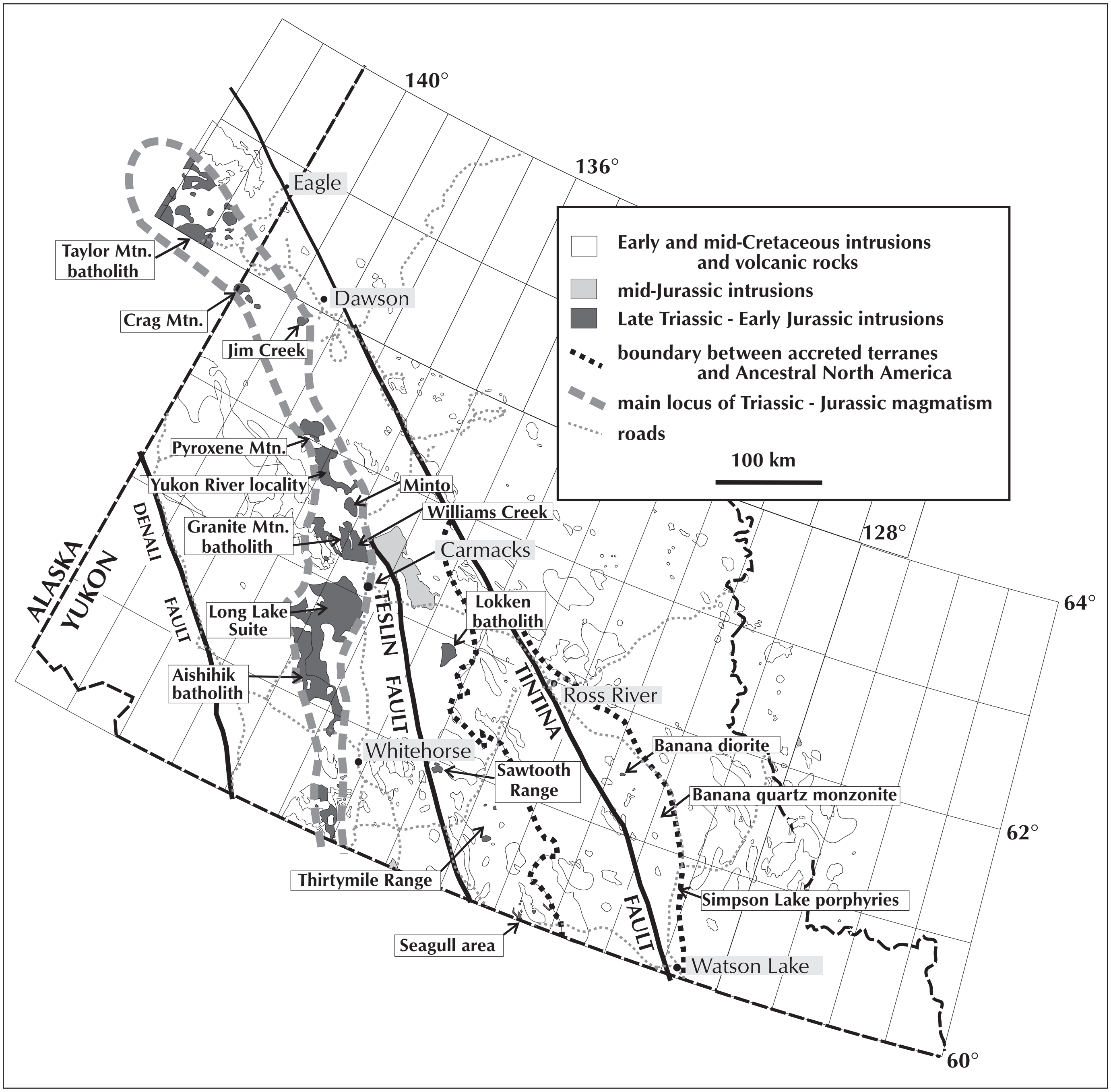

Figure 1. *Distribution of Late Triassic and Early Jurassic plutons in the Yukon and eastern Alaska (modified from Wheeler and McFeely, 1991).*

A Shand's index plot for the samples (Fig. 2a) shows that the Jim Creek granite and the Minto orthogneiss and megacrystic granite are peraluminous in composition, whereas the Simpson Lake porphyry bodies, the Granite Mountain batholith, and all phases of the Aishihik batholith and Long Lake suite are metaluminous. The Rb vs. Nb+Y discrimination diagram of Pearce et al. (1984) shows all samples plotting in the volcanic-arc-granite field (Fig. 2b). This interpretation is consistent with data from the primitive-mantle-normalized multi-element plots for the samples (Sun and McDonough, 1989). All samples show significant negative Nb and Ti anomalies (Fig. 2c), consistent with production in a dominantly arc setting. High field strength element (such as Ti and Nb) depletion is a common feature in igneous rocks from such an environment. The Jim Creek pluton also shows a higher total content of REE and more strongly developed Nb and Ti anomalies than the other samples. A discrimination plot of Ga/Al-Zr (Fig. 2d; Whalen et al., 1987) shows the majority of the samples plotting within the field for I- and S-type granitoids, with the Jim Creek samples plotting on the boundary with the within-plate, A-type granitoids.

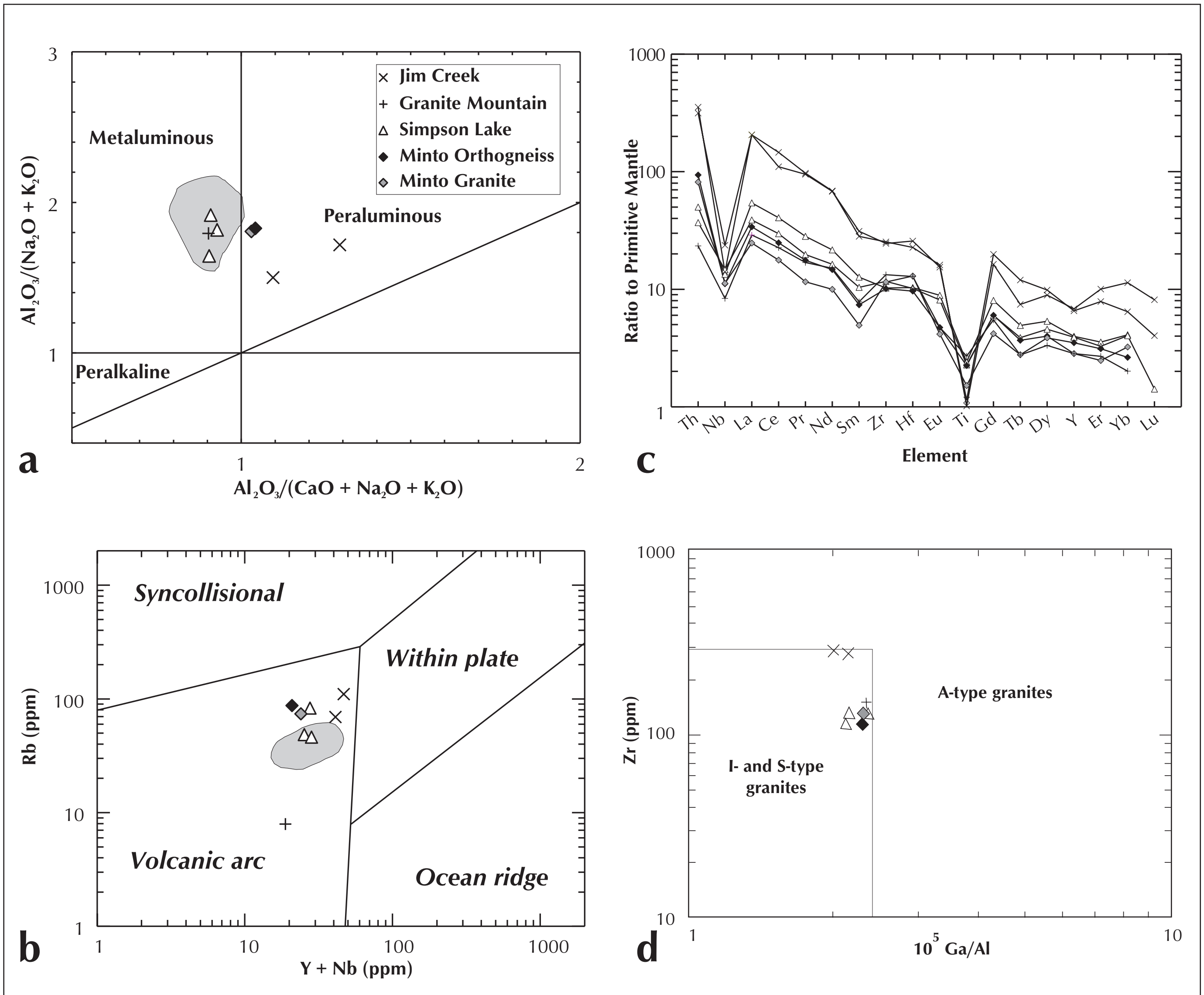

Figure 2. *a) Shand's index plot for Triassic and Jurassic intrusions. Shaded field represents range of analyses from the Aishihik batholith and Long Lake suite (Johnston, unpublished data). b) Nb-Y discrimination diagram for Triassic and Jurassic intrusions from Pearce et al. (1984). Shaded field represents range of analyses from the Aishihik batholith and Long Lake suite (Johnston, unpublished data). c) Primitive-mantle-normalized multi-element plots for Triassic and Jurassic intrusions (from Sun and McDonough, 1989). d) Ga/Al-Zr discrimination plot for I-, S- and A-type granites (from Whalen et al., 1987).*

These preliminary data show that the Late Triassic-Early Jurassic plutons vary from metaluminous to peraluminous, and show trace element distributions consistent with formation in an arc environment. The patterns seen in the Jim Creek samples may indicate evolution toward a more anorogenic environment of formation. At this point, there is no apparent geochemical difference between intrusions in the eastern and western plutonic belts.

METALLOGENY

Several distinct styles of mineralization are spatially and probably genetically associated with the Triassic-Jurassic intrusions. Low-grade, disseminated Au and PGE mineralization occurs within Early Jurassic clinopyroxenite on Pyroxenite Mountain (Fig. 1; occurrence 115NO 116; Yukon Minfile, 1997), and in Early Jurassic mafic and ultramafic intrusions in the Eagle quadrangle in eastern Alaska (Foley et al., 1989; Newberry et al., 1997). In addition, intrusion-hosted, Au-Cu-Te-bearing quartz veins with Early Jurassic Ar-Ar ages in southeastern Eagle quadrangle have also been described by Newberry et al. (1997).

Copper (-gold) deposits at Minto and Williams Creek in west-central Yukon (Fig. 1) represent the most significant mineralization associated with the Triassic-Jurassic magmatism. The nature and origin of mineralization at Minto and Williams Creek has been a topic of debate for many years. The deposits have been variously interpreted as metamorphosed volcanogenic massive sulphide (VMS) deposits, metamorphosed redbed Cu deposits, and deformed Cu (-Au) porphyry deposits (see discussion by Pearson and Clark, 1979). Preliminary work by the authors on the Minto deposit demonstrates that the main host for the ore is a biotite-rich orthogneiss with a U-Pb zircon (crystallization) age of ~194 Ma. Mineralization was probably accompanied by potassic alteration which introduced abundant secondary biotite into the host rock. This occurred prior to deformation and the subsequent intrusion of the undeformed and post-mineral Granite Mountain batholith at ~190 Ma (U-Pb titanite age). These data are quite consistent with a syn-tectonic porphyry model for the deposit, and possible analogies exist with the Gibraltar deposit in south-central B.C.

The Williams Creek deposit is hosted largely within metavolcanic and metasedimentary rocks of the Yukon-Tanana Terrane, and in deformed granitoid bodies that intrude them. These granitoids yield a preliminary zircon U-Pb age of ~193 Ma. As with the Minto deposit, ore bodies at Williams Creek were deformed along with their host rocks prior to the intrusion of the Granite Mountain batholith at ~190 Ma. The Williams Creek deposit is therefore also interpreted by the authors as a deformed, intrusion-related Cu (-Au) deposit resembling better-known Cu-Au deposits such as at Copper Mountain in southern B.C. (Stanley et al., 1995).

Interestingly enough, the age constraints on mineralization at the Minto deposit are very similar to those at the Mt. Milligan Cu-Au porphyry deposit in central B.C. (e.g., Mortensen et al., 1995). Together, the Minto and Williams Creek deposits are thought to represent deformed end members of broadly porphyry-style Cu (-Au) deposits that are intimately associated with Early Jurassic magmatism that is the focus of this study.

DISCUSSION

A better understanding of the Triassic-Jurassic magmatism is important for three main reasons.

- These plutons represent one of the most voluminous plutonic suites in the northern Cordillera, but have received very limited study.
- Emplacement of the intrusions was broadly synchronous with terrane amalgamation in the northern Cordillera; thus, improved constraints on the evolution of the magmatism will help constrain terrane accretion models for this region.
- Two very significant Cu (-Au) deposits (Minto and Williams Creek) are intimately and probably genetically associated with intrusions of this suite. In addition, disseminated magmatic PGE mineralization and gold-bearing quartz-vein occurrences are associated with these intrusions, highlighting the economic importance of the intrusions.

FUTURE WORK

Research to be undertaken over the next three years as part of a Ph.D. dissertation by the second author will include:

- Examination and sampling of Late Triassic and Early Jurassic intrusive rocks throughout southern and western Yukon, and eastern Alaska.
- Geological mapping of intrusions in several specific areas (west-central Stewart River, Minto/Williams Creek deposits) to resolve the exact relationship between intrusion, deformation and mineralization.
- Detailed U-Pb and Ar-Ar dating studies to constrain the emplacement and cooling history of various plutons.
- Additional lithogeochemical and trace isotope (Nd, Sr, Pb) studies to constrain the petrochemical and petrotectonic evolution of the magmatism
- Documentation and Pb isotopic studies of associated mineral occurrences to evaluate the genetic relationships between mineralization and magmatism.

ACKNOWLEDGMENTS

The authors wish to thank the Yukon Geology Program who provided funding for the geochemical analyses. Funding for the on-going geochronological study was provided through J.K. Mortensen's NSERC Research Grant.

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Age, geochemical and metallogenic investigations of Cretaceous intrusions in southeastern Yukon and southwestern NWT: A preliminary report

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Heffernan, S. and Mortensen, J.K., 2000. Age, geochemical and metallogenic investigations of Cretaceous intrusions in southeastern Yukon and southwestern NWT: A preliminary report. *In:* Yukon Exploration and Geology 1999, D.S. Emond and L.H. Weston (eds.), Exploration and Geological Services Division, Yukon, Indian and Northern Affairs Canada, p. 145-149.

ABSTRACT

The geochronology and geochemistry of Cretaceous intrusions and associated mineralization in southeastern Yukon and southwestern NWT is the focus of a new research project. The objective is to investigate the southeastern extension of well-established plutonic suites currently recognized in central and western Yukon. Here we report five new U-Pb zircon ages from the study area that indicate that at least three distinct ages of intrusions are present. Two bodies (Bennett Creek pluton and an unnamed body west of Tungsten) give ages of ~91 Ma and are correlated with the Tombstone Plutonic Suite. Two phases of the Coal River batholith give ages of ~96 Ma and are considered to be part of the Tay River plutonic suite. Finally, the Mt. Billings Batholith east of Tuchitua Junction gives an age of ~106 Ma, and is correlated with the Anvil plutonic suite. Compositionally, the intrusions range from monzogranite to granodiorite and most contain at least minor amounts of biotite ± hornblende ± magnetite. Also, they are dominantly peraluminous to slightly metaluminous, subalkalic, relatively oxidized, and appear to span I-, S-, and A-type (within-plate) fields on various lithogeochemical discriminant plots. These new data will help constrain genetic and exploration models for a wide variety of Cretaceous intrusion-related gold and base metal mineral deposit types in the study area.

RÉSUMÉ

La géochronologie et la géochimie d'intrusions d'âge Crétacé et de la minéralisation associée, dans le sud-est du Yukon et le sud-ouest des T.N.-O., font l'objet d'un nouveau projet de recherches. L'objectif de cette étude est de déterminer l'extension sud-est de suites plutoniques bien établies qui sont actuellement reconnues dans le centre et l'ouest du Yukon. Nous présentons ici cinq nouvelles datations au U-Pb du zircon, provenant de la région à l'étude, qui indiquent la présence d'au moins trois périodes intrusives d'âges distincts. Deux masses intrusives (le pluton de Bennet Creek et un pluton sans nom situé à l'ouest de Tungsten) datent d'environ 91 Ma et on peut les corréler avec la Suite plutonique de Tombstone. Deux des phases du pluton de Coal River datent de 96 Ma et on considère qu'elles appartiennent à la suite plutonique de Tay River. Enfin, le Batholite du mont Billings, situé à l'est de Tuchitua Junction, date de 106 Ma et on peut le corréler avec la suite plutonique d'Anvil. La composition des intrusions varie du monzogranite au granodiorite et la plupart contiennent au moins de petites quantités de biotite ± hornblende ± magnétite. De plus, ils sont surtout hyperalumineux à légèrement méta-alumineux et subalcalins, relativement oxydés et, sur divers graphiques de discrimination lithogéochimique, paraissent chevaucher les champs des types I, S et A (intraplaques). Ces nouvelles données vont aider à définir les modèles génétiques et d'exploration pour une grande variété de types de minéralisations aurifères et de métaux communs qui sont associées aux intrusions d'âge Crétacé qui sont présentes dans la région à l'étude.

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INTRODUCTION

Recent investigations within the Tintina gold belt (TGB) in central and western Yukon, conducted primarily by the Mineral Deposit Research Unit at UBC and the Yukon Geology Program, has led to the identification of numerous distinct plutonic suites (Fig. 1). Individual suites are distinguished based on their lithological, geochemical, and geochronological characteristics, as well as their metallogenic associations. The aim of this project is to investigate extensions of the plutonic suite designations, as currently defined, into the much less studied eastern and southern extent of the TGB in southeastern Yukon and southwestern NWT (Fig. 1). The study area comprises most of map sheets 95 D (Coal River), 95 E (Flat River), 95 L (Glacier Lake), 105 A (Watson Lake), 105 H (Frances Lake) and 105 I (Nahanni).

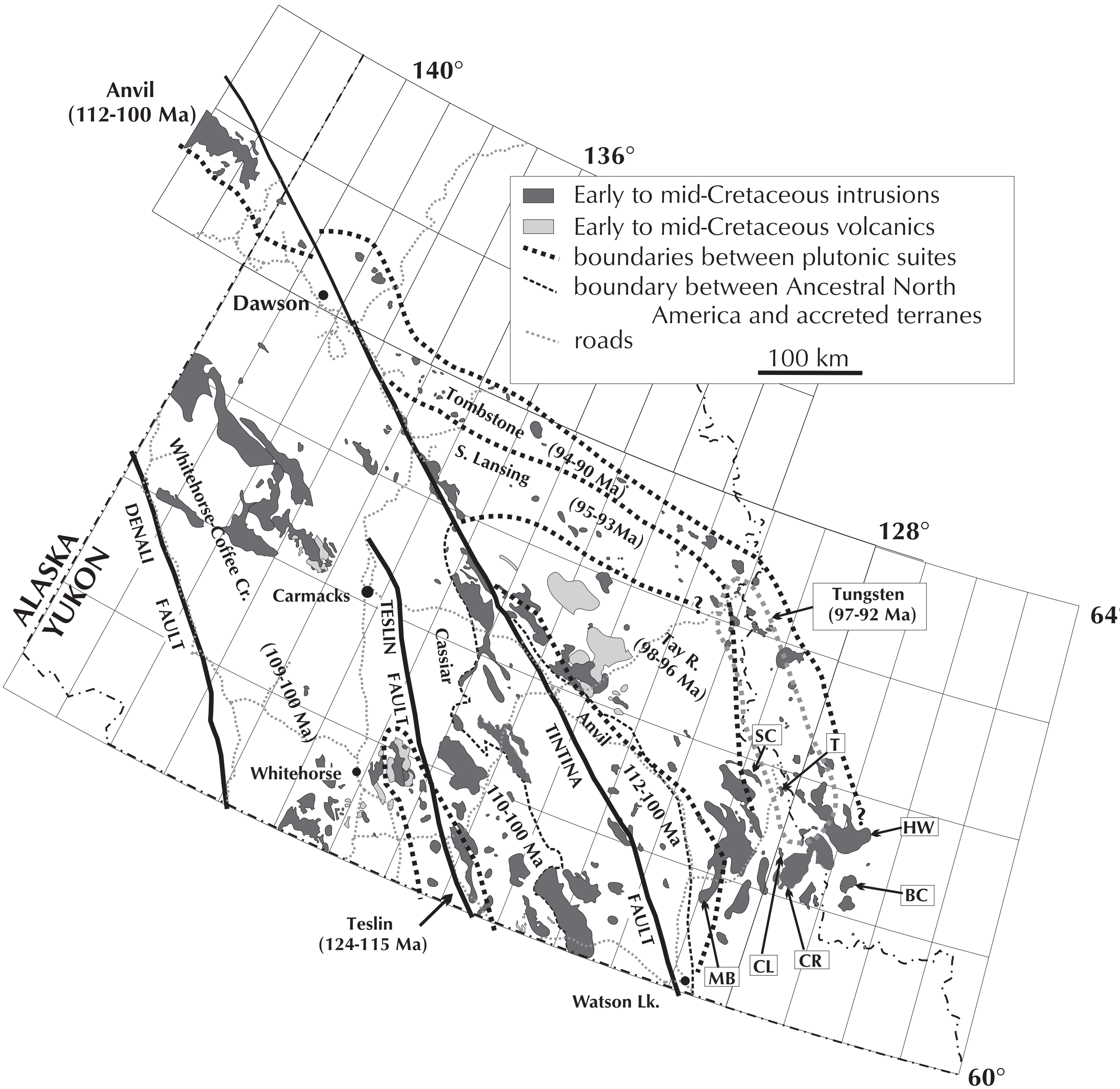

Figure 1. *Regional map showing the distribution of Early and mid-Cretaceous plutons and volcanic rocks (modified from Wheeler and McFeely, 1991). Individual plutons referred to in the text include: MB = Mt. Billings; CR = Coal River; SC = Shannon Creek; BC = Bennett Creek; T = Tuna stock; CL = Caesar Lakes; HW = Hole-in-the-Wall.*

The study area contains a wealth of mineral deposits and occurrences that are likely intrusion-related, including a wide variety of base and precious metal-bearing skarn, carbonate-replacement, porphyry and vein occurrences. Previous exploration efforts in the area, however, have been hampered by a lack of information concerning the age and geochemistry of plutonic rocks, and the relationship between intrusions and mineralization. In this paper we report initial geochronological and geochemical data for samples collected from separate intrusions and/or phases of composite intrusions. Many of the intrusions in the study area are unnamed, and in this report we use informal names (shown in Fig. 1) for simplicity.

TEXTURE AND LITHOLOGY

Three distinct textural varieties are observed within the intrusions in the study area, based on hand sample and initial petrographic examination (Table 1). Most intrusions show an equigranular texture in which grain size can vary greatly, ranging from coarse (~1 cm) to very fine (<1 mm). Equigranular textures are typical of the larger intrusions in the area, such as the Coal River and Mt. Billings batholiths. Megacrystic textures with K-feldspar phenocrysts up to 4 cm in length are less abundant, and are present in some of the smaller bodies such as the Bennett Creek and Caesar Lakes plutons. Distinctly foliated textures have thus far only been observed in the Shannon Creek pluton.

The intrusions all contain roughly subequal amounts of quartz, plagioclase, and K-feldspar, and cluster between the monzogranite and granodiorite fields on a standard Q-A-P (IUGS) granitoid discrimination diagram. All samples contain varying amounts of biotite ± hornblende ± magnetite. The Tuna stock contains a very minor amount (<1%) of muscovite; however it differs from Gordey and Anderson's (1993) 'two-mica plutons' as defined in the Nahanni map area in that it also contains a small amount of hornblende.

GEOCHRONOLOGY

Five new U-Pb zircon ages have been obtained from intrusions in the study area. Results are summarized in Table 1. Zircons from the three smaller plutons (Bennett Creek, Shannon Creek, and Caesar Lakes plutons) show very simple U-Pb systematics, in contrast with the larger intrusive bodies (Mt. Billings and Coal River batholiths) which display much more complex U-Pb zircon systematics, with evidence for a large amount of inherited zircon. U-Pb dating of titanite from several of the intrusions will be undertaken in order to constrain the emplacement ages of these bodies.

The results indicate that intrusions of several ages are present. The southeasternmost intrusion (Bennett Creek) and the northwesternmost intrusion (Shannon Creek) give ages of 91.0 ± 03 to 92.5 ± 04 Ma, suggesting that they represent a southeastern continuation of the Tombstone Plutonic Suite (~92 Ma). Samples from two different phases of the Coal River batholith give ages of ~96 Ma. This age and the mineralogy of the samples support correlation with the Tay River plutonic suite

Table 1. *Summary of sample locations, textural characteristics and U-Pb ages.*

Sample #	Intrusion Name	Easting	Northing	NTS Map Sheet	U-Pb Age (Ma)	Texture/Fabric
SH-99-001	Shannon Creek pluton	511410	6860975	105H15	92.5 ± 0.4	foliated
SH-99-002	Shannon Creek pluton	510575	6861110	105H15	n/a	foliated
SH-99-006	Coal River batholith	569700	6796900	95E/05	96.9 ± 0.4	equigranular
SH-99-007	Coal River batholith	571000	6798125	95E/05	n/a	equigranular
SH-99-008	Coal River batholith	574000	6803635	95E/05	95.6 ± 0.3	equigranular
SH-99-009	Coal River batholith	581700	6824250	95E/11	n/a	equigranular
SH-99-010	Bennett Creek pluton	628757	6799292	95E/07	n/a	megacrystic
SH-99-011	Bennett Creek pluton	624400	6789175	95E/02	91.0 ± 0.3	megacrystic
SH-99-012	Bennett Creek pluton	621528	6794800	95E/07	n/a	megacrystic
SH-99-013	Caesar Lakes pluton	559500	6799200	95E/05	n/a	equigranular
SH-99-014	Caesar Lakes pluton	556750	6802500	95E/05	n/a	equigranular
SH-99-015	Caesar Lakes pluton	555870	6800680	95E/05	n/a	equigranular
SH-99-016	Tuna stock	541644	6855058	105H16	n/a	megacrystic
SH-99-022	Mt. Billings Batholith	507300	6757200	105A15	106.4 ± 0.4	equigranular

to the northwest. The Mt. Billings Batholith is the westernmost body that was dated, and gives a somewhat older age (~106 Ma). This intrusion is therefore considered to be a part of the Anvil plutonic suite.

GEOCHEMISTRY

Geochemical analyses have been obtained from 14 samples from 6 individual intrusions in the study area. Preliminary interpretations of the geochemical data are presented below, and the data are shown on various geochemical discriminant plots in Figure 2. The intrusions are predominantly peraluminous to slightly metaluminous (Fig. 2a), subalkalic with SiO_2 contents ranging from 65 to 75% (Fig. 2b), and are at least slightly oxidized, based on Fe_2O_3/FeO ratios. The primitive-mantle-normalized rare earth element (REE) diagram (Fig. 2c) shows that all intrusions have experienced some degree of feldspar fractionation, as evidenced from the slight to moderate negative Eu anomalies. There is also a less consistent negative Tm anomaly present in the samples, but this is more than likely the result of analytical error as heavy rare earth elements (HREE) tend not to completely dissolve during the analytical process (S. Piercey, pers. comm., 1999). On tectonic discriminant plots (Fig. 2d), it is apparent that these intrusions do not show any particular affinity towards a single, clearly isolated tectonic environment; instead they tend to overlap the boundaries between 'within-plate' (A-type) granites, syncollisional (S-type) and volcanic-arc (I-type) granites.

MINERAL POTENTIAL

A variety of intrusion-hosted and intrusion-related deposits and occurrences are known in the eastern Selwyn Basin. These include W (± base metal) skarns such as Mactung, Cantung, and

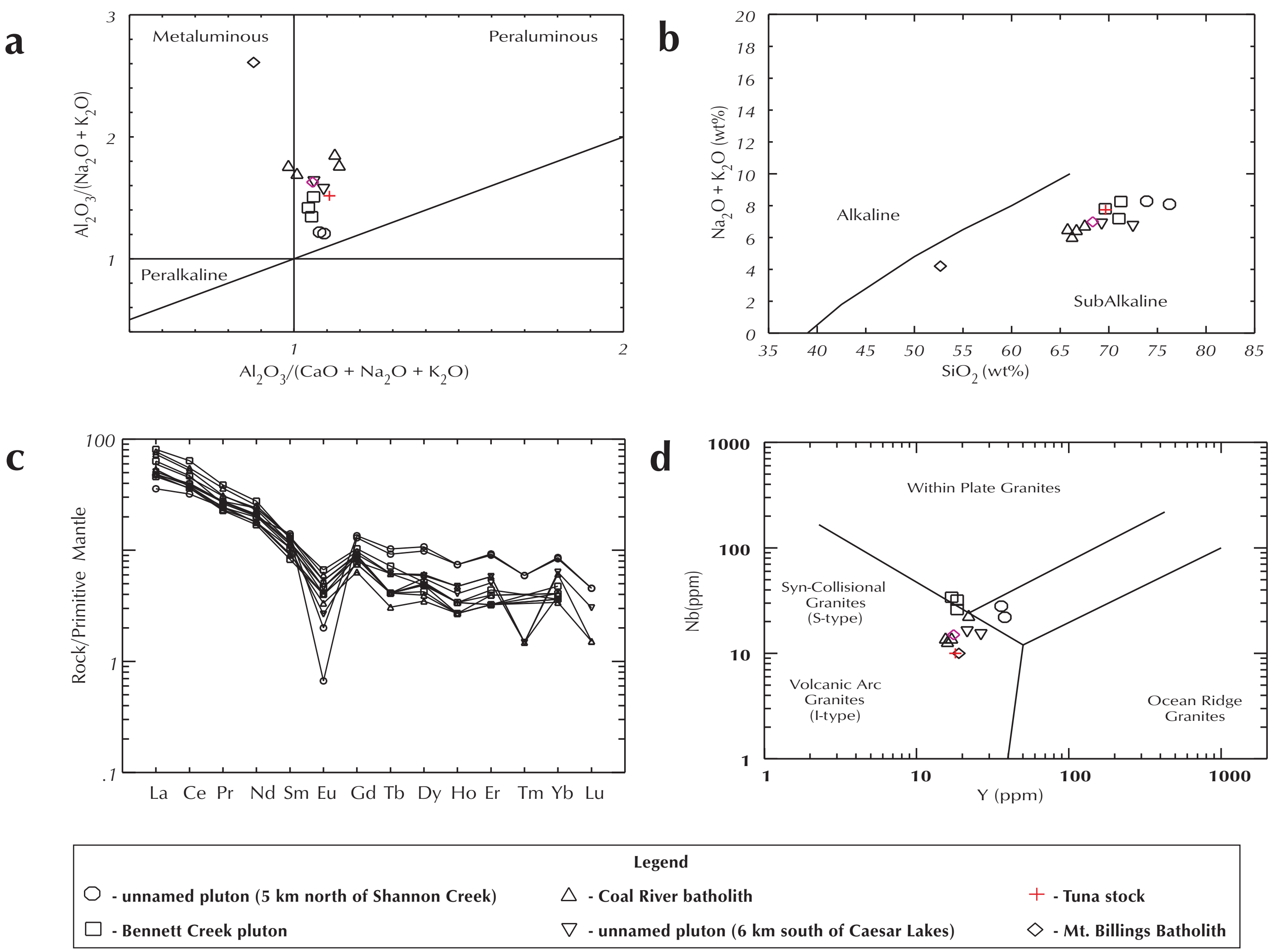

Figure 2. *Geochemical plots from whole rock analyses of granitoid rocks: a) Shand Index (after Maniar and Piccoli, 1989) depicting the dominantly peraluminous nature of the intrusions. b) Total alkalies versus silica plot (Irvine and Barager, 1971). c) Primitive-mantle-normalized REE diagram (values from Sun and McDonough, 1989). d) Nb versus Y diagram (Pearce et al., 1984).*

Lened; Ag-rich base metal skarns and mantos such as Sa Dena Hes; gold-bearing sheeted quartz veins (e.g., within the Mactung intrusion); distal, apparently structurally controlled deposits such as Hyland; and massive sulphide replacement deposits such as Macmillan. Indeed, at least 45% of the 325 Minfile occurrences listed for the six map sheets that comprise the study area are definitely or arguably intrusion-related (Yukon Minfile, 1997). This has led to a considerable amount of interest from exploration companies in the mineral potential of this region. In particular, Hudson Bay Exploration & Development and Viceroy Resources/Novagold Resources have had on-going exploration programs in the region over the past two years, and additional work is likely.

DISCUSSION

Initial results from this study indicate that intrusions in the southeastern part of the TGB show at least subtle differences from intrusions elsewhere in the TGB in the Yukon (as described by Lang et al., in press). Intrusions in the study area have slightly elevated average SiO_2 content, are typically more peraluminous, have significantly larger negative Eu anomalies, and show more of an affinity with A-type ('within-plate') granites. Our results indicate that various intrusions in the study area can be correlated with the Tombstone, Tay River and Anvil plutonic suites, but the Tombstone and Tay River equivalents show complete spatial overlap (Fig. 1).

Future investigations will include:

- additional sampling of intrusions in the study area to complete the lithogeochemical and geochronological coverage;
- radiogenic isotope studies (Nd, Sr, and Pb) to gain a better understanding of the underlying basement rocks within the region;
- sampling of known mineral occurrences for mineralogical and Pb isotopic studies (probably in conjunction with geologists from the Yukon Geology Program); and
- a modest amount of mapping of selected intrusive complexes.

ACKNOWLEDGEMENTS

The authors wish to thank the Yukon Geology Program who provided funding for the geochemical analyses. Funding for the geochronological study was provided through J.K. Mortensen's NSERC Research Grant. And lastly, special thanks go to Mike Buchanan and Hudson Bay Exploration and Development Co. Ltd. who contributed all needed logistical support and to the Hyland (Happy) Valley crew who all assisted in collecting the needed samples.

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Structural evolution and controls on gold mineralization at Clear Creek, Yukon

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Stephens, J.R., Oliver, N.H.S., Baker, T. and Hart, C.J.R., 2000. Structural evolution and controls on gold mineralization at Clear Creek, Yukon. *In:* Yukon Exploration and Geology 1999, D.S. Emond and L.H. Weston (eds.), Exploration and Geological Services Division, Yukon, Indian and Northern Affairs Canada, p. 151-163.

ABSTRACT

Gold mineralization in the Clear Creek area is associated with ca. 92 Ma Tombstone Plutonic Suite intrusions (TPS) emplaced into metasedimentary rocks of the Neoproterozoic to Early Cambrian Hyland Group. Hyland Group rocks have undergone four ductile deformations (D_1-D_4) in the structurally thick (>10 km) Jura-Cretaceous Tombstone high strain zone. Kinematic features indicate overall top-to-the-northwest movement on shallow shear planes. Four different types of quartz veins developed during ductile deformation and are associated with a progression from ductile to brittle-ductile behaviour. Three major brittle structural trends postdate ductile deformation. A set of sinistral ~165° striking faults developed and are crosscut by secondary east-west fracture zones in Hyland Group rocks. The Tombstone Plutonic Suite was then emplaced in a broadly east-west oriented belt, with some local control exerted by the ~165° oriented faults. Continued development of the east-west fracture set after the Tombstone Plutonic Suite intrusion, resulted in an extensive system of gold-bearing sheeted quartz veins. Finally, sinistral reactivation and associated quartz-tourmaline veining occurred on ~165° oriented structures.

Preliminary analysis of fault geometry and connectivity suggests the most favourable sites for mineralization are east-west fracture zones connected to ~165° oriented faults. Other favourable structural sites include misoriented segments of ~165° faults and possibly northeast-striking structures connected to ~165° faults. Mapping has delineated a large area of contact metamorphism suggesting extensive shallowly buried intrusions. The highest priority in any exploration program should be given to sites that are coincident with shallowly buried, or that are near Tombstone Plutonic Suite intrusions and have the above fault/fracture geometries.

RÉSUMÉ

La minéralisation aurifère dans la région de Clear Creek est associée à des intrusions de la Suite plutonique de Tombstone (SPT), datant de 92 Ma, qui ont été mises en place dans les roches métasédimentaires du Groupe de Hyland du Protérozoïque tardif au Cambrien précoce. Dans la zone structuralement épaisse (>10 km) intensément déformée de Tombstone (d'âge Jura-Crétacé) les roches du Groupe de Hyland ont subi quatre épisodes de déformation ductile (D1 à D4). Les indicateurs cinématiques témoignent de mouvements le long de plans de cisaillement à pendage faible à vergence vers le nord-ouest. Quatre types différents de veines de quartz ont été formés lors de la déformation ductile et sont associés au changement de caractère du mouvement de ductile à ductile-cassant. Trois axes structuraux principaux à caractère cassant ont suivi la déformation ductile. Un jeu de failles de direction ~165° et à mouvement senestre a été formé dans les roches du Groupe Hyland et a été suivi par la formation de zones de fractures secondaires orientées vers l'est. La SPT s'est mise en place le long d'une ceinture orientée grossièrement est-ouest, localement contrôlée par les failles orientées à ~165°. La continuation du développement du jeu de fractures orientées est-ouest a produit un vaste réseau de filons paralleles de quartz aurifère. Finalement, une réactivation du mouvement senestre a été accompagnée par la formation de veines de quartz-tourmaline dans les structures orientées à ~165°.

Une analyse préliminaire de la géométrie et de la connectivité des failles indique que les sites les plus favorables pour la minéralisation sont les zones de fractures orientées est-ouest qui interceptent les failles orientées à ~165°. D'autres sites structuraux favorables incluent les segments des failles à ~165° dont l'orientation a été changée ainsi que, peut-être, les structures orientées nord-est qui interceptent les failles à ~165°. Une vaste étendue de métamorphisme de contact, mise à jour par la cartographie sur le terrain, suggère la présence d'intrusions d'envergure à faible profondeur. On devrait accorder la plus haute priorité aux programmes d'exploration ciblant les sites qui coïncident avec des intrusions à faible profondeur de la SPT ou qui sont situés à leur proximité et qui présentent les géométries de failles et de fractures qui ont été décrites ci-haut.

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INTRODUCTION

This study was initiated in order to evaluate the structural, environmental, as well as temperature and pressure conditions, associated with emplacement of Tombstone Plutonic Suite (TPS) intrusions and related gold mineralization. The focus of 1999 field work was the Clear Creek area, with the initial goals as follows:

- Establish the structural setting of granite emplacement.
- Determine the structural and thermal history of the area.
- Place the formation of gold-bearing veins into a paragenetic framework.

The main methods used in this study were field mapping and structural analysis.

LOCAL GEOLOGY

The Clear Creek area is underlain by (in order of abundance) psammite, phyllite, quartzite, conglomerate, schist and calc-silicate rocks of the Neoproterozoic to Early Cambrian Hyland Group (Fig. 1). These rocks have been deformed and metamorphosed in the structurally thick (>10 km) Jura-Cretaceous Tombstone high-strain zone 'THSZ' (Tombstone Strain Zone of Murphy, 1997). Multiple deformation events indicate overall top-to-the-northwest movement on shallow north-dipping planes. These fabrics have been folded by the broad, upright, gently west-plunging McQuesten Antiform.

The TPS intruded deformed Hyland Group rocks under shallow crustal conditions (<3 kb – Baker and Lang, 1999). The intrusions clearly crosscut the main ductile fabrics in the THSZ, and have been dated at 91.4 ± 0.8 Ma (Murphy, 1997). Marsh et al., (1999) described six stocks of the TPS in the Clear Creek area (Fig. 2). The stocks range in composition from medium- to

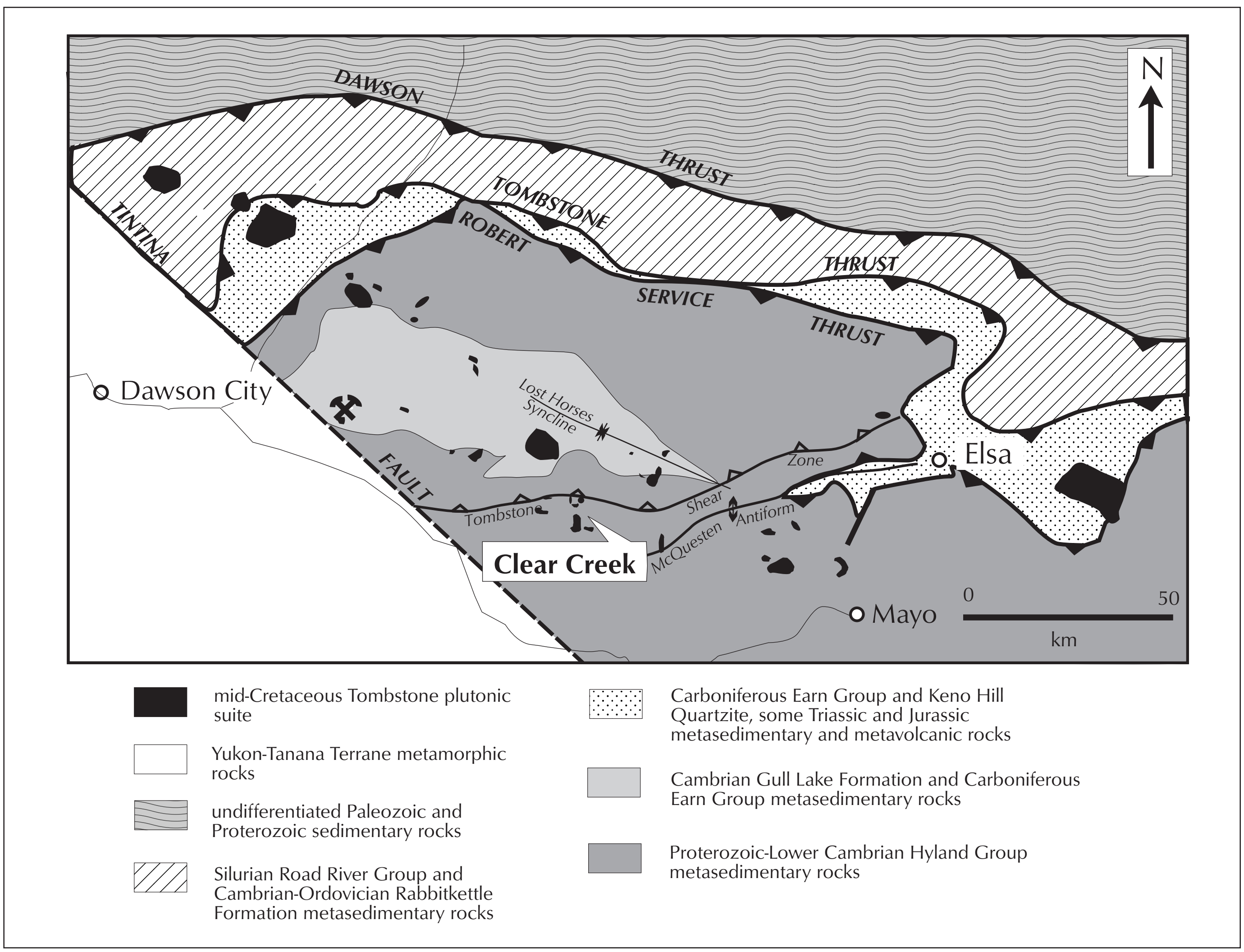


Figure 1. *Location and regional geology map (after Murphy, 1997).*

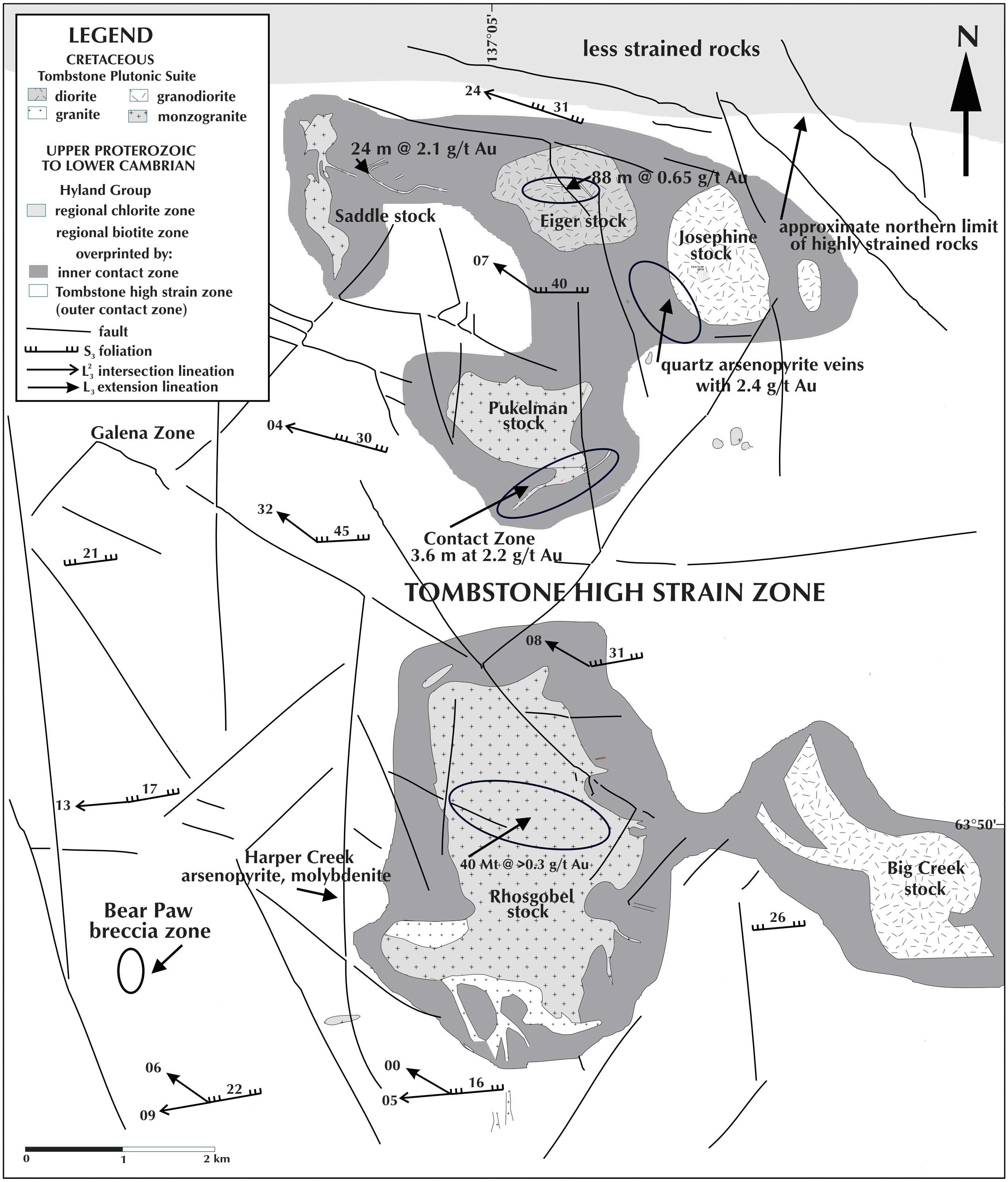


Figure 2. Geological map of the Clear Creek area with metamorphic zones.

coarse-grained quartz monzonite to granodiorite and diorite. There is a broad compositional zoning of the main intrusions at Clear Creek, with more mafic (diorite and granodiorite) plutons to the east and more felsic (quartz monzonite) plutons to the west. West of the main Clear Creek area, however, the Grizzly stock (Allen et al., 1998) and Barney stock have east-west elongation, parallel to the regional trend of the TPS belt. Contact metamorphic aureoles with andalusite and biotite porphyroblasts, and finer grained biotite are present around the stocks. Gold occurs in veins within and surrounding most of these intrusions (Marsh et al., 1999). Recent exploration has outlined significant gold grades over 2 km away from any known, exposed granitoid stocks (Redstar Resources, 1999). Clear Creek has also produced in excess of 130,000 reported ounces of gold (4 million grams).

METAMORPHISM

A two-stage metamorphic evolution has affected sedimentary rocks at Clear Creek. Jura-Cretaceous regional metamorphism was followed by mid-Cretaceous contact metamorphism associated with TPS emplacement. Our mapping, and work by Murphy (1997), indicate that biotite grade was attained during ductile deformation of the THSZ, while the less deformed rocks north of the THSZ only attained chlorite grade. Preliminary petrography indicates peak regional metamorphism in the THSZ occurred during D_2. Regional metamorphic assemblages are overprinted by contact metamorphism associated with intrusion of the TPS stocks. Broad zones of andalusite and biotite porphyroblasts (Fig. 3) and localized cordierite in pelites occur around the stocks, with garnet present within a few metres of intrusion contacts.

The contact aureoles are divisible into two broad zones (Fig. 2).

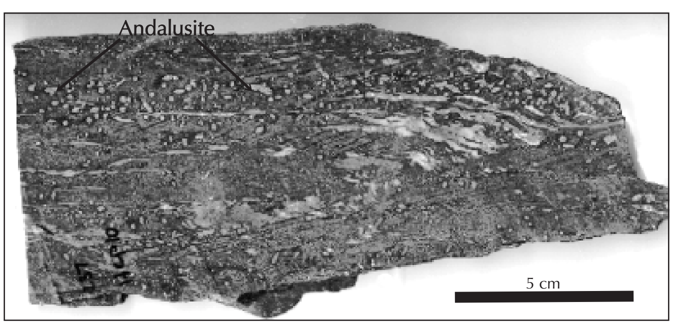


Figure 3. *Polydeformed biotite-muscovite schist overprinted by contact metamorphic andalusite porphyroblasts.*

1) The inner zone is characterized by strongly recrystallized quartz and biotite in pelites and psammites, as well as strong andalusite and local cordierite growth in aluminous rocks. These hornfelsed rocks are strongly resistant, comprise the highest peaks in the area, and extend about 200-500 m laterally from intrusion contacts. The boundary of these zones is marked by a distinct break in slope.
2) An outer zone of contact metamorphism was recognized while mapping. It is defined by andalusite and biotite growth in pelitic rocks and extends at least 3 - 5 km from any known plutons. The outer boundary of this zone is poorly defined, but intriguingly, does not appear to extend into rocks north of the THSZ.

Therefore, a larger area of contact metamorphism than previously known is recognized in this study. This is interpreted to represent an extensive system of shallowly buried intrusions in the area.

STRUCTURE

DUCTILE DEFORMATION FEATURES

Murphy (1997) suggested that the THSZ is the palaeo-depth extension of the Tombstone Thrust. Multiple deformation features in the THSZ indicate overall top-to-the-northwest transport (Murphy, 1997) and are confirmed by this work.

Hyland Group rocks in the Clear Creek area have undergone four major ductile deformational events, which are correlated with those defined by Murphy (1997), and Mair (this volume) in Table 1. D_1 produced a poorly preserved spaced cleavage, S_1 (Fig. 4). D_2 produced rarely preserved isoclinal folds, F_2, with a strong axial planar schistosity, S_2, which is locally mylonitic. D_3 produced tight, reclined, neutral to south-vergent, well preserved 1-cm to 10-cm-scale F_3 folds, which plunge gently west and have a moderate to strongly developed axial planar foliation, S_3. A pervasive extension lineation, L_3, is typically inclined at 35° north of F_3 fold axes (and by definition L^2_3 intersection lineation) on the S_3 foliation plane, and has a northwest plunge (Fig. 5). Weakly developed open crenulations, F_4, were the last small-scale ductile feature to develop. These plunge gently to the northeast and have upright axial planes, with a rarely developed axial planar foliation, S_4.

A protracted history of quartz vein formation during ductile deformation has been identified (Fig. 6). The first veins to develop during early D_2 are strongly boudinaged and isoclinally folded (DV_a). These were followed by boudin-neck veins during D_3 (DV_b), and then tension veins late in D_3 (DV_c). Paragenetic relationships suggest these three vein types developed progressively throughout early D_2 to late D_3. Slightly boudinaged, steep quartz veins that strike ~140° (DV_d) are the last set to show any ductile deformation features.

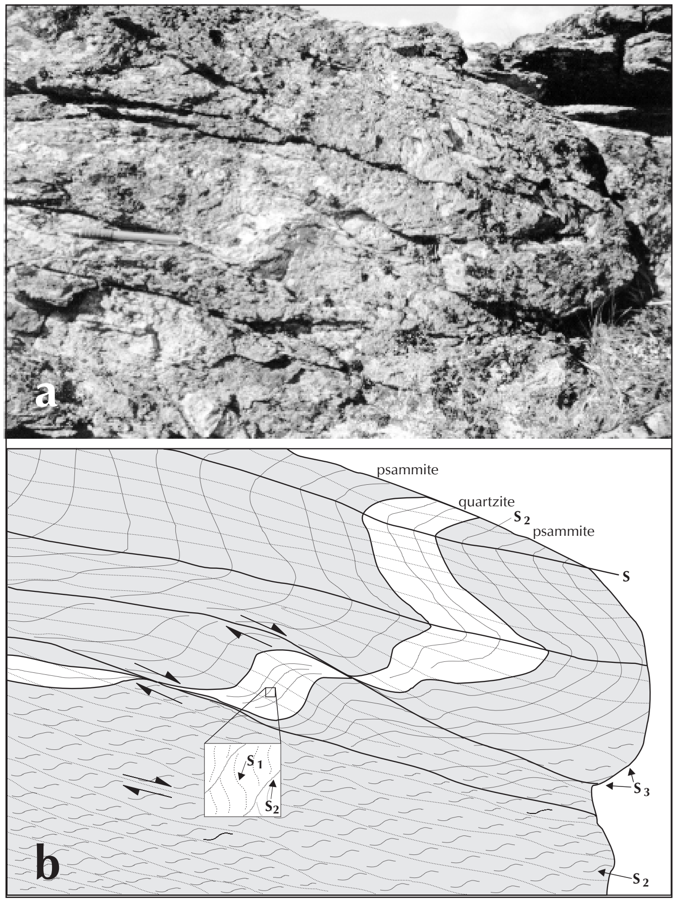


Figure 4. *a) F_3 fold of quartzite and psammite layers just west of the Rhosgobel stock, looking west. b) Sketch of outcrop in a) showing the relationship of THSZ fabrics in the area. Note the southerly to neutral vergence of F_3 folds and S_2/S_3 fabric relationships. The top half of the outcrop has undergone less intense deformation during D_3 due to strain partitioning around the hinge of a more competent quartzite layer.*

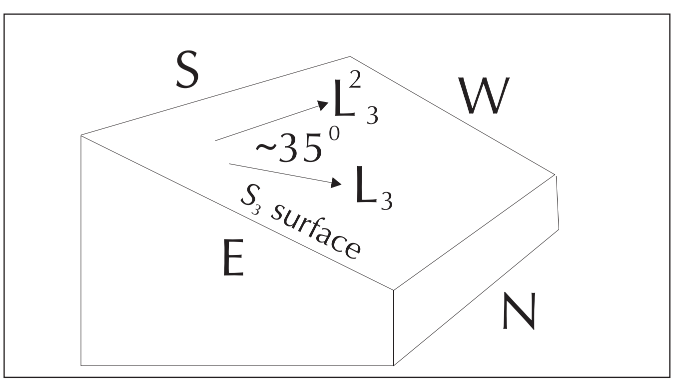
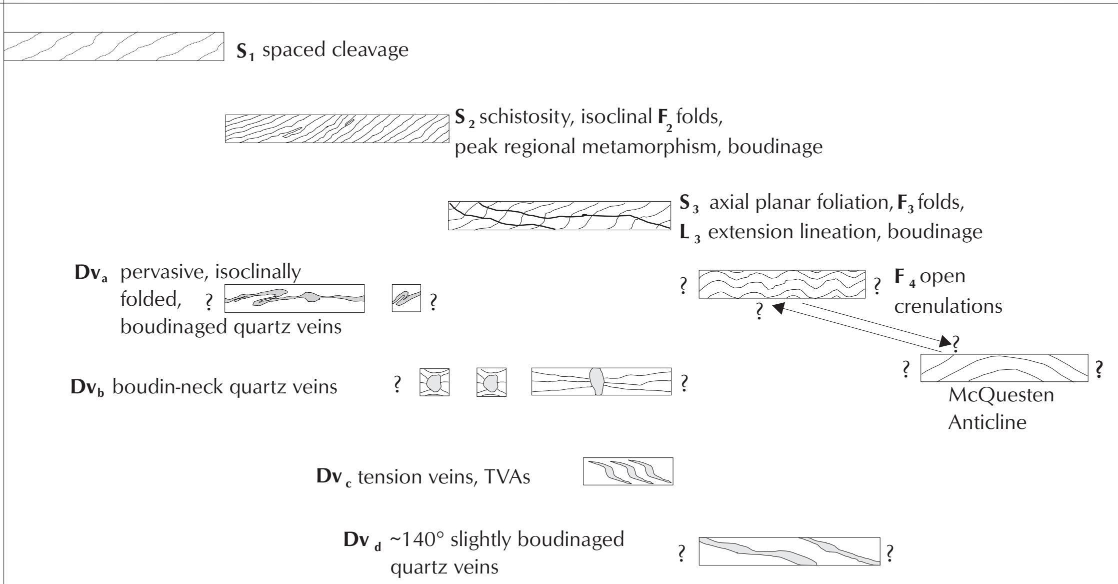


Figure 5. *Block diagram showing the consistent angular relationship of the $L^2{}_3/F_3$ intersection lineation/fold axes to the L_3 extension lineation.*

Figure 6. *a) Boudin-neck quartz vein (DV_b). b) Tension veins (DV_c) in quartzite cutting earlier folded quartz vein (DV_a). c) Tension vein array (DV_c) in gritty quartzite.*

Table 1. *Paragenetic table of all ductile deformation features in the Clear Creek area. An attempt to correlate deformations defined by Murphy (1997) and Mair (this volume) is also made.*

Deformations →	D_1	D_2	D_3	D_4	D_5
This study Clear Creek					
Murphy et al., (1997) Entire THSZ		**Sp, Sp′ Lp?**	**Fc Lp?, Lpxc**	**Fc+?**	**McQuesten Anticline**
Mair et al., (this volume) Scheelite Dome		**D_1**	**D_2**		



BRITTLE DEFORMATION FEATURES

Brittle deformation in the area is manifest as three major fault/fracture sets, with corresponding veins, joints, aplite, granitoid and lamprophyre dykes. These structures post-date the ductile fabrics developed in the THSZ. The following kilometre-scale brittle structures were identified from mapping and air photo interpretation (Fig. 7):

BF_a South- to south-southeast-striking (~165°), steep, major faults with mostly apparent sinistral displacement (pre-, syn- and post-TPS emplacement; Fig. 7g).

BF_b East-southeast-striking (~115°), steep fracture zones (pre-, syn- and post-TPS emplacement; Fig. 7g)

BF_c Northeast-striking (~035°), steep fracture zones (uncertain of relative timing; Fig. 7g).

The dominant outcrop-scale brittle structures are correlated with the air photo-interpreted structures (equivalent subscripts) as follows:

BV_a South- to south-southeast-striking, steeply dipping quartz-tourmaline veins, aplite and granitoid veins/dykelets and joints (syn/post-TPS emplacement; Figs. 7a-f).

BV_b A dominant set of east- to east-southeast-striking (~115°), sheeted gold-bearing quartz veins, quartz-biotite veins, lamprophyre dykes and minor quartz-tourmaline veins. A subset of east-northeast-striking (~070°) aplite and quartz-tourmaline veins also occurs (late syn/post-TPS emplacement; Figs. 7a-f).

BV_c North-northeast-striking (~015°), minor set of quartz veins and joints (uncertain of relative timing; Figs. 7a-f).

BRITTLE GEOMETRICAL ANALYSIS

Stereonets and rose diagrams of brittle structural data (Fig. 7) collected at Clear Creek show the following features (all data in strike direction):

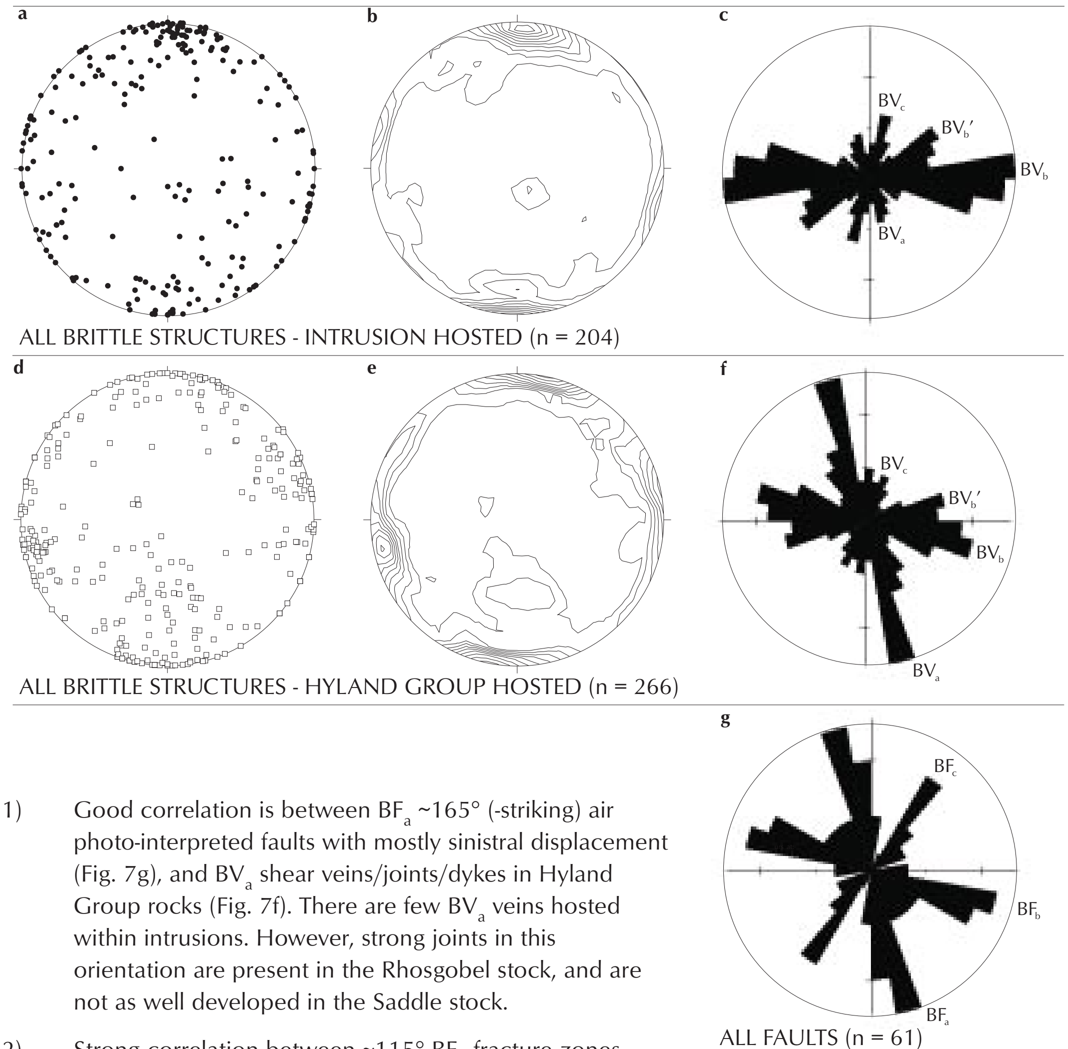


Figure 7. *Stereonets and rose diagrams – all brittle structures measured in outcrop (a-f) and from air photo interpretation (g).*

1) Good correlation is between BF_a ~165° (-striking) air photo-interpreted faults with mostly sinistral displacement (Fig. 7g), and BV_a shear veins/joints/dykes in Hyland Group rocks (Fig. 7f). There are few BV_a veins hosted within intrusions. However, strong joints in this orientation are present in the Rhosgobel stock, and are not as well developed in the Saddle stock.

2) Strong correlation between ~115° BF_b fracture zones (Fig. 7g) and BV_b tensile veins (Fig. 7f) in Hyland Group rocks. There is moderately good correlation with BV_b in intrusions (Fig. 7c), although the maxima is at ~085°. Possible subsets or conjugate sets of BV_b (BV_b') occur at ~055° within intrusions (Fig. 7c) and at ~075° in Hyland Group rocks (Fig. 7f).

3) Weak correlation is shown between ~035° BF_c air photo linears (Fig. 7g) and BV_c ~015° outcrop-scale structures (Fig. 7c, f).

4) Moderate similarity in orientation is displayed by the BV_c ~015° veins in both intrusions and Hyland Group rocks (Fig. 7c, f).

Therefore, in general, the km-scale faults and fractures correspond well with those at outcrop scale. The main differences include orientation of the tensile veins in Hyland Group rocks BV_b (~115°) versus those hosted in intrusions (maxima ~085°). In addition, the lack of dilatant ~165° structures measured within intrusions as compared to Hyland Group rocks is significant.

PRELIMINARY FAULT AND FRACTURE CONNECTIVITY ANALYSIS

Oliver (1999) stated, "In complex brittle settings, the relationship of individual fault branches or segments to the inferred far-field stresses is most important. The key structural condition for ore formation in any fault-related mineralized region is the linking up of fracture networks. In this case, relatively connected faults will form long-distance fluid channelways. Ore deposition may occur at specific structural sites such as terminal fault branches, faults in particular orientations, and smaller faults that connect larger faults."

Linked fault systems provide real-rock permeability and thus potential for major ore accumulation. However, real-time (syn-faulting) connectivity between faults is difficult to prove from field relations. Despite these difficulties, it is possible to make preliminary estimates of the degree of fault interconnectivity on a complex fracture array. A favourably oriented fault segment that is linked to other faults is more likely to be able to transmit fluid considerable distance than one that is isolated in three dimensions (Oliver, 1999).

The Clear Creek area is dominated by three kilometre-scale brittle structural trends. Field mapping and air photo interpretation data indicate the BF_a/BV_a structures are mostly sinistral faults and shear veins, BF_b/BV_b structures are mostly dilatant faults/fracture zones and tensile veins and dykes, and BF_c/BV_c structures are mostly antidilational faults/fractures and joints. An interpretation of near east-west overall shortening in the area is permitted, where BF_a are strike-slip faults, BF_b are transtensional faults and BF_c are transpressional faults (Fig. 8).

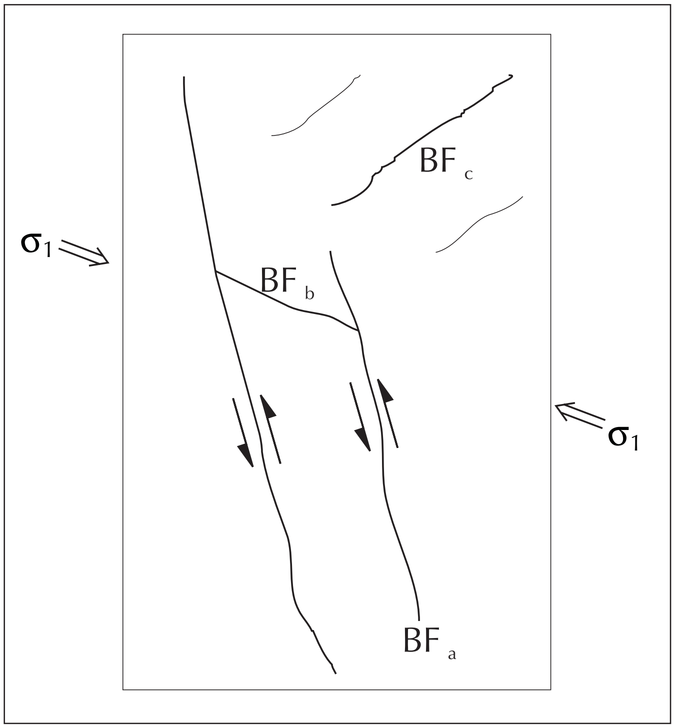


Figure 8. *Schematic sketch of the major fault/fracture types at Clear Creek. BF_a are strike-slip faults, BF_b are transtensional and BF_c are transpressional faults.*

These data suggest BF_a structures act as master faults, with BF_b and BF_c structures occurring as secondary fractures. Thus BF_a faults seem most likely to be able to transmit fluid over large distances. Straight sections of these faults, however, would not be particularly favourable sites for mineralization as they will not be very dilatant. More easterly striking, misoriented segments of these faults would be more dilational and thus more favourable sites for mineralization (Fig. 9a). North-south oriented portions of these faults, that is ~180° striking, will be antidilational and thus poor targets for mineralization (Fig. 9b). BF_b structures are by far the most dilational set in the area. Therefore any BF_b structure directly connected to a BF_a fault conduit could provide an ideal site for fluid trapping and thus mineralization (Fig. 9c). Furthermore, any BF_b structure linking two BF_a faults should be very highly regarded as an exploration target (Fig. 9d). BF_c structures seem to be the least dilational of the three sets, and thus are considered poor targets for mineralization. It should be noted, however, that a reversal in the shear-sense on BF_a faults could make BF_c structures dilational (Fig. 9e).

MINERALIZATION

A number of styles of gold mineralization are present at Clear Creek, with accompanying tungsten and silver-lead. Marsh et al. (1998) identified two geochemically distinct metal suites in the Clear Creek gold occurrences. The first is characterized by As-Au-Bi ± Sb and Te association, with a minor metal factor defined

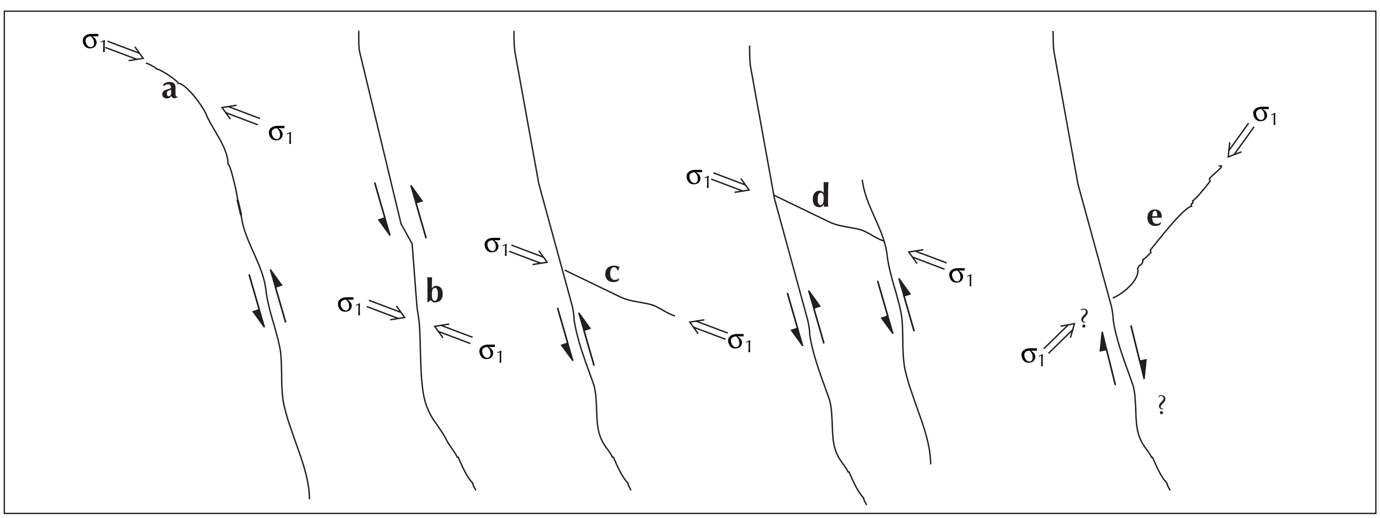
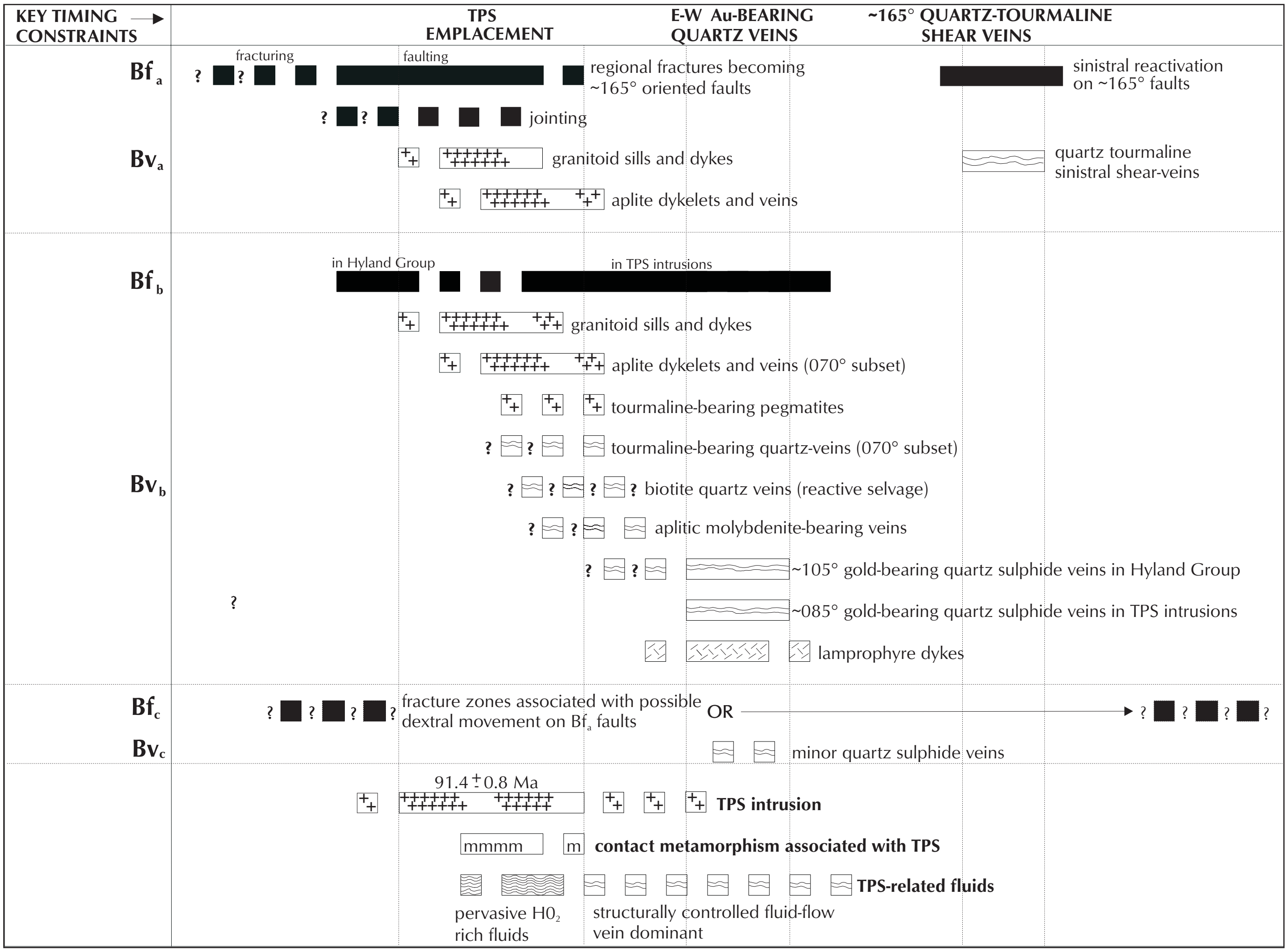


Figure 9. *Favourable structural sites for mineralization a) favourably misoriented segment of BF_a fault b) unfavourably misoriented segment of BF_a fault c) BF_b fracture zone linked to BF_a fault d) BF_b fracture zone linking two BF_a faults e) BF_c fracture zone connected to BF_a fault, perhaps with dextral movement.*

Table 2. *Paragenetic table depicting the geological history during brittle deformation. Note the timing of BF_c/BV_c structures is uncertain.*



by Ag-Bi-Pb ± As, Au and Te. Tungsten was more erratic, and showed no particular association with either of the above metal factors.

Mineralization styles identified in this study are outlined by previous workers (e.g., Emond and Lynch, 1990; Marsh et al., 1999; Murphy, 1997) and others. These are correlated within the proposed structural framework as follows and in Table 2 (locations of stocks and zones in Figure 2).

- East-west sheeted quartz veins within intrusions, e.g., Rhosgobel stock (BF_b/BV_b zone connected to BF_a fault), Eiger stock (BV_b zone connected to misoriented section of BF_a fault).
- East-west sheeted quartz veins in Hyland Group, e.g., Josephine Switchback (BV_b).
- Silicified shear-zones, e.g., Contact Zone (BF_b?).
- Distal or roof-zone fault breccias, e.g., Bear Paw breccia (misoriented segment of BF_a fault?).
- Aplitic-molybdenite-bearing veins, e.g., Harper Creek (BV_b).
- Distal silver-lead fault breccia zones, e.g., Galena Zone (BF_b/BF_c intersection, linked to BF_a fault).
- Scheelite-bearing quartz veins in calc-silicate rocks and skarns, e.g., Harper Creek (BV_b).
- Arsenopyrite alteration of diopside in alteration selvages of deformed DV_a/DV_b quartz veins, e.g., Harper Creek (overprinting of DV_a and DV_b veins during contact metamorphism/metasomatism).
- Disseminated arsenopyrite associated with metasomatism of calc-silicate rocks, e.g., Harper Creek (pervasive fluid-flow controlled by pre-existing S_2 and S_3 fabrics).

The main mineralization styles therefore support the fault connectivity model proposed above which predicts BF_b structures and misoriented BF_a faults will be the most dilational and thus most favourable sites for mineralization.

PARAGENESIS AND STRUCTURAL EVOLUTION

The overall paragenesis from ductile deformation/regional metamorphism through to granite emplacement, contact metamorphism and related veining and mineralization (Figs. 10-12) can be used in a preliminary attempt to model the changing stress field over time.

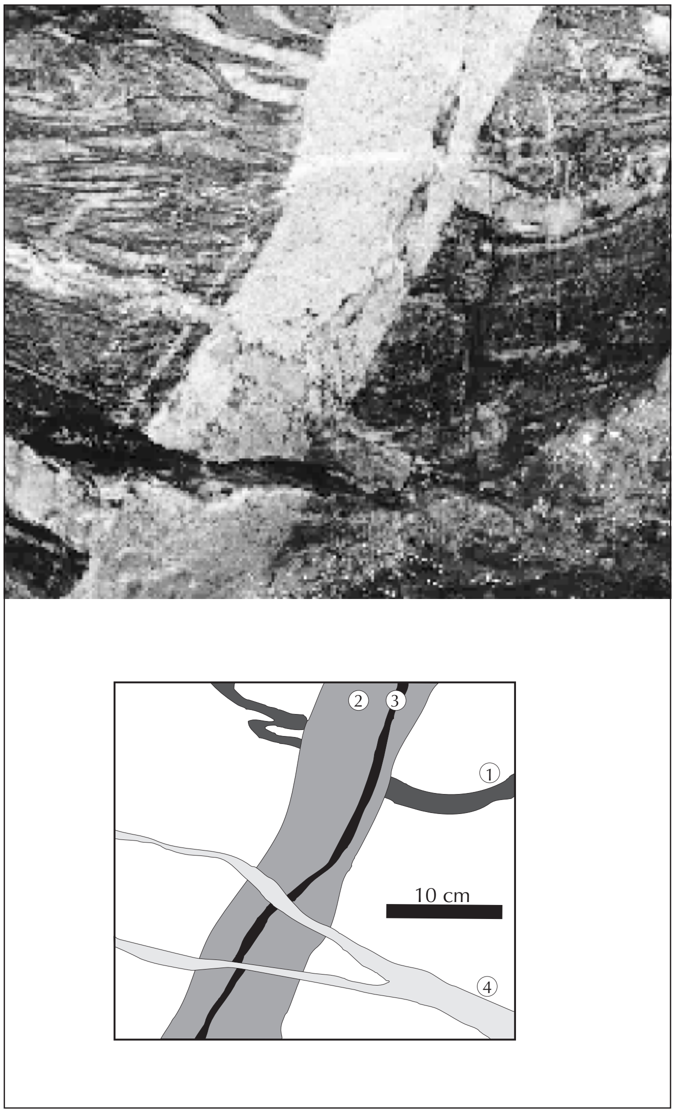


Figure 10. *THSZ-related, isoclinally folded quartz vein 1 (DV_a) cut by aplite dykelet 2 (BV_a), which is in turn cut by a quartz-tourmaline vein 3 (BV_a). Finally, all features are cut by moderately north-dipping quartz veins 4 (BV_b - gold mineralized set).*

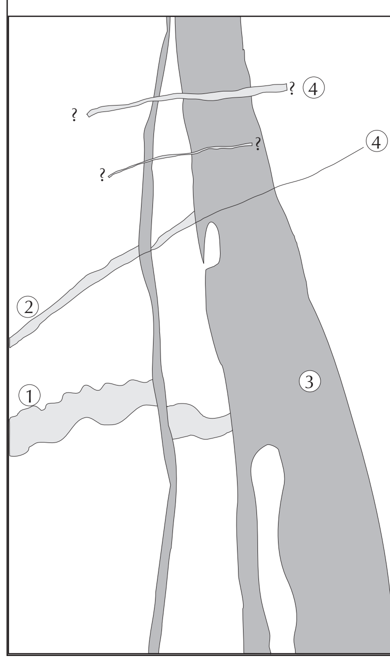


Figure 11. *THSZ-related boudin-neck quartz vein 1 (DV_b), and ~140° oriented, slightly boudinaged quartz vein 2 (DV_d) cut by quartz-monzonite dykelets 3 (BV_b). Late quartz ± tourmaline veins 4 (BV_a) cut the monzogranite, and a joint propagates along 2.*

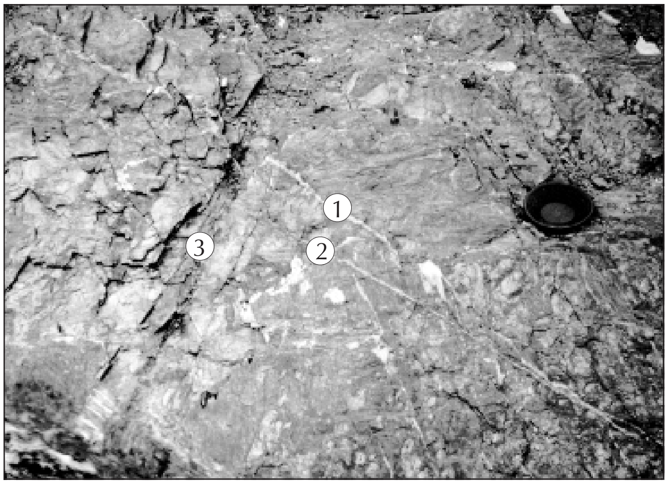


Figure 12. *Slightly wavy, aplitic quartz vein 1 (BV_b) cut by sheeted quartz vein 2 (BV_b). A quartz-tourmaline sinistral shear vein 3 (BV_a) cuts both 1 and 2.*

One possible model for the development of the brittle structural architecture at Clear Creek is proposed in Figure 13.

a) Northwest-southeast directed σ_1 probably initiated ~165° striking faults (BF_a) with sinistral movement (Fig. 13a).

b) The BF_b and BV_b tensile fracture/vein set was probably initiated within Hyland Group rocks by a slight (~30°) anticlockwise rotation of σ_1. This set has formed broadly en echelon to the sinistral ~165° oriented faults (BF_a; Fig. 13b).

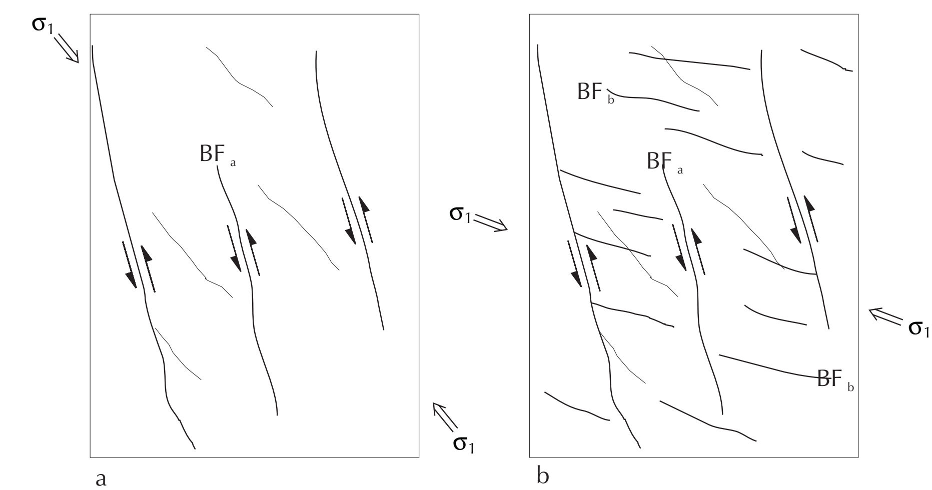
c) Emplacement of the TPS then occurred, with possible pre-existing control by ~165° faults (BF_a, e.g., Saddle and Rhosgobel stocks) and some east-west control (e.g., Barney and Grizzly stocks), also reflected regionally in the TPS (Fig. 13c).

d) Further development of BF_b and BV_b structures occurred, particularly within intrusions that had crystallized and cooled, with σ_1 possibly further rotated to the east-west. This rotation is reflected in the dominant ~085° orientation of BV_b veins within the intrusions. At this stage, ~165° BF_a faults would lock up due to their high angle with σ_1, and BF_b/BV_b could take up most of the strain by north-south extension and thus dilation (Fig. 13d).

e) The final stage of deformation was sinistral reactivation on ~165° BF_a faults with associated development of quartz-tourmaline shear veins that cut all ductile and brittle features (Fig. 13e).

There are a number of problems with the above model which are detailed as follows:

- The timing of BF_c/BV_c structures in the area remains unresolved.



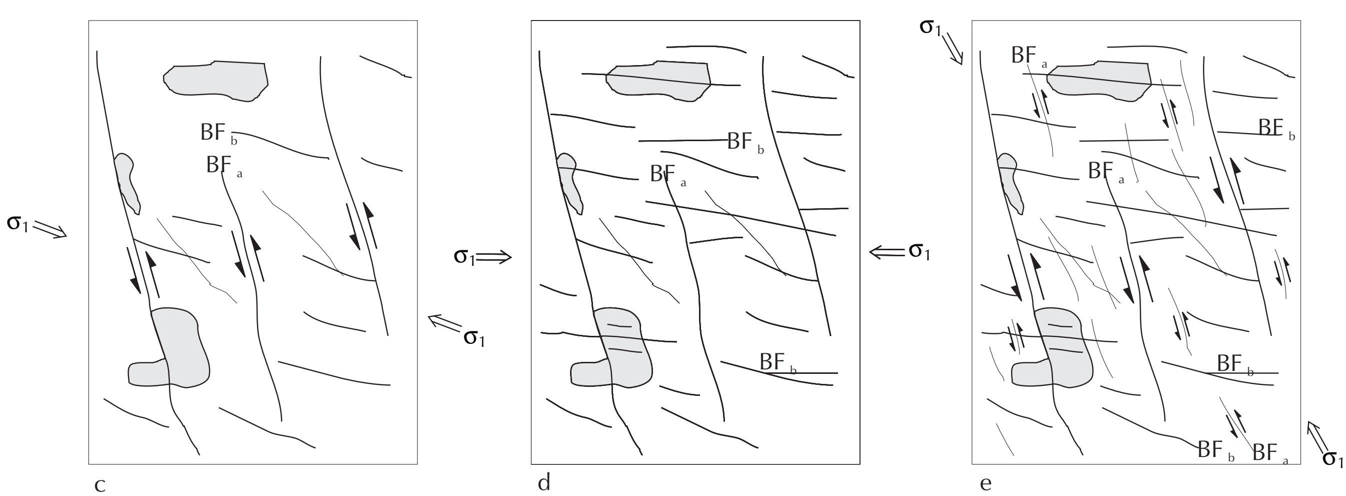


Figure 13. *Preliminary model for the structural evolution at Clear Creek (see text).*

- The model does not explain possible ~055° and ~075° striking subsets/conjugates of the BV_b vein set.
- The difference in BV_b orientations between Hyland Group rocks and TPS intrusions could be explained by refraction through the more brittle plutons.
- Real fault solutions could not be determined due to a lack of markers in the strongly deformed Hyland Group. Fault movements were mainly assumed from stepped slickensides, angular relationships and foliation surfaces bending into faults.
- The timing of large-scale structures in the area is equivocal from aerial photography; thus relationships on outcrop-scale that have been applied to these structures may lead to potential mis-correlation.

On a broader scale, a number of features indicate the possibility of a crustal-scale controlling structure for the TPS belt and related mineralization. These include the broad east-west orientation of the TPS belt, east-west dominant sheeted veins and east-west oriented lamprophyre dykes. These data, in addition to local structural data suggest the possibility of a Riedel shear model (Fig. 14). The east-west oriented TPS belt could be the upper crustal manifestation of a *master fault (C)*, with *low angle Riedel (R)* and *high angle Riedel (R')* shears represented by BF_b/BV_b and BF_a/BV_a structures, respectively. The *pressure shears (P)* may be represented by the subset BV_b' structures.

DISCUSSION

It is apparent that the rocks in the Clear Creek area have undergone a protracted history involving ductile, brittle-ductile and brittle deformation. The intense ductile deformation history has been overprinted by the later contact metamorphism, metasomatism and brittle deformation associated with TPS intrusions. An extensive system of buried TPS intrusions is indicated by very broad contact metamorphic aureoles at Clear Creek.

Application of basic fault percolation analysis suggests the most favourable sites for fluid pooling, and thus gold mineralization, are BF_b fracture zones connected to BF_a fault conduits (Fig. 13). Any BF_b fracture zones linking two BF_a faults should be even more highly regarded. Misoriented, more easterly striking segments of BF_a faults should also be considered as exploration targets. The timing of BF_c northeast-oriented fracture zones is not known, however any of these linked to major BF_a faults could provide dilational sites for mineralization.

TPS intrusions are widely considered the source of mineralizing fluids (Thompson et al., 1999); thus proximity to these intrusions is considered to be a major factor controlling the occurrence of gold mineralization. The recently discovered Bear Paw breccia zone is likely to be located above buried intrusions, and may represent a new roof-zone style of mineralization. This structural exploration model therefore ranks highly those favourable structural sites that

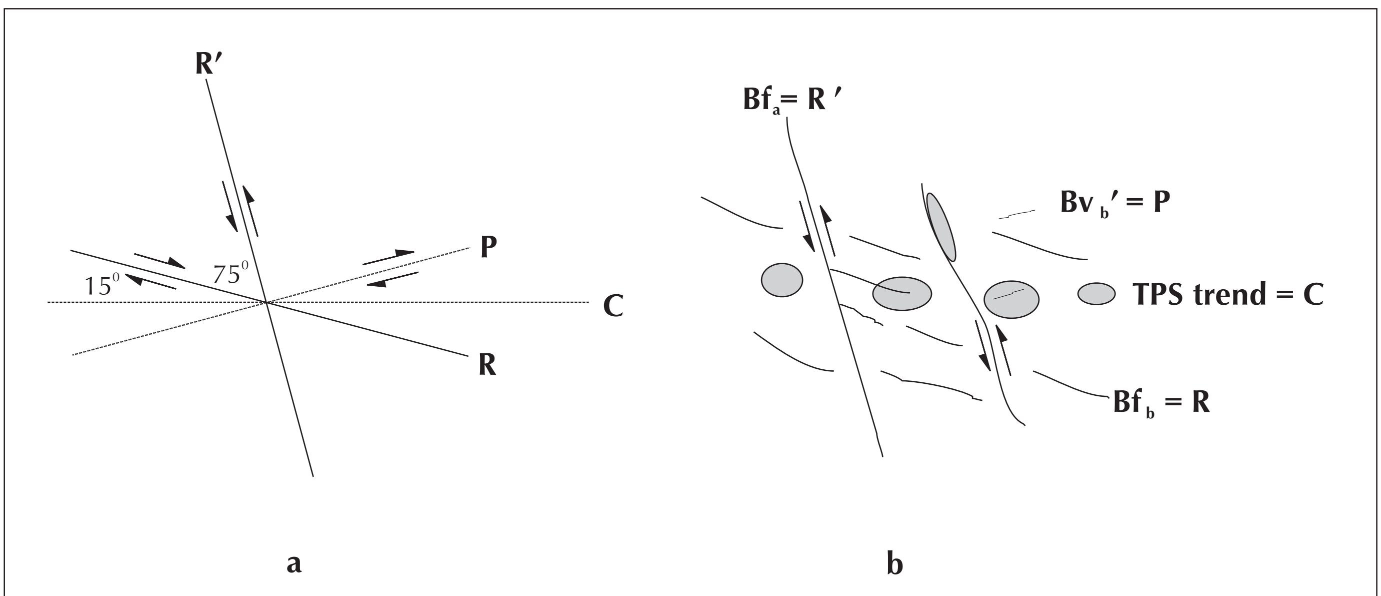


Figure 14. *Possible application of a Riedel shear model to the Clear Creek area. C is represented by the E-W trend of the TPS belt, R' is represented by BF_a sinistral faults, R is represented by BF_b/BV_b fracture zones and veins, P is represented by the subset BV_b' (only observed at outcrop scale).*

are coincident with shallowly buried TPS intrusions, or associated with ~165° BF_a faults that link into TPS intrusion systems.

Other TPS intrusion-related gold mineralization and deposits within the Selwyn Basin have similar dominant brittle structural trends to Clear Creek (e.g., Brewery Creek: Lindsay, this volume; Scheelite Dome: Mair, this volume). This, in addition to the coincident broad east-west trend of the TPS belt, dominant east-west sheeted veins and lamprophyre dykes suggests a crustal-scale controlling structure at depth such as a basement block boundary or a former suture zone. A Riedel shear model (Riedel, 1929) is therefore possible and is not mutually exclusive of the structural evolution proposed above.

FURTHER WORK

Continuing work on the structural, thermal and chemical evolution of TPS-related gold deposits will include:

1) Detailed petrography, fluid inclusion, stable isotope and Ar-Ar dating on collected samples to further constrain the paragenetic sequence of events defined in the field. A particular emphasis will be placed on constraining pressures of TPS emplacement and mineralization.
2) Similar work to be undertaken at Dublin Gulch should provide a framework for a regional-scale fault and fracture analysis. This will involve comparisons with other TPS-related deposits (e.g., Scheelite Dome and Brewery Creek), and mechanical modelling of fault/fracture arrays.
3) Petrologic and hydrothermal geochemical modelling of contact aureole fluid/rock interaction may constrain fluid-flow paths and fluxes around TPS intrusions.
4) Structural mapping of ca. 65 Ma McQuesten suite intrusions west of Clear Creek may provide links to the deformation regime associated with TPS intrusions. The longevity of any crustal-scale structures would be of particular interest.

ACKNOWLEDGEMENTS

Thanks to everyone at the YGP for their help, in particular Lisabeth Bryon, Kaori Torigai, Melanie Reinecke and Leyla Weston. Discussions with Don Murphy, Richard Goldfarb and Don Keedicks were very helpful. Nels, Madeline and Dianne Harper provided excellent accommodation and entertainment at Clear Creek. Erin and Aladdin Marsh and John Mair are thanked for their help in the field and interesting discussions. Thanks also to Mike Stammers from Pamicon and Redstar Resources for useful discussions and providing some transportation while in the field.

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Geology and metallogenic signature of gold occurrences at Scheelite Dome, Tombstone gold belt, Yukon

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ABSTRACT

The study area is centred on the 91.2 ± 0.9 Ma Scheelite Dome quartz-monzonite stock of the Tombstone Plutonic Suite (TPS). This stock and associated dykes and sills intrude highly deformed metasedimentary strata of the Yusezyu Formation of the Neoproterozoic to Lower Cambrian Hyland Group. The emplacement of TPS intrusions post-dates regional greenschist-facies metamorphism and multiple phases of ductile deformation related to the Tombstone strain zone. Although the Scheelite Dome stock hosts auriferous, sheeted quartz veins, extensive soil geochemistry indicates that the bulk of the gold resource is hosted in the variably hornfelsed metasedimentary rocks immediately south of the stock. The associated gold-in-soil anomaly forms an east-trending corridor of anomalous gold values (>80 ppb) approximately 6 km long by 1.5 km wide, with a more weakly defined eastern continuation. Where metasedimentary bedrock is exposed in the corridor, gold is hosted in fault-vein arrays, and less commonly as disseminated grains and in replacement zones. The styles and distribution of mineralization are largely controlled by brittle structures; a phase of east-west shortening was largely coeval with gold mineralization.

R-mode factor analysis of multi-element geochemical data indicates two geochemically distinct metal suites within the area of the gold-in-soil anomaly at Scheelite Dome. The first suite, characterized by Au-Te-Bi ± W ± As, possesses the stronger gold association and is typical of intrusion-related gold occurrences elsewhere in the Tombstone gold belt. The second suite displays a metal association of Ag-Pb-Zn-Cd-Sb ± Cu ± Au, which is more characteristic of mid-Cretaceous Ag-Pb-Zn mineralization in the Keno Hill district, located approximately 60 km to the east-northeast. Field observations, combined with soil geochemistry, suggest that the different metal associations are paragenetically related. However, the possibility of two distinct hydrothermal events cannot yet be ruled out.

RÉSUMÉ

La région à l'étude est centrée sur le dôme Scheelite, un petit massif intrusif de monzonite quartzifère appartenant à la Série plutonique de Tombstone (SPT) et datant de 91,2 ± 0,9 Ma. Ce petit massif intrusif, et les dykes et filons-couches qui lui sont associés, s'introduisent dans les couches métasédimentaires intensément déformées de la Formation de Yusezyu, du Groupe de Hyland datant du Néoprotérozoïque au Cambrien. La mise en place des intrusions de la SPT est postérieure au métamorphisme du faciès des schistes verts dans la région et aux multiples phases de déformation ductile reliées à la zone de déformation de Tombstone. Bien que le petit massif intrusif du dôme Scheelite renferme des groupes de filons de quartz aurifère, de nombreuses analyses géochimiques des sols révèlent que la plus grande partie de la minéralisation en or se retrouve dans les roches métamorphisées à des degrés variables en cornéennes immédiatement au sud du massif. Les teneurs anomales en or (>80 ppb) du sol forment un corridor d'orientation est-ouest, long de 6 km et large de 1,5 km environ, avec un prolongement moins bien défini vers l'est. L'or se trouve dans des filons du type faille et, par endroits, sous formes de dissémination et de zones de substitution, là où les roches métasédimentaires affleurent à l'interieur de ce corridor. Les styles et la répartition de la minéralisation suggèrent un net contrôle par des structures cassantes généralement contemporaines de celle-ci et formées au cours d'un épisode de raccourcissement suivant l'axe est-ouest.

L'analyse factorielle mode-R de données géochimiques multi-élémentaires indique la présence de deux séries métalliques géochimiquement distinctes à l'intérieur de l'anomalie en or du sol au dôme Scheelite. La première, Au-Te-Bi ± W ± As, présente la plus intense association avec l'or et est caractéristique des manifestations aurifères reliées aux intrusions ailleurs dans la zone aurifère de Tombstone. La deuxième série, dans laquelle sont associés Ag-Pb-Zn-Cd-Sb ± Cu ± Au, est davantage caractéristique des minéralisations du Crétacé moyen du district de Keno Hill, situé à environ 60 km à l'est-nord-est. Les observations sur le terrain combinées aux analyses géochimiques du sol suggèrent que les différentes associations métalliques sont paragénétiquement reliées. La possibilité de deux événement hydrothermaux distincts ne peut cependant être écartée.

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INTRODUCTION

Scheelite Dome, located 27 km northwest of Mayo in central Yukon (Fig. 1), forms a topographic high at the headwaters of two actively mined placer gold-bearing creeks. The summit (1506 m) is underlain by the Scheelite Dome quartz-monzonite stock of the mid-Cretaceous Tombstone Plutonic Suite (TPS). Two other TPS stocks are present in the area: 1) the Morrison Creek stock, located approximately 6 km to the east of Scheelite Dome; and 2) the Minto Lake stock, located 6 km to the south of Scheelite Dome. All of the stocks were emplaced at approximately 92 Ma into highly deformed miogeoclinal metasedimentary rocks of the Yusezyu Formation of the Neoproterozoic to Lower Cambrian Hyland Group (Murphy, 1997). Placer gold has been mined from creeks draining Scheelite Dome for more than a century; however, it has only been in the last decade that the primary gold lodes in the area have been evaluated as possible economic targets.

The exploration history of the Scheelite Dome property is summarized by Hulstein et al. (1999). Extensive soil sampling was carried out by H6000 Holdings Ltd., Kennecott Canada Exploration Inc., La Teko Resources Ltd, and, most recently, current property owners Copper Ridge Explorations Inc. This has identified a 6- by 1.5-km, east-trending corridor of anomalously high gold concentrations, in an area underlain by metasedimentary rocks immediately south of the Scheelite Dome stock (Figs. 2 and 3). The large geochemical anomaly reflects an extensive hydrothermal system that deposited anomalous amounts of gold, tellurium, bismuth, tungsten, arsenic, and antimony.

Tungsten-bearing skarn mineralization is known to occur in calcic metasedimentary rocks immediately adjacent to the northern side of the Scheelite Dome stock (Fig. 2; Kuran et al., 1982). Gold is also hosted in sheeted quartz-K-feldspar veins within the stock, whereas in metasedimentary rocks to the south of the stock, gold occurs in fault veins, extension veins, replacement zones and as disseminated grains. Locally, felsic dykes cut auriferous quartz veins within the Scheelite Dome stock, indicating that mineralization occurred prior to the final phases of mid-Cretaceous magmatic activity. East-trending lamprophyre dykes within, and south of the stock, also cut auriferous quartz veins. These dykes are elsewhere considered

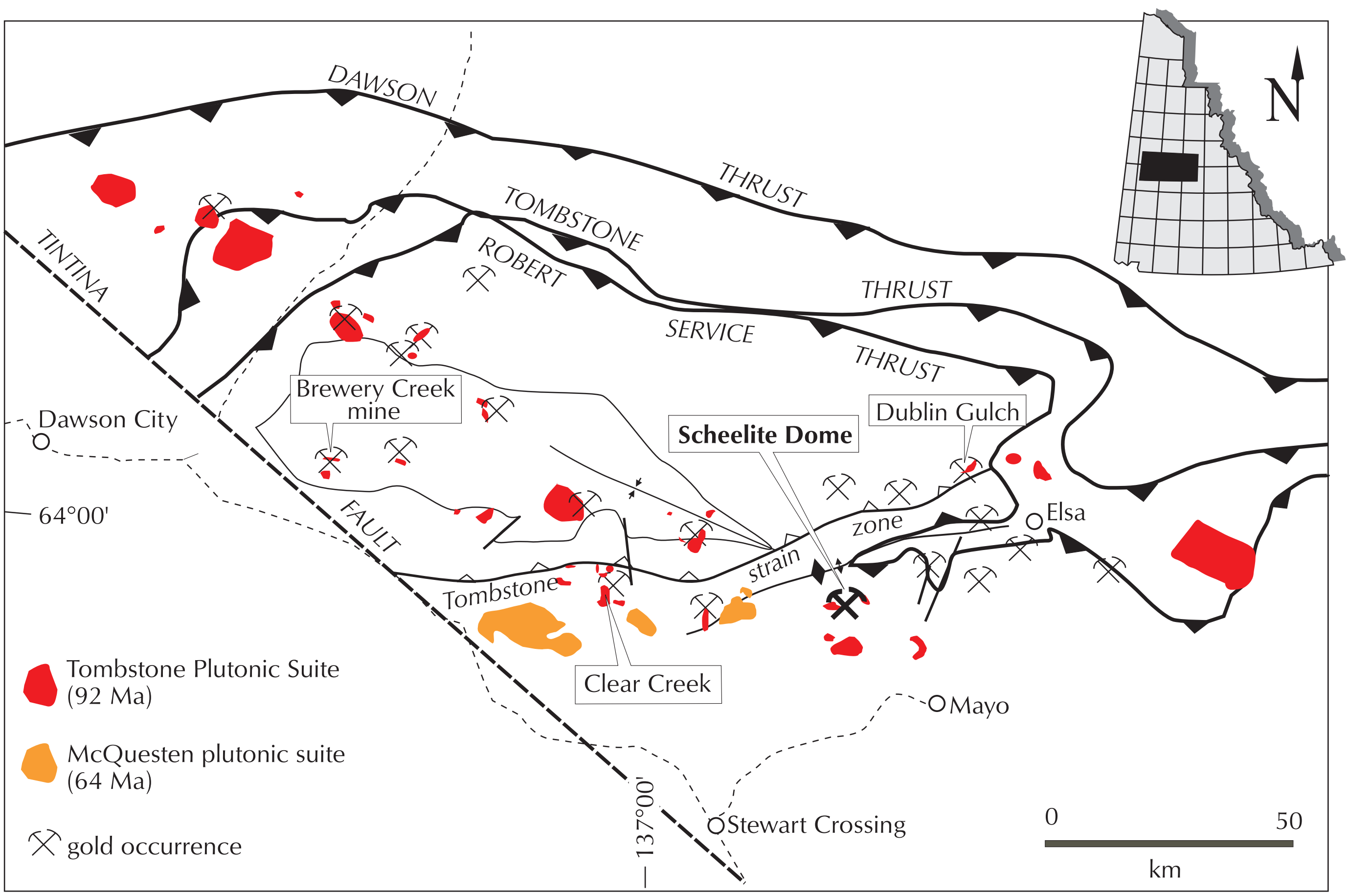

Figure 1. *Geological framework of the northern Selwyn Basin in west-central Yukon (modified after Murphy, 1997). The Scheelite Dome area is shown in Figure 2 and is located centrally within the Tombstone strain zone, near Mayo.*

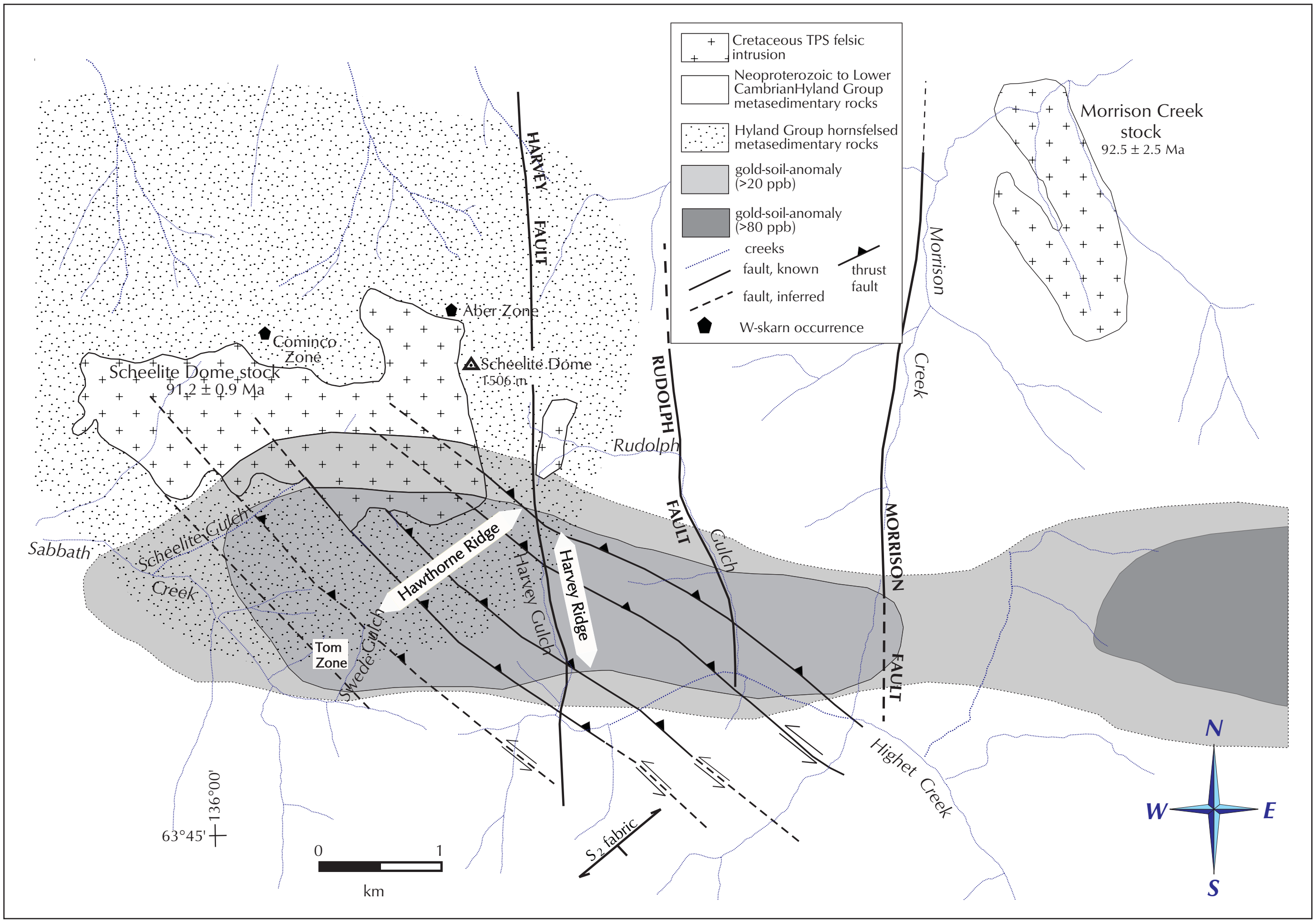

Figure 2. *Simplified geology of the Scheelite Dome area. The gold-in-soil anomaly indicates gold occurrences are concentrated within and beyond the thermal aureole, to the immediate south of the Scheelite Dome stock. Auriferous extension veins are best developed in psammitic rocks on Hawthorne and Harvey ridges; replacement-style gold occurrences are best developed at the Tom Zone; and disseminated gold-occurrences are best developed in psammites and phyllites between Harvey Ridge and Rudolph Gulch.*

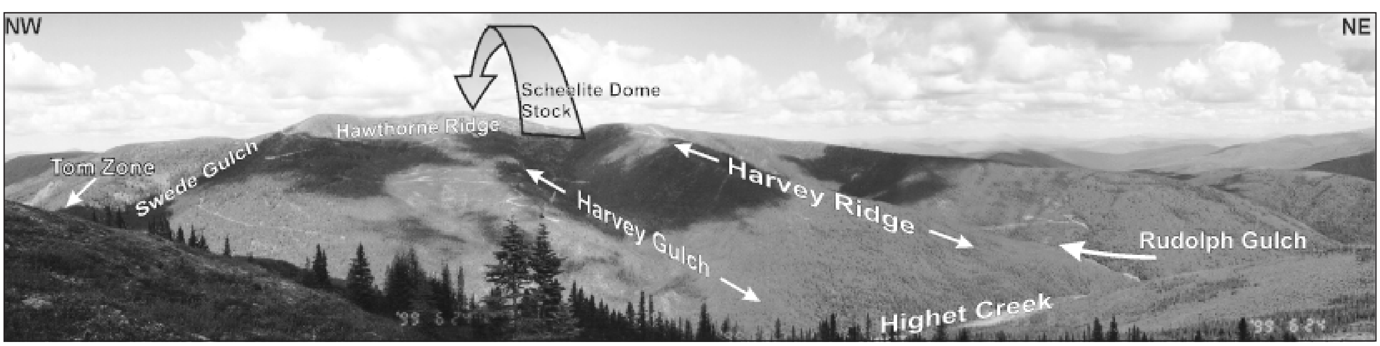

Figure 3. *View north toward Hawthorne and Harvey ridges. The Scheelite Dome stock weathers recessively, located behind Hawthorne Ridge (see Figure 2).*

to be related to TPS magmatism (Marsh et al., 1999; Gordey and Anderson, 1993). Hence, gold mineralization at Scheelite Dome bears a strong spatial and temporal relationship to the emplacement of TPS intrusions.

LOCAL GEOLOGY

LITHOSTRATIGRAPHY

The Scheelite Dome area is underlain by highly deformed miogeoclinal, metaclastic rocks of the Yusezyu Formation of the Neoproterozoic to earliest Paleozoic Hyland Group (Murphy, 1997). Psammitic and phyllitic rocks dominate the stratigraphy, with thin, metre-scale intercalations of calc-silicate rocks and carbonaceous siltstones. Psammitic rocks range from fine- to medium-grained, variably micaceous quartzites, to less commonly, quartzofeldspathic gritty psammites. Phyllitic rocks are composed of mainly chlorite and muscovite, with lesser biotite. The transition between phyllitic and psammitic rocks is commonly gradational due to extensive silica remobilization during high-strain deformation. Carbonaceous units are less than 1 m thick, and are characteristically dark and fine-grained. These units may contain disseminated, fine-grained syngenetic to diagenetic pyrite. Quartz-rich psammitic rocks commonly form ridges, in contrast to phyllitic rocks, which weather recessively.

Both the Scheelite Dome and Morrison Creek stocks are monzonitic, with biotite as the dominant mafic phase and minor hornblende. Both stocks are medium- to coarse-grained and are variably porphyritic with orthoclase phenocrysts. The surface expression of the Scheelite Dome stock is broadly east-trending, whereas the surface expression of the Morrison Creek stock is north-trending. Monzonitic sills and dykes, as much as a few metres in thickness, have intruded metasedimentary rocks surrounding the stocks. Aplite dykes cut the Scheelite Dome stock, and biotite-rich lamprophyre dykes cut both the Scheelite Dome stock and surrounding metasedimentary strata.

METAMORPHISM AND DEFORMATION

The metamorphic and deformational history of the Scheelite Dome area can be considered in two episodes: first, regional metamorphism and ductile deformation prior to the emplacement of the TPS; and, second, contact metamorphism and brittle deformation syn- to post-emplacement of the TPS.

Pre-TPS events

All sedimentary strata in the Scheelite Dome area have undergone regional mid-greenschist facies metamorphism, and been subjected to multiple phases of ductile deformation prior to the emplacement of TPS intrusions. Scheelite Dome is located centrally within the extensive, structurally complex, Tombstone strain zone, on the southern limb of the east-trending McQuesten Antiform (Murphy, 1997). Two main fabrics are developed in metasedimentary rocks in the area. The first, a pervasively transposed foliation (S_1), is subparallel to primary compositional layering. Micas formed during regional metamorphism are aligned with this fabric, clearly defining this foliation. The S_1 fabric has then been folded by northwest-verging, tight to isoclinal folds. The second significant fabric (S_2) forms the most prominent surface in the area, along which preferential weathering takes place. The S_2 fabric formed axial-planar to the northwest-verging, tight to isoclinal folds, strikes northeast, and dips moderately (30° to 50°) southeast (Fig. 4). In psammitic rocks, S_2 is commonly expressed as a spaced axial-planar cleavage, whereas in phyllitic rocks, S_2 is expressed as a pervasive foliation, sub-parallel to S_1. The variation in the expression of the S_2 fabric reflects different proportions

Figure 4. *The prominent S_2 fabric, formed axial-planar to tight folds of the S_1 regional metamorphic fabric, developed in psammite, Hawthorne Ridge (view toward the east).*

of strain accommodation by the rheologically contrasting phyllitic and psammitic rocks. Intersection lineations, defined by the intersection of the S_1 fabric with S_2 surfaces, commonly dip shallowly toward 070°. The S_2 fabric was later reactivated during high-strain, non co-axial deformation, as shear or 'C' surfaces. Shear bands are commonly well developed in phyllitic rocks, with 'S-C' shear-fabric relationships indicating north-northwest-directed movement. Other weakly developed ductile fabrics, which post-date the formation of S_2, are present locally and remain poorly understood. The S_2 fabric is also gently folded around north-trending axial planes. Such folds are rarely apparent at outcrop scale, but are recognized by variation in the orientation in S_2 at different outcrops. The gentle folds result in local variations in both the orientation of S_2 , and the S_1-S_2 intersection lineation. The orientation of gentle folds infers a phase of east-west shortening, which post-dates ductile shearing.

Syn- to post-TPS events

The stocks in the Scheelite Dome area, as with many intrusions of the TPS, are surrounded by extensive and well developed contact metamorphic aureoles. These are characterized by the development of metamorphic silicate minerals and pyrrhotite, which overprint the pre-intrusion ductile fabrics (Murphy, 1997). Within a few hundred metres of the Scheelite Dome stock, metasedimentary strata exhibit partial fabric destruction due to recrystallization of quartz. Andalusite is well developed in phyllitic rocks as far as 1.5 km from the stock; however, beyond 1 km, biotite development is more ubiquitous, characterizing the outer hornfels zone. Aeromagnetic data indicate that the pyrrhotite development around the Scheelite Dome stock is relatively weak, particularly in comparison to pyrrhotite development around the Minto Lake stock, located 6 km to the south. This is likely a reflection of a greater proportion of authigenic-pyrite-bearing rocks (favoured for pyrrhotite development during contact metamorphism), such as phyllites and carbonaceous siltstones, in close proximity to the Minto Lake stock, whereas the Scheelite Dome stock intrudes a part of the miogeoclinal sequence characterized by a greater proportion of psammitic rocks.

Two generations of brittle faults, which postdate earlier ductile deformation, formed during TSP emplacement. The first generation strikes north and dips subvertically. The second generation strikes northwest, and dips moderately to steeply toward the northeast. Immediately adjacent to the north-trending Rudolph fault (Fig. 2), the S_2 fabric is drawn into alignment with the fault, in a manner indicating sinistral displacement. The same exposure of the fault is cut by east-trending mineralized quartz veins, confirming that formation of the north-trending faults pre-dated the mineralizing event. In contrast, mineralized quartz veins are locally drawn into the north-trending Harvey fault in such a manner as to indicate post-mineralization dextral displacement. North-striking faults form topographic and geophysical lineaments, and may, in part, have influenced the morphology of the Scheelite Dome stock, and to a greater degree, the north-trending Morrison Creek stock. Northwest-trending brittle faults display evidence for oblique-slip displacement, and clearly offset the Scheelite Dome stock. Offset along northwest-trending faults, as indicated by aeromagnetic data, clearly suggests sinistral displacement. However, in plan view, offset of the Scheelite Dome stock by northwest-trending faults appears dextral. This conflict can be explained by the shallowly south-dipping contact of the Scheelite Dome stock being offset by a component of reverse movement, raising hanging-wall blocks and resulting in apparent dextral offset in plan. A prominent set of east-striking tension fractures, which dip moderately to the north, are best developed in psammitic rocks across the ridges immediately to the south of the Scheelite Dome stock. Both northwest-striking faults and east-striking tension fractures host gold mineralization. North-trending faults locally contain massive milky quartz veins, but do not host gold mineralization. East-striking tension fractures also host post-mineralization lamprophyre dykes. There is no evidence of structural disruption immediately adjacent to Scheelite Dome, and there is only minor warping of the prominent S_2 fabric. Small TPS intrusions in the area occur as both sills concordant to the S_2 fabric, and as dykes exploiting the east-trending fractures, discordant to the S_2 fabric.

GOLD MINERALIZATION

The Scheelite Dome area features many of the styles of gold mineralization typical of the Tombstone gold belt (Poulsen et al., 1997; Hart et al., 2000), including sheeted quartz veins within the Scheelite Dome stock, as well as fault-vein arrays, disseminated gold grains, and replacement bodies in the surrounding metasedimentary rocks (*cf*. Hulstein et al., 1999). Extensive soil sampling across the property has identified an east-trending gold-in-soil anomaly (>80 ppb Au), which is approximately 6- by 1.5-km-wide, and with a 2-km-long continuation of the anomaly to the east (Fig. 2). Throughout the gold-in-soil anomaly, arsenic concentrations are mostly above 100 ppm, and antimony concentrations are commonly above 5 ppm. The positioning of the anomaly indicates that the bulk of the gold resource occurs within, and beyond the thermal aureole, immediately south of the Scheelite Dome stock.

Gold in the Scheelite Dome stock is hosted in predominantly east-trending, variably dipping, sheeted quartz-K-feldspar veins typical of intrusion-hosted gold mineralization elsewhere in the Tombstone gold belt (Poulsen et al. 1997). Arsenopyrite is the dominant sulphide mineral, comprising between 0.5 to 2% by volume of the veins. Alteration adjacent to veins is extremely subtle, with weak chloritization of feldspars. Late felsic dykes locally cut the sheeted veins within the stock, suggesting a late-magmatic relative timing for vein emplacement.

Surrounding the Scheelite Dome stock, extension veins (Fig. 5a) generally range from 2 mm to 20 cm in width. The quartz veins contain variable amounts of carbonate, and 1 to 10% by volume sulphide minerals, which include arsenopyrite, stibnite, and lesser pyrite. Extension veins are surrounded by sericite alteration selvages, which extend laterally for up to 5 times the thickness of the vein. Fault veins feature characteristic crack-seal textures (Fig. 5b) and polyphase brecciation. They occur sporadically along northwest-trending faults, suggesting certain areas of faults were dilational and favoured fluid pathways. The best exposed fault vein, the Hawthorne vein, features an early quartz generation, followed by a quartz-arsenopyrite stage, and then a late massive-sulphide stage of predominately stibnite. Veins are commonly surrounded by sericitic alteration haloes of variable width and intensity. Disseminated gold mineralization (Fig. 5c) occurs locally within psammites and phyllites. It is associated with areas of pervasive sericitization, variable degrees of silicification, and disseminated arsenopyrite, lesser pyrite, and rare bismuthinite. Such zones commonly display evidence of elevated structural permeability in the form of randomly oriented fracture networks. Replacement-style gold mineralization (Fig. 5d) is restricted to variably calcareous rocks, with folioform replacement dominated by pyrrhotite, with lesser arsenopyrite and rare chalcopyrite. Notably, this style of mineralization occurs in more distal settings from the Scheelite Dome stock than tungsten-bearing skarn mineralization, concentrated in calcareous rocks immediately north of the stock (Fig. 2).

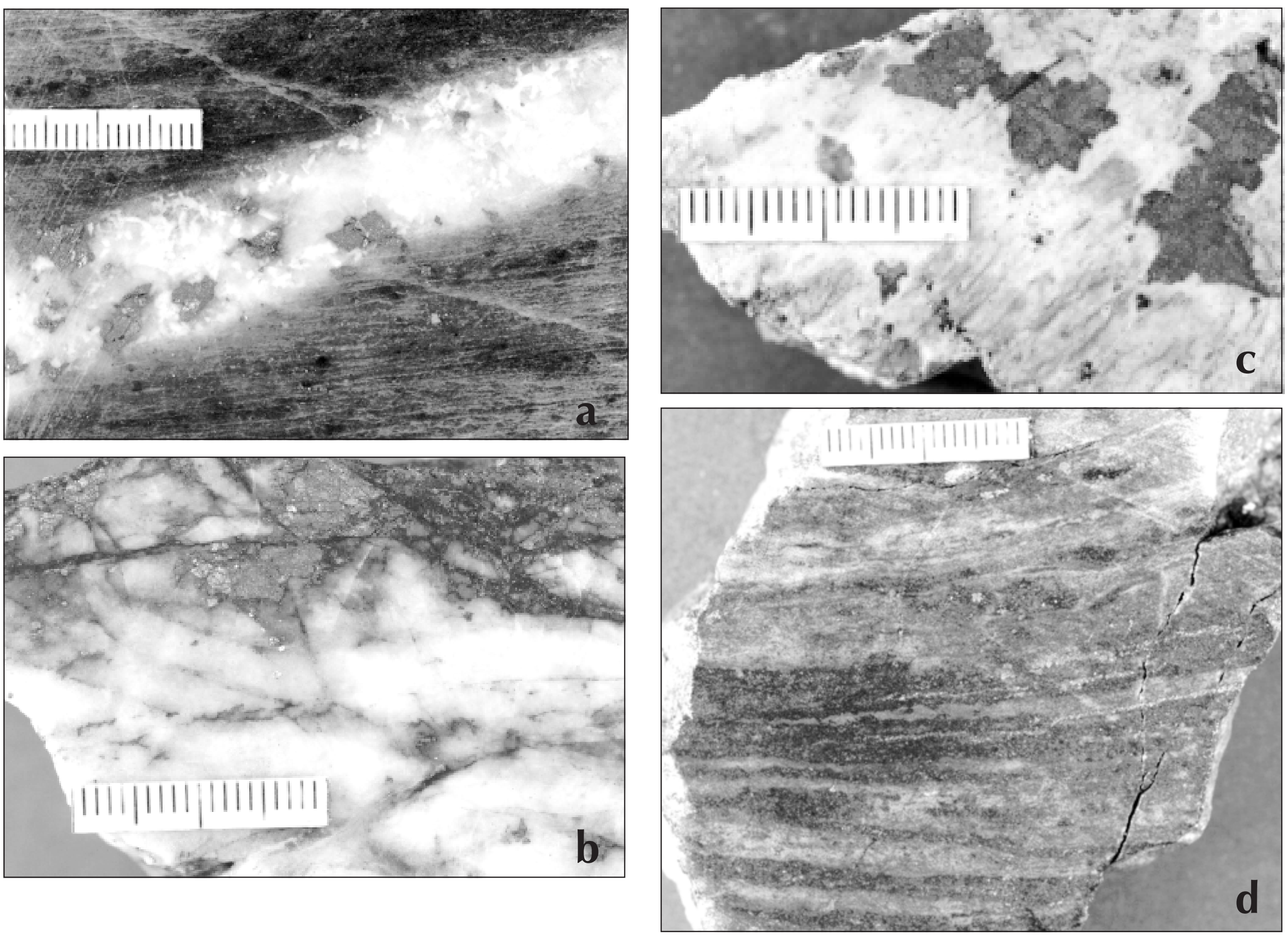

Figure 5. *Styles of gold mineralization at Scheelite Dome: a) quartz-arsenopyrite extension veins; b) typical fault-vein material displaying crack seal textures (stibnite is concentrated along fractures in the quartz-arsenopyrite assemblage); c) disseminated arsenopyrite in sericitized quartz-phyllite; and d) folioform replacement of calc-silicate rock by pyrrhotite, lesser arsenopyrite, and minor chalcopyrite.*

STRUCTURAL CONTROL

The distribution of gold mineralization at Scheelite Dome is largely controlled by the interaction of northwest-trending, northeast-dipping faults, and east-trending, north-dipping tension fractures. Both structural elements contain similar gold-bearing hydrothermal assemblages. The east-striking fractures are responsible for the east-trend of the gold-in-soil anomaly; however, lateral constrains, to the north and south, along the corridor of hydrothermal activity, remain undetermined. Crack-seal textures in the northwest-trending fault veins indicate multiple failure events and fluid pulses during the life span of the hydrothermal system. East-trending extension veins (Fig. 6) are locally cut at low angles by similarly oriented, extension veins, suggesting that tension fractures formed synchronous with hydrothermal activity. Although east-trending tension fractures are well developed in both the footwalls and hanging walls of northwest-trending faults, the majority of veins are hosted by fractures in the hanging walls (Fig. 7). Quartz crystals in extension veins exhibit growth normal to vein margins, indicating pure extension. Slickenlines on exposed northwest-trending faults indicate oblique-slip displacement, such that the inferred extension direction corresponds to that for east-trending extension veins (a north-oriented, south-plunging, minimum compressive stress). Such structural relationships infer a phase of east-west shortening, and inclined north extension (Fig. 7) during the gold-forming events. This correlates with an interpreted phase of east-west shortening during the formation of mineralized brittle faults at Clear Creek, located approximately 50 km to the west (Stevens, this volume). Lamprophyre dykes, which post-date gold mineralization at Scheelite Dome, also exploit the same east-trending fractures, suggesting that the far-field stress regime was maintained subsequent to the hydrothermal activity.

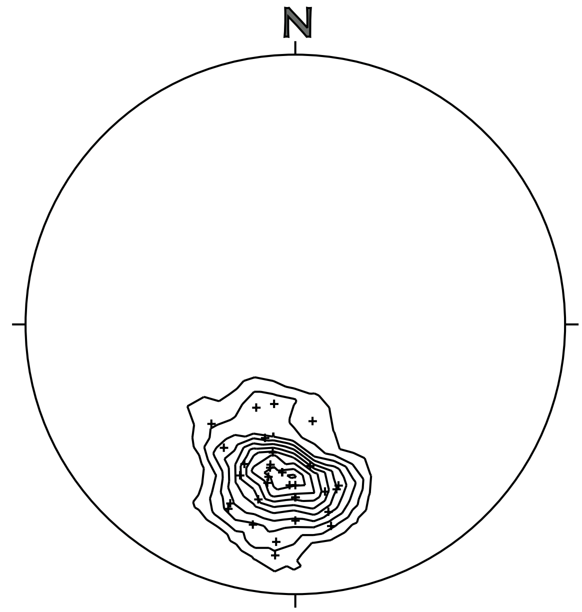

Figure 6. *Equal area, lower hemisphere projection, poles to auriferous-quartz extension veins from Hawthorne and Harvey ridges, and Rudolph Gulch.*

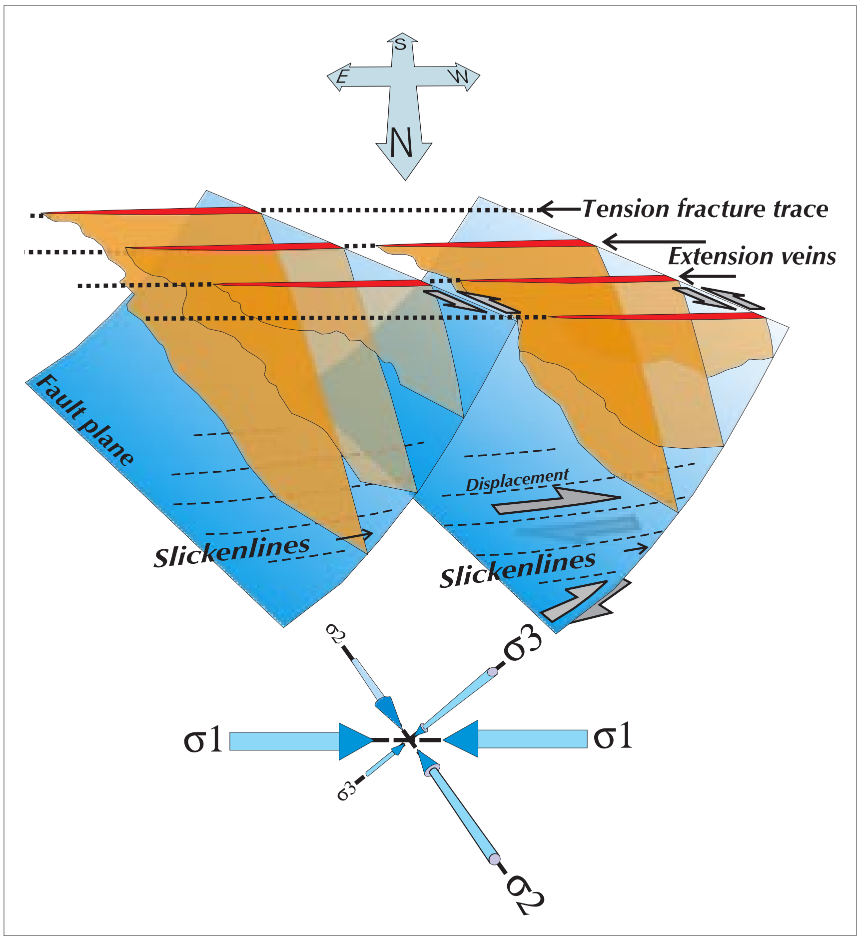

Figure 7. *Schematic depiction of the key structures controlling mineralization and the inferred orientation of the far-field stress regime at the time (view toward the south). Note, extension veins are best developed in the hanging walls of northwest-trending faults.*

METAL GEOCHEMISTRY OF THE SCHEELITE DOME GOLD OCCURRENCES

Grab samples and drill core samples, of hydrothermally altered wallrock or metalliferous vein material, were collected throughout the extent of the main gold-in-soil anomaly, spanning from the Tom Zone in the west, to east of Rudolph Gulch (Fig. 2). Of the 102 samples submitted for analyses, the majority were hydrothermally altered metasedimentary rocks, within and beyond the extent of the hornfels zone surrounding the Scheelite Dome stock. All styles of mineralization (as discussed above) were sampled. Analyses were performed by Acme Analytical Laboratories Ltd., Vancouver, B.C. (Table 1). Gold concentrations were determined to a lower detection limit of 5 ppb by standard fire assay with atomic absorption (AA) finish. Concentrations of 31 other major, minor, and trace elements in the 102 samples were determined by inductively coupled plasma-atomic emission spectroscopy (ICP-AES) analysis. Samples were also analyzed for tellurium by AA methods.

Arsenic concentrations are >1000 ppm in 70% of the samples since arsenopyrite was, by far, the most widely visible sulphide phase observed during sampling of metalliferous outcrops in the field. However, samples containing high arsenic levels do not consistently show high gold values ($r = 0.57$). Antimony concentrations are also consistently elevated, with 40% of the samples containing >100 ppm. All mineralization styles are characterized by a broad range of gold concentrations. Although only 18 samples of disseminated and replacement mineralization styles were analyzed, they include more than half of all the samples with greater than 4 ppm Au. This suggests any high-grade targets that are eventually delineated during future resource estimation are likely to be within zones characterized by these mineralization styles. Of the nine samples containing >10 ppm Au, most also contain >300 ppm W and >50 ppm Bi. Samples with Sb concentrations >1000 ppm, consistently feature Pb concentrations >100 ppm.

FACTOR ANALYSES

R-mode factor analysis, using Varimax rotation of log-transformed data, was used to identify the main elemental associations within the geochemical data set. This information was used in an attempt to characterize the metallogenic signature(s) of gold mineralization. Factor analysis enables a large, multivariate data set to be explained by a small number of factors, which identify the dominant associations between variables (i.e., the elements). The calculated factor loadings may be interpreted similarly to correlation coefficients, with highest absolute loadings onto each factor defining a group of variables that are strongly inter-correlated within the data set. Factor analyses were performed using Stat View™ 512+. Results of the factor analysis are presented in Table 2. In order to carry out the factor analysis, elemental concentrations below the limit of detection were replaced with values 0.7 times the lower detection limit. Highly censored elements (containing a large proportion of 'less than' values), including uranium and thallium, were eliminated from the analysis. Because geochemical data distributions are typically log-normal, a log transformation of all data was performed prior to factor analysis. A six-factor model was used to explain approximately 77% of the total variance within the Scheelite Dome lithogeochemical database. Additional factors were deemed statistically insignificant because they were characterized by Eigen values <1.0 and thus explained less of the data variance than the single elements themselves.

The calculated second and fourth factors define the precious metal associations at Scheelite Dome. The strongest loading for gold is onto factor 4, which also contains high loadings for tellurium and bismuth, and, to a lesser degree, Ag, As, Fe and W. Examination of factor scores (i.e., the relative correlation of each sample with that factor association) indicates that all styles of mineralization may be characterized by the factor 4 metal suite and there is no obvious spatial restriction to the suite. This factor suggests that bismuth- and tellurium-bearing mineral phases are most consistently associated with gold in the Scheelite Dome occurrences. The high loadings for arsenic and tungsten reflect the common presence of arsenopyrite and scheelite; silver is likely enriched with gold as electrum. The high loading for iron particularly reflects the high pyrrhotite content of replacement-style samples (such as samples 3 and 4 from the Tom Zone, and sample 92 from Rudolph Gulch, Table 1), which have notably high scores onto factor 4.

Factor 2 defines a second, significant gold-bearing association. It is characterized by a strong base metal association, with high factor loadings for Ag, Pb, Zn, Cd, Sb, and, to a lesser degree, Cu, Au, and As. Samples that score highly onto factor 2 include those of paragenetically late, massive sulphide mineralization (predominately stibnite) from within fault veins and quartz-stibnite-arsenopyrite extension veins (e.g., samples 19 and 64, Table 1). The factor loading onto Au may be exaggerated, due to fault-vein samples incorporating different paragenetic stages, including an earlier Au-rich phase characterized by the metal association in factor 4 (Fig. 5b). It is possible that this association represents a greater metal contribution leached from the metasedimentary rocks, when compared to the association of factor 4. It is also interesting to note that Marsh et al. (1999) determined the same two gold-related associations at Clear Creek, which further suggests that this is a regional feature inherent to the hydrothermal systems.

Factor 1 contains high loadings for Fe, Na, Ca, Mg, Al, Ti, Sr, V, Ni, Co, and Mn. This association is representative of analyzed samples that simply contained a large proportion of metasedimentary rock, as most of the elements in the

***Table 1**. Lithogeochemical data for mineralized samples collected throughout the extent of the gold-in-soil anomaly at Scheelite Dome (see Figure 2 for location of anomalous zones). Most elemental concentrations are ppm; Au is in ppb; Fe, Ca and Mg are in percent. Mineralization abbreviations: rep. = replacement; dis. = disseminated; f.v. = fault vein; e.v. = extension vein.*

Sample no.	Description	Mineralization style	Mo	Cu	Pb	Zn	Ag	Ni	Co	Mn	Fe	As	Cd	Sb	Bi	V	Ca	La	Cr	Mg	Ba	W	Te	Au
Tom Zone																								
1	calc-silicate rock	rep.	31	17	2.1	11	0.21	22	6	240	0.59	100	0.14	2.1	5	23	4.28	14	17	0.39	63	10	0.18	256
2	gritty psammite	dis.	3	14	11	4	1.4	4	1	58	0.63	3406	0.14	42	7	2	0.08	14	19	0.03	27	9	0.4	543
3	calc-silicate rock	rep.	5	767	4	10	5.4	83	71	739	17.73	3589	0.14	3	301	18	5.29	16	14	0.51	20	323	8.6	10032
4	calc-silicate rock	rep.	5	1450	2.1	18	8	66	113	966	15.92	6354	0.14	10	510	29	5.88	17	17	0.8	35	529	18.28	18041
5	calcareous psammite	dis.	3	111	21	52	11.9	48	102	2283	7.09	18369	0.3	3929	2292	45	11.61	11	18	2.81	47	693	52.48	57873
Hawthorne Ridge																								
6	early quartz phase	f.v.	5	11	6	1	0.8	2	1	29	0.33	535	0.14	910	2.1	1	0.007	1	29	0.007	2	3	0.014	32
7	quartz-arsenopyrite vein	e.v.	5	4	4	4	0.5	3	1	60	0.51	510	0.14	66	3	1	0.01	4	30	0.01	30	5	0.02	54
8	quartz-arsenopyrite vein	e.v.	1	4	6	4	0.7	3	1	71	0.61	819	0.14	44	2.1	1	0.01	4	25	0.01	58	8	0.03	87
9	quartz-arsenopyrite vein	e.v.	1	7	52	10	1.3	12	3	189	0.64	1019	2.4	89	5	3	0.04	15	22	0.02	30	64	0.03	104
10	psammite with quartz-arsenopyrite vein	e.v.	1	17	6	9	0.5	5	2	59	0.83	614	0.14	10	5	3	0.01	12	24	0.06	70	5	0.08	123
11	psammite with quartz-arsenopyrite vein	e.v.	5	13	37	14	1.9	8	2	104	0.94	1453	0.14	19	6	5	0.03	16	27	0.07	95	4	0.43	136
12	psammite with quartz-arsenopyrite vein	e.v.	0.7	15	6	17	0.5	15	8	382	1.43	2910	0.14	14	3	3	0.04	18	22	0.04	133	8	0.13	179
13	psammite with quartz-arsenopyrite vein	e.v.	3	26	21	31	0.4	8	3	175	2.96	3767	1.1	41	6	14	0.04	40	38	0.37	160	5	0.12	237
14	quartz-arsenopyrite vein	e.v.	5	4	9	1	1.2	2	0.7	45	0.58	3632	0.14	20	2.1	1	0.01	2	32	0.007	97	4	0.24	256
15	quartz-arsenopyrite vein	e.v.	21	27	11	21	1.1	8	3	73	2.24	7725	0.3	129	2.1	4	0.03	17	31	0.06	192	4	0.22	300
16	phyllite with quartz-arsenopyrite-stibnite vein	e.v.	2	10	67	7	10.4	3	1	36	0.99	2139	0.14	647	6	2	0.01	14	20	0.01	49	7	0.21	385
17	psammite with quartz-arsenopyrite vein	e.v.	5	18	27	9	2.1	2	1	59	2.59	17945	0.14	133	4	3	0.01	19	24	0.01	118	3	0.1	451
18	quartz-arsenopyrite, stibnite vein	f.v.	5	29	2358	15	37.5	1	1	56	1.14	9312	3.4	2565	11	1	0.01	6	31	0.007	383	5	0.7	517
19	massive sulphide	f.v.	1	312	260	366	274.7	0.7	3	28	1.03	507	12	50937	11	1	0.01	2	21	0.01	4	4	0.03	808
20	altered quartz-phyllite	dis.	1	36	59	14	5.9	1	1	56	3.39	14589	0.6	182	5	3	0.01	35	14	0.02	104	2	0.17	1033
21	quartz-arsenopyrite vein	e.v.	1	24	767	182	9.5	4	2	88	2.79	46447	13.7	525	6	2	0.02	10	24	0.01	255	8	0.24	1264
22	psammite with quartz-arsenopyrite vein	e.v.	3	31	323	42	18	17	3	160	2.99	11758	0.7	232	41	15	0.03	20	40	0.32	63	4	2.92	1381
23	brecciated vein-quartz	f.v.	7	159	28	21	1.2	7	3	42	4.6	1492	1.6	17	6	2	0.01	4	26	0.01	12	4	0.61	1539
24	quartz-arsenopyrite, stibnite vein	f.v.	1	75	7414	92	61.3	1	1	111	3.69	85306	35.8	3396	16	3	0.04	13	22	0.01	266	4	0.33	1720
25	quartz-arsenopyrite, stibnite vein	f.v.	2	48	61	4	16	1	4	31	1.45	15514	0.5	11945	4	1	0.007	3	26	0.007	3	6	1.71	1792
26	phyllite with quartz-arsenopyrite vein	e.v.	1	23	1868	111	17.7	4	2	102	3.69	85420	15	1131	8	5	0.03	14	18	0.03	184	4	0.28	2122
27	altered quartz-phyllite with vein	e.v.	4	19	827	49	15.2	2	1	91	4.02	84231	5.5	567	11	2	0.03	9	23	0.01	355	2	0.4	2286
28	quartz-arsenopyrite vein	e.v.	10	7	36	5	1.9	4	2	70	0.58	1519	0.2	64	142	2	0.01	4	34	0.01	8	5	5.09	3670
29	quartz-arsenopyrite, stibnite vein	f.v.	9	158	4691	420	90.2	0.7	1	43	1.7	17616	227.7	4755	15	1	0.01	1	32	0.007	5	5	0.67	4712
30	quartz-arsenopyrite, stibnite vein	f.v.	6	33	803	8	32.1	0.7	1	45	1.52	16842	3.7	2966	62	0.7	0.01	1	33	0.007	30	5	2.19	17583
Harvey Ridge/Harvey Gulch																								
31	quartz breccia	f.v.	1	93	9	48	0.21	17	6	130	6.72	1712	0.14	35	2.1	4	0.01	18	15	0.01	24	5	0.02	5
32	quartz breccia	f.v.	4	29	6	60	0.8	26	7	181	6.83	4375	0.14	236	5	3	0.04	23	19	0.01	155	3	0.05	25
33	quartz vein	e.v.	1	4	3	1	0.3	3	1	41	0.38	50	0.14	4	3	0.7	0.007	2	17	0.01	6	20	0.09	46
34	psammite with quartz-arsenopyrite vein	e.v.	1	11	9	20	0.3	7	2	90	1.2	1012	0.14	26	2.1	3	0.01	18	14	0.02	87	5	0.24	47
35	psammite with quartz-arsenopyrite vein	e.v.	5	6	4	6	0.5	3	2	153	0.71	695	0.14	10	2.1	2	0.01	10	23	0.01	81	5	0.11	47
36	psammite with quartz-arsenopyrite vein	e.v.	4	5	5	8	0.4	4	2	316	0.75	629	0.14	12	2.1	2	0.01	13	20	0.01	47	4	0.08	57
37	psammite with quartz-arsenopyrite vein	e.v.	3	6	3	4	0.21	2	1	154	0.52	463	0.14	8	2.1	1	0.01	10	26	0.01	33	5	0.11	61
38	psammite with quartz-arsenopyrite vein	e.v.	1	8	9	15	0.5	6	2	189	1.03	1204	0.14	11	2.1	2	0.01	15	17	0.02	67	7	0.19	65
39	psammite with quartz-arsenopyrite vein	e.v.	2	25	10	19	0.7	14	5	422	1.43	2732	0.14	21	5	4	0.96	15	17	0.25	32	5	0.45	72
40	phyllite with quartz veinlets	e.v.	1	3	4	5	0.9	2	1	43	0.45	210	0.14	88	2.1	2	0.007	17	17	0.01	28	4	0.03	72
41	psammite with quartz-arsenopyrite vein	e.v.	2	25	8	8	0.6	11	4	236	1.15	344	0.14	13	3	2	0.63	11	17	0.18	21	5	0.14	91
42	quartz-arsenopyrite vein	e.v.	1	20	7	9	0.8	4	1	69	0.79	1297	0.14	14	3	3	0.01	12	18	0.03	42	13	0.29	111
43	psammite with quartz-arsenopyrite vein	e.v.	4	18	21	16	1.4	12	3	114	1.37	1068	0.14	16	2.1	3	0.01	17	22	0.01	39	6	0.14	122
44	quartz-arsenopyrite vein	e.v.	3	5	116	8	2.9	7	1	203	0.93	2612	0.8	60	3	2	0.01	11	21	0.01	73	8	0.48	132
45	psammite with quartz-arsenopyrite vein	e.v.	2	15	23	30	1.2	17	8	558	2.02	870	0.14	42	2.1	2	1.06	9	15	0.35	115	4	0.16	190
46	psammite with quartz-arsenopyrite-stibnite vein	e.v.	4	23	3174	39	17.9	6	1	51	1.14	3837	3.3	393	2.1	2	0.007	16	17	0.02	26	6	0.23	194
47	psammite with quartz-arsenopyrite vein	e.v.	3	10	8	15	0.21	12	3	329	1.39	2883	0.14	21	2.1	2	0.51	13	19	0.16	23	7	0.21	217
48	psammite with quartz-arsenopyrite-stibnite vein	e.v.	4	11	2836	17	15.3	6	0.7	47	0.83	3567	2.6	320	2.1	1	0.007	6	15	0.01	19	8	0.26	222
49	psammite with quartz-arsenopyrite vein	e.v.	2	9	20	12	0.6	10	2	129	1.15	2226	0.14	33	2.1	2	0.02	15	16	0.02	157	6	0.23	229
50	phyllite with quartz-arsenopyrite vein	e.v.	4	3	10	4	0.7	3	1	43	1	5814	0.2	9	4	2	0.01	10	27	0.01	243	4	1.45	240
51	phyllite with quartz-arsenopyrite vein	e.v.	3	12	6	29	0.21	14	5	559	2.22	504	0.14	17	2.1	8	0.36	13	28	0.35	29	4	0.06	241
52	psammite with quartz-arsenopyrite veins	e.v.	3	30	10	11	1.4	13	5	233	1.78	10379	0.14	43	5	2	0.41	11	19	0.15	26	5	2.49	275
53	psammite with quartz-arsenopyrite vein	e.v.	1	5	7	5	0.9	3	1	37	0.64	2270	0.14	9	2.1	1	0.01	14	14	0.01	44	5	1.15	308
54	psammite with quartz-arsenopyrite vein	e.v.	1	33	11	37	0.7	20	11	117	2.14	1888	0.14	10	4	7	0.03	42	20	0.15	82	2	0.33	326
55	altered psammite with disseminated arsenopyrite	dis.	1	9	7	8	0.8	3	1	40	0.79	4669	0.14	10	2.1	2	0.02	14	14	0.01	22	5	0.42	386
56	quartz-stibnite vein	e.v.	1	70	32	185	18.4	0.7	1	55	0.74	179	13.8	19084	2.1	1	0.02	2	20	0.01	11	1.4	0.03	458
57	phyllite with quartz-arsenopyrite vein	e.v.	3	27	16	13	0.9	25	9	383	1.76	5820	0.2	236	5	4	0.19	22	17	0.1	63	9	0.41	506
58	phyllite with quartz-arsenopyrite vein	e.v.	8	18	7	7	0.3	2	1	52	2.22	6300	0.4	14	4	4	0.01	33	15	0.02	123	5	0.82	647
59	psammite with quartz-arsenopyrite vein	e.v.	3	10	74	5	1.6	6	1	62	1.1	7522	0.14	31	4	2	0.01	11	21	0.01	18	6	0.94	667
60	psammite with quartz-arsenopyrite vein	e.v.	125	23	12	61	0.6	28	11	430	2.7	1051	0.14	31	14	3	0.39	19	17	0.58	46	7	0.77	795
61	psammite with quartz-arsenopyrite vein	e.v.	3	21	8	31	0.4	20	8	280	2.51	12223	0.3	28	3	4	0.24	20	20	0.23	43	5	3.16	802
62	phyllite with quartz-arsenopyrite vein	e.v.	4	20	26	25	0.9	16	6	288	1.66	942	0.14	35	11	9	0.78	11	29	0.35	49	8	0.52	803
63	gritty psammite with quartz-arsenopyrite vein	e.v.	3	53	21	8	2.1	13	7	219	2.2	18806	0.14	75	12	2	0.47	10	18	0.13	27	7	6.03	847
64	massive sulphide	f.v.	1	141	2.1	13	16.7	0.7	2	17	0.33	44	0.9	19026	105	1	0.007	1	4	0.01	1	1.4	0.03	859
65	quartz-arsenopyrite vein	e.v.	3	12	290	2	130.4	7	1	52	0.64	2807	1.1	187	4	1	0.007	2	20	0.007	107	9	0.08	1057
66	psammite with quartz-arsenopyrite vein	e.v.	4	39	23	23	1.6	13	7	479	1.75	5203	0.3	41	3	2	0.56	12	21	0.21	28	5	1.02	1132
67	phyllite with quartz-arsenopyrite vein	e.v.	2	42	23	60	0.5	58	22	349	3.85	17137	0.14	25	6	16	0.13	21	26	0.69	93	5	2.25	1429

continued...

Table 1. *continued (most elemental concentrations are ppm; Au is in ppb; Fe, Ca and Mg are in percent. Mineralization abbreviations: rep. = replacement; dis. = disseminated; f.v. = fault vein; e.v. = extension vein.)*

Sample no.	Description	Mineralization style	Mo	Cu	Pb	Zn	Ag	Ni	Co	Mn	Fe	As	Cd	Sb	Bi	V	Ca	La	Cr	Mg	Ba	W	Te	Au
68	quartz breccia	f.v. ?	2	12	181	3	61.9	7	1	66	1.28	11974	0.5	70	3	1	0.02	8	14	0.01	218	7	0.24	1468
69	altered psammite	dis.	5	17	330	10	11.2	5	1	59	1.85	17449	0.3	205	4	1	0.007	9	22	0.01	89	7	0.4	1633
70	psammite with quartz-arsenopyrite-veins	e.v.	5	18	24	23	0.9	10	3	721	2.79	13008	0.2	1442	4	2	1.61	11	29	0.52	35	8	3.77	1728
71	altered monzonite dyke	dis.	4	204	21	26	1.5	25	15	935	4.43	10004	0.5	309	18	8	1.96	50	11	0.47	86	3	0.47	1735
72	quartz-stibnite vein	f.v.	1	247	55	92	16.1	10	8	277	1.62	982	1.8	19236	2.1	1	0.34	2	15	0.17	8	3	0.02	1899
73	phyllite with quartz-arsenopyrite vein	e.v.	6	25	29	3	2.4	32	8	125	0.8	3472	0.14	28	24	2	0.53	22	20	0.02	38	6	1.62	2196
74	phyllite with quartz-arsenopyrite-stibnite vein	e.v.	5	29	4247	340	54.8	5	1	55	0.93	5995	91.8	3524	6	1	0.007	2	26	0.007	132	4	0.19	2548
75	phyllite with quartz-arsenopyrite-stibnite vein	e.v.	2	32	2570	248	25.1	7	2	62	2.92	8490	56	1304	8	6	0.05	32	11	0.02	99	19	0.63	2865
76	phyllite with quartz-arsenopyrite vein	e.v.	4	8	3	14	0.4	7	3	120	1.59	1841	0.14	6	2.1	3	0.03	13	20	0.03	17	4	0.36	4068
77	altered monzonite dyke	dis.	4	296	50	47	3.4	38	15	752	4.49	14344	1	68	29	9	0.97	45	16	0.35	43	3	0.74	4171
78	phyllite with quartz-stibnite-arsenopyrite vein	e.v.	3	78	25281	50	232.5	0.7	1	53	1.11	2310	56.4	25482	39	2	0.01	7	18	0.03	39	1.4	0.08	11233
79	psammite with quartz vein	e.v.	4	5	22	5	3.3	4	1	58	0.58	438	0.14	42	540	2	0.02	6	23	0.01	29	324	15.06	12307
80	psammite with disseminated arsenopyrite	dis.	2	22	83	11	12.5	16	29	262	4.77	51242	1.5	258	145	3	1.56	12	15	0.33	30	658	5.78	34419
81	phyllite with quartz-arsenopyrite vein	e.v.	2	46	125	82	10.6	66	26	723	5.53	35867	0.8	84	27	9	0.74	17	14	0.86	59	1.4	3.92	59575
Rudolph Gulch																								
82	phyllite with quartz-arsenopyrite vein	e.v.	2	7	6	19	0.3	10	1	97	0.91	3679	0.2	20	2.1	2	0.02	13	19	0.02	48	7	0.16	59
83	calc-silicate rock with disseminated arsenopyrite	dis.	2	131	5	20	0.3	102	50	497	4.77	30543	0.3	30	6	64	3	10	64	1.17	33	1.4	0.22	77
84	psammite crosscut by quartz vein	e.v.	3	30	5	19	0.8	11	3	105	0.96	1097	0.14	86	4	3	0.01	19	17	0.02	62	4	0.11	93
85	psammite with quartz-arsenopyrite-stibnite vein	e.v.	3	17	246	32	4.3	14	3	121	1.42	1596	0.14	480	4	8	0.01	13	26	0.14	65	5	0.12	96
86	psammite with quartz-arsenopyrite vein	e.v.	4	14	10	14	0.7	9	3	151	1.16	4378	0.9	28	2.1	3	0.03	21	21	0.02	538	6	0.27	101
87	psammite with quartz-arsenopyrite vein	e.v.	3	11	65	16	1.4	11	2	105	0.91	3692	0.3	440	3	3	0.02	16	18	0.02	33	12	0.27	120
88	psammite with quartz-arsenopyrite vein	e.v.	3	8	18	13	0.6	16	4	369	1.13	3993	0.14	437	2.1	3	0.01	14	23	0.02	176	6	0.24	133
89	quartz-arsenopyrite vein	f.v.?	3	12	16	10	0.7	9	2	127	0.74	2023	0.4	20	2.1	1	0.03	4	23	0.02	7	9	0.03	159
90	quartz-arsenopyrite, stibnite vein	f.v.?	5	26	253	39	90.3	8	2	65	0.84	6079	5.4	310	3	1	0.01	4	25	0.007	21	32	0.13	213
91	psammite with quartz-arsenopyrite vein	e.v.	1	21	5	20	0.5	11	4	152	1.73	4457	0.14	7	8	4	0.04	53	12	0.04	57	4	0.23	436
92	calc-silicate rock (partially replaced)	rep.	2	405	7	38	0.3	41	22	389	5.47	26731	0.2	49	28	26	1.77	22	37	1.04	35	5	0.68	461
93	psammite with quartz-arsenopyrite veinlets	e.v.	4	8	235	30	4.8	7	1	70	0.88	4871	2.4	113	3	1	0.05	10	19	0.02	8	6	0.03	685
94	quartz-arsenopyrite vein	e.v.	6	8	601	8	7.5	8	1	78	1.47	13627	2.6	219	11	1	0.01	1	30	0.007	5	12	0.16	1247
95	quartz-arseonpyrite-stibnite vein	e.v.	4	40	1352	8	12.4	6	0.7	77	2.43	23850	0.8	749	36	2	0.02	3	20	0.007	34	8	2.26	1404
96	massive sulphide	f.v.	1	244	270	407	134.8	5	4	90	0.45	254	45.1	19798	28	1	0.27	2	7	0.01	3	1.4	0.04	1611
97	quartz-arsenopyrite-stibnite vein	f.v.?	2	1865	21040	173	288.3	0.7	1	47	3.23	14883	64.1	20431	24	1	0.06	3	14	0.01	13	3	0.11	2131
98	quartz-arsenopyrite-stibnite vein	e.v.	2	39	2632	24	52.7	6	1	70	1.04	8914	6.5	2844	17	1	0.02	1	26	0.007	3	10	0.1	2542
99	calc-silicate rock (partially replaced)	rep.	1	1839	16	16	2.8	44	25	358	20.09	6046	0.14	37	362	22	1.26	28	29	0.58	15	155	4.05	3041
100	psammite with quartz-arsenopyrite vein	e.v.	4	38	6	37	2.6	14	5	99	2.64	1816	0.14	30	7	6	0.01	17	25	0.14	100	18	0.45	3401
101	psammite with disseminated arsenopyrite	dis.	3	55	31	14	3.1	4	2	71	3.06	32211	1.4	47	16	2	0.02	12	17	0.03	64	34	0.55	3448
102	quartz-arsenopyrite vein	e.v.	5	12	847	7	15.4	9	2	132	1.15	7589	0.3	815	61	3	0.02	4	24	0.03	40	478	1	16523

Table 2. *Six-factor model of R-mode factor analysis of lithogeochemical data presented in Table 1. Factors 2 and 4 describe the metallogenic associations, whereas factors 1, 3 ,5 and 6 describe lithological associations. Positive numbers indicate the degree of positive correlation. The strongest gold association occurs in Factor 4.*

Element	Factor 1	Factor 2	Factor 3	Factor 4	Factor 5	Factor 6
Mo	0.153	-0.162	-0.15	0.141	0.468	-0.494
Cu	0.516	0.571	-0.061	0.235	-0.197	0.319
Pb	-0.268	0.792	0.075	0.242	0.187	-0.099
Zn	0.352	0.773	0.207	-0.187	-0.072	-0.02
Ag	-0.24	0.797	-0.132	0.39	-0.095	0.017
Ni	0.804	-0.287	0.165	0.054	0.044	-0.06
Co	0.882	-0.026	0.077	0.174	-0.137	0.079
Mn	0.864	-0.138	0.168	0.014	-0.022	-0.246
Fe	0.621	0.262	0.409	0.355	0.079	0.145
As	0.032	0.376	0.53	0.552	0.132	-0.097
Th	0.357	-0.368	0.753	0.041	-0.21	0.06
Sr	0.674	0.173	0.359	0.248	-0.089	-0.156
Cd	-0.199	0.894	-0.058	0.071	0.029	-0.03
Sb	-0.134	0.847	-0.125	0.062	-0.088	-0.002
Bi	0.346	0.234	-0.189	0.795	-0.094	0.17
V	0.795	-0.118	0.295	0.092	0.209	0.316

Element	Factor 1	Factor 2	Factor 3	Factor 4	Factor 5	Factor 6
Ca	0.884	-0.036	-0.027	0.168	-0.159	-0.187
P	0.504	-0.011	0.611	0.145	0.217	0.192
La	0.384	-0.305	0.797	0.006	-0.141	0.134
Cr	0.095	-0.08	-0.053	-0.061	0.875	0.006
Mg	0.92	-0.093	0.14	0.043	0.014	-0.018
Ba	0.029	-0.129	0.748	0.026	0.287	-0.11
Ti	0.636	-0.033	0.023	-0.066	0.402	0.529
B	-0.477	0.108	0.464	-0.028	-0.121	-0.047
Al	0.742	-0.159	0.491	0.028	0.055	0.29
Na	0.71	-0.081	0.093	0.141	0.062	0.429
K	0.418	-0.133	0.742	-0.15	-0.101	0.022
W	0.212	-0.309	-0.348	0.552	0.059	-0.082
Te	0.322	-0.048	0.217	0.799	0.023	-0.058
Hg	0.038	0.275	0.175	-0.022	0.483	0.022
Au	0.169	0.453	0.038	0.751	-0.138	-0.045
Cumulative %	33.7	51.3	62.1	67.7	73.6	77

association form common silicate and carbonate mineral phases. Factor 3 is defined by high loadings for Th, P, La, Ba, and K, and, to a lesser extent, for Fe, B and Al. Samples with high scores onto factor 3 are the most intensely sericitically altered phyllitic and psammitic rocks, although they may or may not be enriched in gold. Factor 5 contains high loadings for Mo, Cr, and Hg, and most likely explain the variance in the data due to a few samples with a high component of black shale protolith. Factor 6 is also interpreted to reflect minor lithogeochemical variations among a few samples.

DISCUSSION OF THE FACTOR ANALYSIS

Results of the factor analysis indicate that many of the gold-rich lodes at Scheelite Dome are characterized by a metallogenic signature of Au-Te-Bi ± W, As ± Ag, Fe. This signature is broadly consistent with that for other gold occurrences within the Tombstone gold belt, including Clear Creek (Marsh et al., 1999), Fort Knox (Bakke, 1995), and Dublin Gulch (Smit et al., 1996). Elements such as Te, Bi, and W are often assumed to be associated with magmatic hydrothermal systems (Sillitoe and Thompson, 1998). If correct, then this element association may define hydrothermal fluids exsolved from the Scheelite Dome crystallizing magma or a leaching of the stock by hydrothermal fluids from any source subsequent to crystallization.

The strong base metal association in factor 2, which is also associated with elevated gold levels at Scheelite Dome, as well as at Clear Creek (Marsh et al., 1999), is somewhat characteristic of the mineralization in the Keno Hill district (approximately 60 km to the east-northeast). Lynch (1986) recognized a regional zonation in metals and associated hydrothermal assemblages over a 25-km-long, east-trending corridor of mid-Cretaceous hydrothermal activity in the Keno Hill district. He speculated that the eastern-most mineral occurrences, dominated by pyrrhotite, arsenopyrite, and gold, were, on a district scale, most proximal to the primary fluid source. They were hypothesized to represent the deeper metallogenic expression of the widespread, zoned hydrothermal system. The extensively-mined central Keno Hill and Galena Hill areas near Elsa (Fig. 1) contained a large Ag-Pb-Zn resource, which was thought to perhaps have reflected a shallower, cooler part to the hydrothermal system (Lynch, 1986).

At Scheelite Dome, it remains to be determined whether a more telescoped, but geochemically similar, hydrothermal system is also defined by an early Au-W-Bi-Te-As fluid and a later Au-Ag-Pb-Zn-Sb fluid pulse. Initial evaluation of our data from Scheelite Dome suggests no apparent spatial zonation of metals within the aerial extent of the hydrothermal system. However, samples with highest scores onto factor 2 tend to be characterized by late-stage massive sulphide mineralization in fault veins. Therefore, it is interpreted that enrichment of base metals may represent a later paragenetic stage within the evolution of the hydrothermal system. Additional study is required before we can determine whether the metals in both stages likely have been derived from the same sources.

SUMMARY

Scheelite Dome hosts multiple styles of gold mineralization, and tungsten- and tin-bearing skarn occurrences. Extensive soil and rock sampling have identified an east-trending geochemical anomaly greater than 6 km long, indicative of an extensive hydrothermal system. Field evidence indicates that gold mineralization bears a temporal and spatial relationship to the Scheelite Dome quartz monzonite stock of the TPS, although most significant occurrences are distal to the stock, within and near the thermal aureole. The distribution of gold mineralization at Scheelite Dome is mainly controlled by northwest-trending brittle faults, and east-trending tension fractures, formed during a phase of east-west shortening that was coeval with the mineralizing event. Styles of gold mineralization in metasedimentary rocks include extension veins, fault veins, replacement zones, and disseminated zones. The diversity of mineralization styles outside the stock reflects the chemical and rheological heterogeneity of the metasedimentary strata. Within the Scheelite Dome stock, gold is only hosted in sheeted quartz-K-feldspar veins.

R-mode factor analyses of the log-transformed lithogeochemical data for mineralized grab and drill core samples indicates two precious metal associations within the extent of the soil geochemical anomaly at Scheelite Dome. The most consistent gold association occurs with Bi-Te ± As, W, which is broadly consistent with granitoid-hosted gold occurrences elsewhere in the Tombstone gold belt. The second precious metal association features a strong Ag-Pb-Zn-Sb-Cd ± Cu, As association, which is more characteristic of Ag-Pb-Zn mineralization in the nearby Keno Hill district. Field evidence, combined with soil and grab sample geochemistry, indicate that there is no apparent spatial zonation of metals within the extent of the soil geochemical anomaly at Scheelite Dome. However, rock samples which feature the Ag-Pb-Zn-Sb-Cd ± Cu, As, Au association, are typically paragenetically late, suggesting that the two precious metal associations may be related to different paragenetic stages in the evolution of the hydrothermal system.

ACKNOWLEDGEMENTS

Thanks to Copper Ridge Explorations Ltd. for access to the Scheelite Dome property and all available data. Julian Stephens, Erin Marsh, Mark Lindsay and Don Murphy are thanked for constructive discussions throughout the field season. The Society of Economic Geologists is acknowledged for financial support. A special thanks to Leyla Weston and Diane Emond for having the patience to wait diligently for this manuscipt. Finally, the Pointer Brothers are acknowledged for their quality tunes during field breaks in Dawson.

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An evaluation of coal-bearing strata at Division Mountain (115H/8 east-half, 105E/5 west-half), south-central Yukon

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Allen, T.L., 2000. An evaluation of coal-bearing strata at Division Mountain (115H/8 east-half, 105E/5 west-half), south-central Yukon. *In:* Yukon Exploration and Geology 1999, D.S. Emond and L.H. Weston (eds.), Exploration and Geological Services Division, Yukon, Indian and Northern Affairs Canada, p. 177-198.

ABSTRACT

The Division Mountain area is underlain primarily by Jurassic to Cretaceous(?) sedimentary rocks of the Laberge Group and Tantalus Formation. The Laberge Group is divisible into the following informal units: the Richthofen, Nordenskiöld, Conglomerate, and Tanglefoot formations. The Tanglefoot, which comprises a large portion of the exposed strata at Division Mountain, is here subdivided into the lower and upper members. The lower member consists of quartz-rich sandstone, grit, polymicitic conglomerate and laminated siltstone. The upper member is coal-bearing and typified by white grit, sandstone, and carbonaceous shale. The overlying Tantalus Formation is characterized by thick packages of resistant chert pebble conglomerate with intercalated sandstone beds, which form local highlands at Cub, Corduroy, Division, and Vowel mountains.

The strata at Division Mountain are folded into several upright, tight northwest-trending anticlines and synclines with amplitudes of 2 to 7 km. The folded strata are intruded by feldspar-hornblende andesite sills and dykes.

Organic matter identified within coal and siltstone of the Tanglefoot and Tantalus formations consists of Type III and subordinate Type I kerogen, suggesting the material is largely gas-prone. A combination of thermal maturation indicators (vitrinite reflectance and T_{max}) suggests that the coal and related strata are in the early to late stages of thermal diagenesis. Samples of the underlying Richthofen formation contain Type III kerogen matured beyond the oil window. Local folding and thickening of the Tanglefoot and Tantalus strata, as well as local intrusions in the Tanglefoot, may play a key role in the determination of hydrocarbon potential of the Division Mountain area.

RÉSUMÉ

La région du mont Division est principalement sous-tendue par les roches sédimentaires du Groupe de Laberge et de la Formation de Tantalus du Jurassique au Crétacé (?). On peut diviser le Groupe de Laberge selon les unités suivantes (non officielles) ; les formations de Richthofen, de Nordenskiöld, de Conglomerate et de Tanglefoot. La formation de Tanglefoot, qui constitue une partie importante des strates exposées au mont Division, est divisée ici en membres inférieur et supérieur. Le membre inférieur comprend des grès riches en quartz, des grès grossiers, des conglomérats polygéniques et des siltstones laminés. Le membre supérieur est carbonifère et est caractérisé par des grès grossiers blancs, des grès et du shale carbonifères. La Formation de Tantalus sus-jacente est caractérisé par des ensembles épais de conglomérats résistants à cailloux de chert, interstratifiés de lits de grès qui forment les sommets des monts Cub, Corduroy, Division et Vowel.

Au mont Division, les strates sont plissées en une série d'anticlinaux et de synclinaux serrés de direction nord-ouest ayant des amplitudes de 2 à 7 km et sont par endroits pénétrés par des filons couches et des dykes d'andésite à feldspath et à hornblende.

La matière organique qui a été identifiée dans le charbon et les siltstones de la formation de Tanglefoot et dans ceux de la Formation de Tantalus est surtout constituée de kérogène de type III, avec une fraction subordonnée de kérogène de type I ce qui suggère que le matériau a une forte prédisposition au gaz. Une combinaison des indicateurs de maturité thermique (réflectance de la vitrinite et T_{max}) indique que le charbon et les strates associées ont atteint le stade avancé à tardif de la diagénèse thermique. Des échantillons prélevés dans la formation de Richthofen sous-jacente contiennent du kérogène de type III qui présente une maturité qui a dépassé l'intervalle du pétrole. Le plissement local et l'épaississement des strates les Formations de Tanglefoot et de Tantalus ainsi que la présence d'intrusions par endroits dans la Formation de Tanglefoot pourraient jouer un rôle important dans la détermination du potentiel en hydrocarbures de la région du mont Division.

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INTRODUCTION

The Division Mountain area, located along the western margin of the Whitehorse Trough (Fig. 1), contains one of the Yukon's most prospective coal desposits and may have natural gas potential. The potential for both coal and natural gas is not yet clear. This study attempts to better define the stratigraphy and sedimentology of the coal resources at Division Mountain and aids in the search for coal and hydrocarbon resources in the Whitehorse Trough.

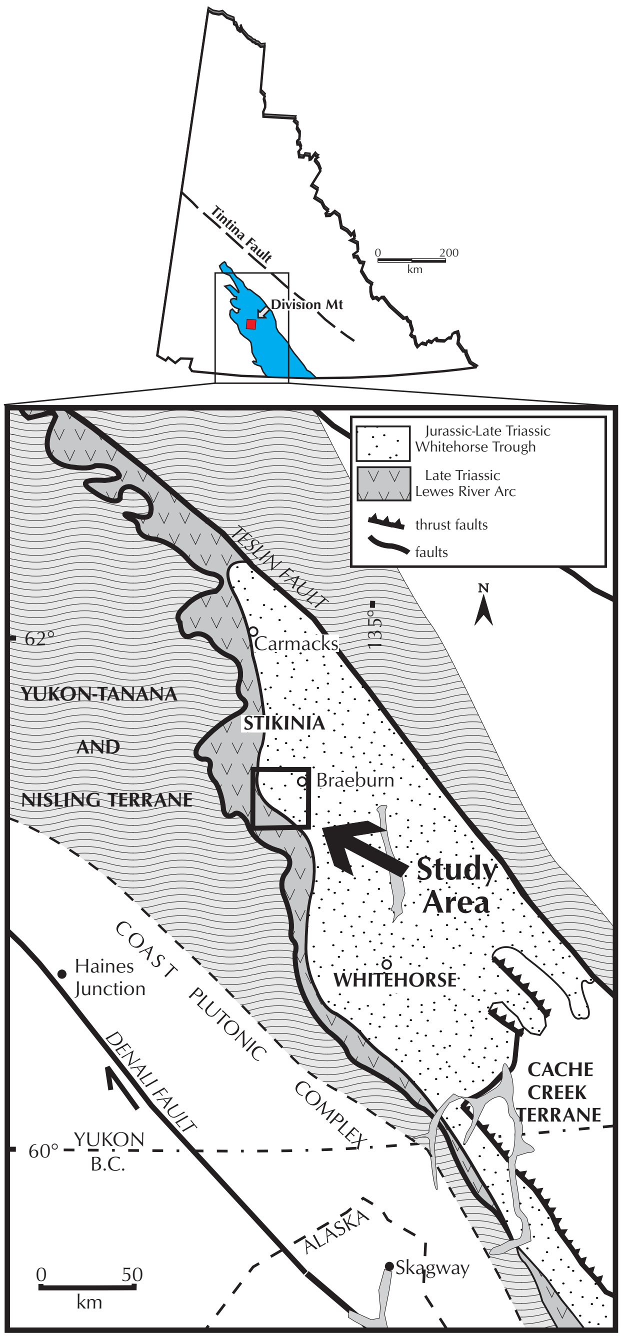

__Figure 1.__ Location of Division Mountain map area (after Hart, 1997).

Coal was first discovered near Division Mountain at the turn of the century. Cairnes (1908) identified three coal seams near Teslin Creek and one at the base of Vowel Mountain (Red Ridge). The area then lay dormant until the early 1970s, and has since been intermittently explored. Drilling and trenching has outlined mineable reserves of 52.9 million tonnes of high volatile bituminous B coal (Gish and Carne, 1998). The coal reserves are concentrated in a 50 m interval in the uppermost Jurassic Laberge Group below the Tantalus Formation chert pebble conglomerate (Mineral Resources Branch, 1998). Strata closely related to the coal measures consist of bleached quartzo-feldspathic sandstone, grit, pebbly grit, as well as grey siltstone and carbonaceous shale. North of Division Mountain, in the Carmacks region, coal seams occur in the upper Laberge Group as well as the Tantalus Formation. This study examines the uppermost Laberge Group strata associated with the coal measures in the Division Mountain area, focussing on their lithology, relationships, and distribution.

Little exploration or research has been initiated to determine the hydrocarbon potential of the Whitehorse Trough (Fig. 1), although the Trough is believed to be an immature, mainly gas-prone basin (Gilmore, 1985). Previous research was limited to a reconnaissance study of analysis, including a total of eight samples collected for analysis in the Division Mountain area (Gilmore, 1985; Beaton et al., 1992). No seismic surveys or drilling have been undertaken. In this study, twenty-three samples from the map area were analyzed to test source rock potential.

LOCATION, ACCESS, AND EXPOSURE

The Division Mountain area (parts of Vowel Mountain, 115H/8 east-half and Braeburn Lake, 105E/5 west-half) is located approximately 30 km west of the Braeburn airstrip, off the North Klondike Highway (Fig. 2). The North Klondike Highway crosses the northeast corner of the study area, approximately 90 km north-northwest of Whitehorse. Access from the highway is provided along Klusha Creek by the 4-wheel drive Trans Canada Trail (formerly the Dawson Trail). Further access is provided by an exploration road that branches off the Trans Canada Trail, approximately 21 km from the Braeburn Airstrip and continues due west to the Nordenskiöld River.

Fieldwork was mainly by foot traverse with limited helicopter access provided from Whitehorse. A walking trail (Dalton Trail), paralleling the west side of the Nordenskiöld River, provided limited access where portions of the trail have been maintained near Vowel Mountain. A large portion of the Dalton Trail, which originally ran the extent of the map sheet, is overgrown and covered with deadfall from old forest fires. A forest fire covered large portions of the map area during the mid 1960s. Today, these areas of the map sheet are covered with deadfall and dense secondary growth making traversing difficult.

Bedrock exposure is limited to less than 5%. Most streams and low-lying areas are blanketed with thick glacial material. Best exposures of strata occur at Teslin Creek (the discovery area) in trenches and natural exposures, and at Joe Creek, Red Ridge Canyon, Vowel, Cub, Corduroy, and Division mountains. Exposures tend to be scattered along ridge crests, grassy slopes, and canyons where glacial material has been downcut or eroded. Additional information of the coal-bearing strata was obtained from diamond drill core left on the property by Cash Resources Ltd.

PHYSIOGRAPHY

The study area includes two landforms that reflect underlying geology. Rounded hills with low to moderate relief cover most of the area and reflect the recessive strata of the Laberge Group and lower part of the Tantalus Formation. In contrast, a few larger landforms are underlain by thick conglomerate beds of the upper part of the Tantalus Formation. Elevations range from 700 to 1570 m (at Vowel Mountain). Overall, the ground is heavily vegetated except for south-facing slopes that are typically grass to aspen and poplar covered, providing patchy exposure.

Major watercourses in the map area include the approximately north-south oriented Nordenskiöld River and Klusha Creek (Fig. 2). These watercourses are small compared to the valleys they occupy, as the valleys were sites of large meltwater channels (outwash plains) during the McConnell glacial period (late Pleistocene; Klassen and Morison, 1987; Hughes, 1989). The Nordenskiöld and Klusha valleys are confined on either side by multiple McConnell age glaciofluvial terraces (Hughes, 1989), that extend 1 to 2 km across the valley bottoms, covering potential bedrock exposures. As ice retreated following the last glaciation, glaciofluvial plains were downcut in response to base-level change, leaving behind the stepped terraces that formed the valley walls. Cash Resources Ltd. intersected 60 m of overburden in drill holes along Klusha Creek and Nordenskiöld River terraces (Gish and Carne, 1998).

Braeburn Lake and the surrounding low ground consists of glaciofluvial and/or glaciolacustrine deposits (Klassen and Morison, 1987). Numerous swamps, small ponds and lakes occur within the study area, notably in areas once occupied by glaciers.

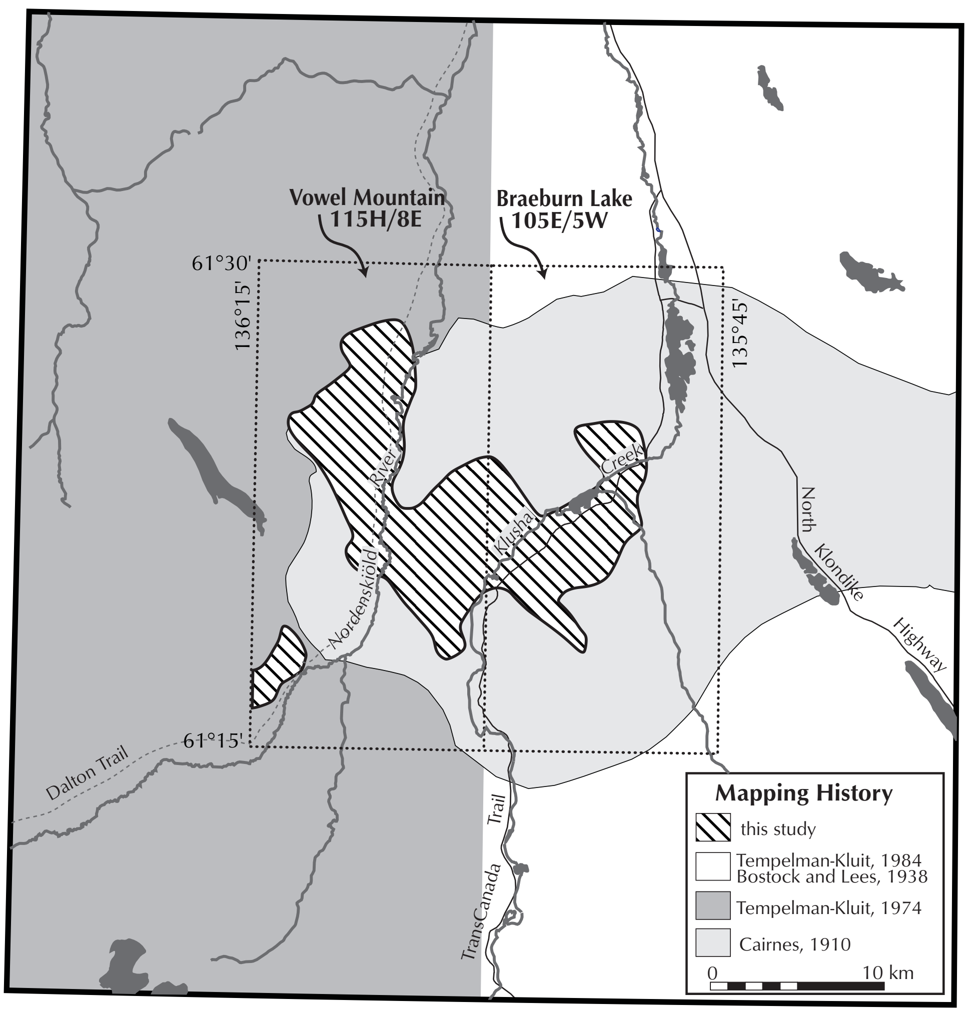

Figure 2. *Limits of previous and recent mapping in the Division Mountain area.*

PREVIOUS WORK

Cairnes (1910) first mapped the Division Mountain area, defining the Nordenskiöld dacites, Laberge series and Tantalus conglomerate. Lees (1934), maintaining Cairnes' nomenclature for sedimentary packages, mapped the Laberge map sheet and proposed the Lewes River Group. Bostock and Lees (1938) named the Nordenskiöld dacite, the Nordenskiöld formation, and the Tantalus conglomerate, the Tantalus Formation. In 1984, Tempelman-Kluit informally subdivided the Laberge Group into the Richthofen, Conglomerate, Nordenskiöld, and Tanglefoot formations on the Laberge map sheet. Refer to Appendix A for a summary of geological mapping in the Division Mountain area.

A geology map by Carne and Gish (1996) included the coal measures in the Tanglefoot formation, while assigning strata directly underlying the coal measures to the Richthofen formation. However, this interpretation is inconsistent with other reports regarding the Whitehorse Trough (Tempelman-Kluit, 1984; Hart, 1997). In this study, the coal measures are included in the upper member of the Tanglefoot formation. The underlying strata are included in the lower member of the Tanglefoot formation.

John Quinn and H.E. Porter first staked coal near Division Mountain in 1903 (Yukon Minfile, 1997). The next record of coal exploration was in 1970. Since then, intermittent exploration has outlined raw coal reserves estimated at 54.7 million tonnes (Burke, 1998). Exploration history is outlined in Appendix B.

Previous studies dealing with hydrocarbon potential in the Division Mountain area include six samples collected from the Cairnes Seam at Teslin Creek that suggested a low hydrocarbon potential (Beaton et al., 1992). In 1985, the Petro-Canada Whitehorse Field Party, as part of a hydrocarbon reconnaissance in the Whitehorse Trough, collected two samples from the map area that also gave poor results (Gilmore, 1985).

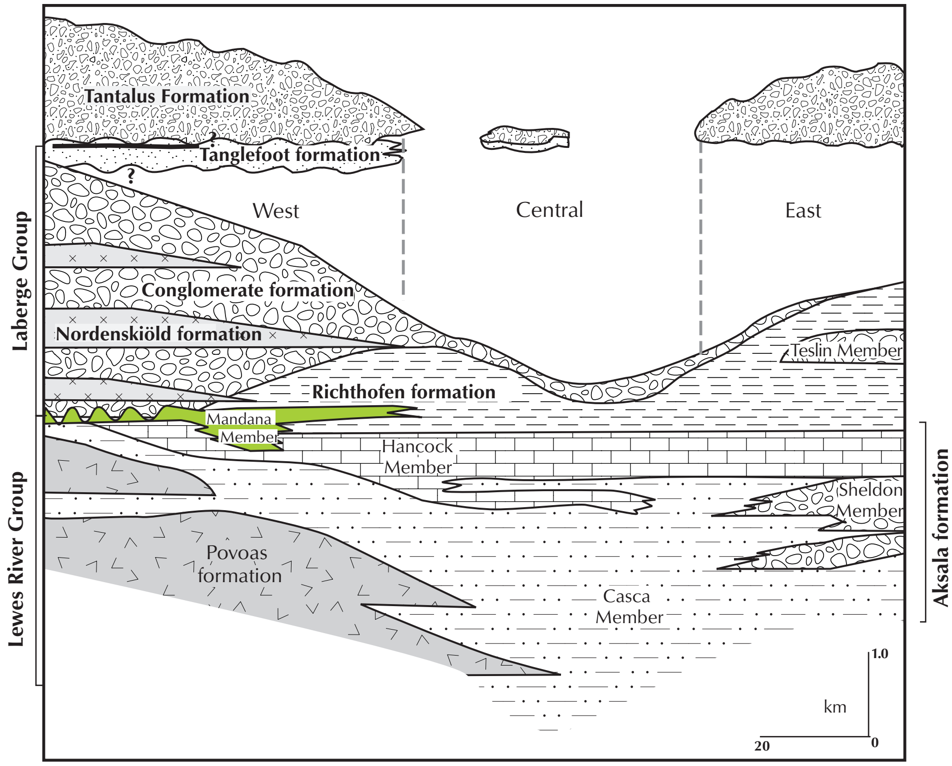

Figure 3. *Stratigraphic representation of the Whitehorse Trough (after Hart, 1997). The contact between the Conglomerate formation and the overlying Tanglefoot formation is undetermined, as is the upper contact of the Tanglefoot formation.*

PRESENT WORK

This project involved bedrock mapping at 1:50 000 scale of coal-bearing and related strata in the Division Mountain area, during the 1999 field season. Samples were collected for palynology and source-rock potential determination (TOC, Rock-Eval, and vitrinite reflectance).

REGIONAL SETTING

LEWES RIVER GROUP

The Upper Triassic Lewes River Group records the earliest known sedimentation in the Whitehorse Trough (Lees, 1934; Wheeler, 1961; Fig. 3). The basal Povoas formation, (Tempelman-Kluit, 1984) comprises largely volcanic rocks, and is dated as Carnian (and older?; Tempelman-Kluit, 1984). The overlying Upper Triassic to Jurassic Aksala formation rests in part, conformably on the Povoas formation (Hart, 1997). Tempelman-Kluit (1984) divided the Aksala formation into the

Casca, Hancock, and Mandanna members, consisting largely of sandstone, siltstone, mudstone, and limestone, deposited within a marine environment (Fig. 3). The upper contact of the Aksala formation (Tempelman-Kluit, 1984) is conformable with the Laberge Group, although locally disconformable (Hart, 1997).

LABERGE GROUP

The Jurassic Laberge Group (Cairnes, 1910) is a thick accumulation of marine conglomerate, tuff, shale, sandstone, and coal. The Laberge Group is conformable (Bostock, 1936; Bostock and Lees, 1938) to unconformable (Cairnes, 1910; Cockfield and Bell, 1926; Lees, 1934) over the Lewes River Group. Tempelman-Kluit (1979) argues that the contact between the Lewes River and Laberge groups is unknown; rather the two groups represent a single continuous sequence of fanglomerate, beach, reef, and turbidite deposits. The Laberge Group has traditionally been subdivided into three units, although mapped as one (Cockfield and Bell, 1926; Bostock and Lees, 1938). Tempelman-Kluit (1984) was the first to informally subdivide and map the Laberge Group as four lithologically different units including Richthofen, Conglomerate, Nordenskiöld, and Tanglefoot formations (Fig. 3).

No complete section has been recorded where the entire thickness of the Laberge Group could be accurately measured (Cairnes, 1910; Bostock and Lees, 1938). The known thickness of the Laberge Group ranges from over 1158 m in the Braeburn-Kynocks area (Cairnes, 1910) to an assumed thickness of 3048 m in the Whitehorse district (Cockfield and Bell, 1926), although this is likely under represented (Hart, 1997).

The Laberge Group succession was initially recorded as Jurassic or Cretaceous (Cairnes, 1910) in the Braeburn area. Later examinations (outlined in Table 1) of the Laberge Group revealed a more constrained age. In the Whitehorse area, a middle Lias to lower Middle Jurassic age was assigned to the Laberge Group (Cockfield and Bell, 1926). In 1934, Lees presented a lower Liassic to lower inferior Oolite age for the Laberge Group in the Laberge area. At Five Finger Rapids, fossils 853 m above the base of the series were dated as late Lower or early Middle Jurassic (Bostock, 1936). Wheeler (1961) reported an age range of lower Lias to early Middle Jurassic for the Laberge Group in the Whitehorse area. Trigoniid bivalves identified from Red Ridge Canyon have been dated as middle Bajocian (Tempelman-Kluit, 1974; Poulton, 1979), suggesting Laberge strata in Red Ridge Canyon is of the lower member of the Tanglefoot formation. Tempelman-Kluit (1984) suggested an age of Hettangian to Bajocian (Early to Middle Jurassic) for the Laberge Group in his map legend. In the Whitehorse area, Palfy and Hart (1998) determined an age of Sinemurian to Bajocian based on ammonite stratigraphy.

TANTALUS FORMATION

The upper Jurassic to early Cretaceous(?) Tantalus Formation (Cairnes, 1910; Cockfield and Bell, 1926; and Lees, 1934; Bostock, 1936) represents the most recent record of deposition in the Whitehorse Trough. The Tantalus Formation, characterized by thick-bedded chert-pebble conglomerate, was named for the sequence containing coal measures of the Tantalus mine, near Carmacks (Cairnes, 1910).

Table 1. *Summary of recorded age dates for the Laberge Group.*

Author (year)	Age	Area	Evidence
Cairnes (1910)	Jurassic to Cretaceous	Braeburn-Kynocks	Trigonia, Dawsoni, Nerinoea, Maudensis, and Rhynchonella orthidoides
Cockfield and Bell (1926)	middle Lias to lower Middle Jurassic	Whitehorse	numerous small ammonoids and pelecypods
Lees (1934)	lower Liassic to lower inferior Oolite (Early to early Middle Jurassic)	Laberge	Mytilus, Modiola, Gervilla, Pinna, Trigonia, Belemnites
Bostock (1936)	late Lower or early Middle Jurassic	Five Finger Rapids	Hildoceratids, Belemnites, Cucullaca
Bostock and Lees (1938)	early Lower Jurassic		same as Lees (1934)
Wheeler (1961)	lower Lias to early Middle Jurassic	Whitehorse	pelecypods and ammonoids (Hildoceraceae)
Tempelman-Kluit (1974)	middle Bajocian	Red Ridge Canyon, Vowel Mountain	Trigoniids (upper Laberge Group)
Tempelman-Kluit (1984)	Hettangian to Bajocian	Laberge	not stated
Pálfy and Hart (1995)	Sinemurian to Bajocian	Whitehorse	ammonite stratigraphy

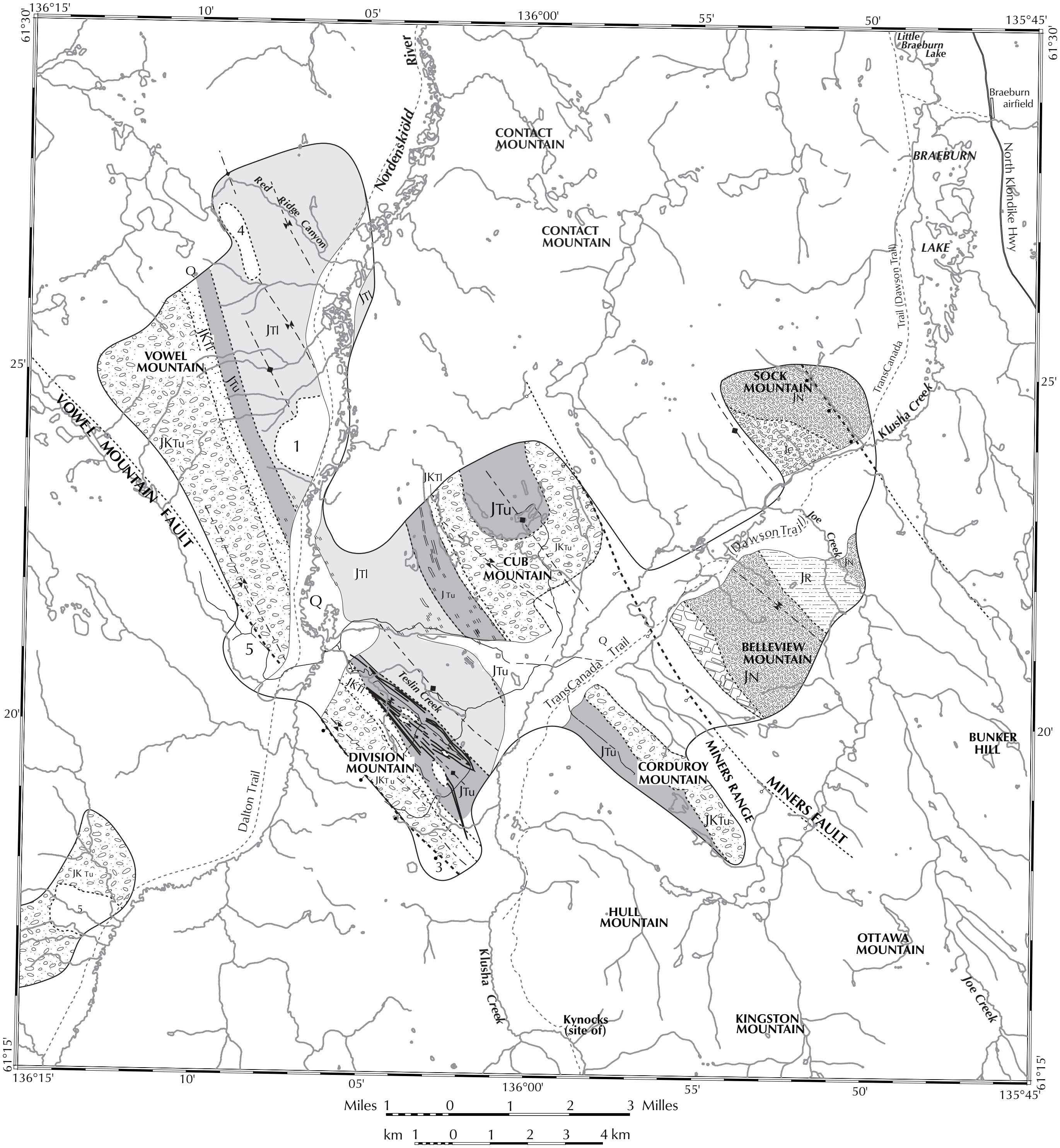

Figure 4. *Geological map of the Division Mountain area (after Allen, in progress). See Figure 1 for location and next page for legend.*

LEGEND

QUATERNARY

Q — unconsolidated sand, silt and gravel

UPPER CRETACEOUS(?)
CARMACKS GROUP(?)

1 — green to light greyish-red feldspar- and hornblende-porphyry sills, dykes, and flows

2 — maroon feldspar porphyry

3 — greyish-red feldspar porphyry and breccia

4 — greenish-black monzodiorite

5 — amygdaloidal to vesicular basalt and extrusive flows

UPPER JURASSIC to LOWER CRETACEOUS
TANTALUS FORMATION

JKTu — Upper Member - Clast-supported chert-pebble conglomerate, resistant and thickly bedded, with intercalated medium- to coarse-grained sandstone beds made up of quartz, feldspar, and chert grains. Clasts are typically 1 to 3 cm across, subrounded to well-rounded and moderately to well sorted.

JKTl — Lower Member - Matrix-supported chert-pebble conglomerate, made up predominantly of coarse- to very coarse-grained sandstone composed of quartz, feldspar, and chert grains.This member is recessive. Also contains subordinate fine-grained, grey to brown weathered, laminated, plant-rich sandstone.

LOWER to MIDDLE JURASSIC
LABERGE GROUP

Tanglefoot formation

JTu — Upper Member - Yellowish grey to bleached white, coarse- to very coarse-grained sandstone, grit, and pebbly grit with conspicuous quartz and feldspar granules within a white to buff chalky cement. Other lithologies include grey interlaminated siltstone and very fine-grained sandstone, carbonaceous shale, and coal seams.

JTl — Lower Member - Light olive grey, fine- to very coarse-grained quartz-rich sandstone, grit, heterolithic conglomerate, and laminated siltstone. Fining-up packages commonly include the above lithologies. Macerated plant debris is common at the top of sequences. The conglomerate is matrix- to clast-supported with clasts ranging from pebbles to boulders, subangular to rounded, and include vein quartz, felsic granite and porphyry.

Nordenskiöld / Conglomerate formations

JC JN — JN - Steel grey to medium greenish grey tuff, weathers dark brown, medium- to coarsely crystalline, well indurated, massive, locally calcareous.

JC - Olive grey, heterolithic conglomerate, clasts range from pebbles to boulders including predominantly granitic rocks up to 30 cm across and subrounded to well-rounded.

Richthofen formation

JR — Fine-grained grey sandstone, weathered buff, parallel- to cross-laminated, dark grey siltstone, recessive, platy to flaggy beds.

SYMBOLS

Geological contact (defined, approximate, assumed)

Fault, displacement unknown (defined, approximate, covered)

Fold axis (anticline, syncline)

Coal seam

Limit of mapping

Roads

Figure 4. *continued*

LOCAL STRATIGRAPHY

RICHTHOFEN FORMATION

In the Division Mountain area, the Richthofen formation (Tempelman-Kluit, 1984) has only been recognized near Joe Creek (Fig. 4) where siltstone and intercalated sandstone beds are exposed in intervals less than 15 m thick in a few outcrops. The siltstone, medium to dark grey, with thin laminae (1 to 20 mm) of very fine-grained, calcareous sandstone, exhibits platy weathering. These sandstone laminae are light grey and weather buff. Thicker sandstone beds interbedded with the siltstone are commonly 30 cm thick, although may be as thick as 75 cm (Fig. 5). These beds are resistant and have sharp top and basal contacts with the siltstone. The sandstone is parallel- to cross-laminated and locally exhibits soft sediment deformation.

Figure 5. *Interbedded sandstone and siltstone beds of the Richthofen formation, Joe Creek.*

CONTACT RELATIONSHIPS

In the Division Mountain area, contacts with the Richthofen formation were not observed, although it is believed that strata on Joe Creek are within a faulted anticline, with Richthofen formation on the western limb of the fold. Elsewhere in the Whitehorse Trough, the lower contact of the Richthofen is conformable to transitional over limestone of the Hancock Member and locally unconformable on limestone and conglomerate of the Hancock Member (Hart, 1997).

THICKNESS

Due to limited exposure, the thickness of the Richthofen formation in the map area is unknown. In the Whitehorse region, the Richthofen formation ranges from 1500 m thick at Horse Creek to approximately 200 m at the Takhini Game Farm, west of Lake Laberge, showing a dramatic decrease in thickness to the west (Hart, 1997).

AGE

Harpoceratid ammonites (possibly *Protogrammoceras*) were collected by Tempelman-Kluit from strata in Joe Creek (GSC Loc No. C-86549) and dated as late Pliensbachian (identified by H.W. Tipper, unpublished report). The age of strata in the drainage parallel and north of Joe Creek was determined as Lower Jurassic (probably upper Sinemurian), based on the fauna collection GSC Loc No. C-86697. Fossils identified in this collection include pelecypod fragment and *Paltechioceras(?)* sp. (a loosely coiled ammonite; H.W. Tipper, unpublished report).

NORDENSKIÖLD AND CONGLOMERATE FORMATIONS

Age equivalent Nordenskiöld and Conglomerate formations crop out on Belleview Mountain, Sock Mountain (name proposed here for geographic reference) and Joe Creek as fine- to medium-grained tuff and heterolithic conglomerate (Fig. 4).

Nordenskiöld formation

Typically, tuff of the Nordenskiöld formation weathers brownish green on the outer surface with a weathering rind 2 to 20 mm thick, forming a sharp to diffuse boundary around the fresh rock (Fig. 6a). On the fresh surface, the tuff ranges from medium bluish grey to brownish grey and locally greyish red (colour scale: 5 R 4/2). The tuff is massive and breaks into sharp, angular fragments due to intense fracturing. The rocks are well indurated with a siliceous and, locally, a calcareous cement. Locally, the tuff is banded with fine- to coarse-grained bands ranging from grey to greyish red. In one locality, carbonized plant debris was noted.

Overall, the rock is medium- to coarse-textured and moderately to well sorted. Individual grains of predominantly quartz and feldspar are crystalline to subcrystalline; the rock displays no obvious structures. The percentage of feldspar, 1 to 2 mm across, varies from 5 to 20% within a finer matrix of predominantly feldspar and quartz. Small quartz phenocrysts (< 1 mm across), comprising 5 to 15% of the rock, occur as rounded glassy crystals with broken faces. The tuff locally has zones of differential weathering demonstrating colour mottling of light and dark grey in a honeycomb style (Fig. 6b).

A very fine- to fine-grained sandstone, which may be a finer grained version of the tuff, occurs on Joe Creek in association with grey laminated shale and intercalated calcareous sandstone. The sandstone is pale yellowish brown (tawny), fine- to medium-grained and well sorted. It is a well indurated, quartz-rich sandstone with a small percentage of muscovite and plant debris, and rusty patches in the cement. This lithology occurs in the middle of a syncline, suggesting that it is younger than the coarser-grained tuff.

On Belleview and Sock mountains, coarse- to very coarse-grained tuffaceous sandstone (Fig. 6c), closely associated with conglomerate, appears to interfinger the Nordenskiöld dacite. The sandstone is medium olive grey on fresh surfaces, with a salt and pepper appearance made up of almost equal amounts of feldspar and quartz with lesser hornblende. Feldspar occurs as chalky white to buff laths and crystals 1 to 2 mm across. Quartz crystals (< 4 mm across) are white to dark grey, rounded and resistant. The matrix between the crystals is fine grained and blurry, ranging from dark olive grey to buff. Overall, the sandstone is moderately to poorly sorted and locally contains rounded clasts largely of mud chips up to 18 cm across (less than 10%).

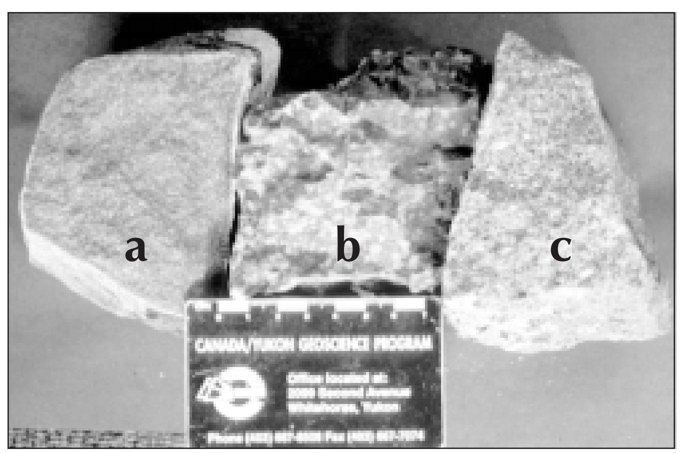

Figure 6. *Tuff of the Nordenskiöld formation: a) medium-textured and medium grey, b) mottled weathering of the grey tuff, c) coarse-grained and olive grey.*

Conglomerate formation

The Nordenskiöld tuff occurs associated with a polymicitic conglomerate assigned to the Conglomerate formation on Sock Mountain, although the relationship is not exposed or well understood. In outcrop, the contact of the polymictic conglomerate with neighbouring tuff and sandstone is sharp. The conglomerate (Fig. 7) is dark brown on the weathered surface, dark olive grey on the fresh surface and locally iron-stained. The poorly sorted conglomerate is clast-supported (80 to 90% clasts) with clasts ranging from small pebbles to boulders up to 30 cm in diameter. Most clasts are subround to round, although they may range from angular to well rounded. Clast boundaries are sharp to diffuse. Due to dense lichen cover, clast lithologies are difficult to differentiate, but include felsic porphyritic, granitoid and very fine-grained maroon rocks. The matrix is fine- to very coarse-grained, consisting primarily of euhedral feldspar and quartz (1-3 mm) with minor biotite (1-2 mm) and dull black rounded grains (2-5 mm).

Figure 7. *Conglomerate on Belleview Mountain. Clasts range from pebbles to boulders up to 30 cm across; lithologies consist predominantly of felsic intrusive clasts.*

CONTACT RELATIONSHIPS

In the Division Mountain area, the Conglomerate formation appears to underlie and interfinger the Nordenskiöld formation, although observations are based on limited exposure. In the Whitehorse area, the Nordenskiöld formation occurs at several levels within a stratigraphic interval including most of the Conglomerate formation and upper Richthofen formation (Hart, 1997). At Braeburn, Takhini Hot Springs, and Fish Lake, the Laberge Conglomerate conformably overlies the Lewes River Group (Dickie and Hein, 1988).

THICKNESS

In the Division Mountain area, the thickness of the Nordenskiöld and Conglomerate formations is undetermined. In the Whitehorse region, the Nordenskiöld ranges from 200 to 700 m at Takhini Crossing, while the Conglomerate formation ranges from 1 to 3 km thick (Hart, 1997).

AGE

No ages were determined for the Nordenskiöld or Conglomerate formations in the Division Mountain area, although the age of the Nordenskiöld is well constrained in the Whitehorse area as early to late Pliensbachian (Palfy and Hart, 1995; Hart, 1997).

TANGLEFOOT FORMATION

The Tanglefoot formation (Tempelman-Kluit, 1984) occurs on the limbs of an anticline (west)–syncline (east) pair between Vowel and Contact mountains (Fig. 4). On the south side of Klusha Creek, the Tanglefoot formation continues in an anticline between Division and Cub mountains. Based on lithostratigraphic differences in the Division Mountain area, the Tanglefoot formation can be subdivided into two mappable units, here named the lower and upper members (Fig. 8).

Lower member

The lower member of the Tanglefoot formation consists of repeated fining-upward sequences on the order of 25 cm to 7.5 m, averaging 1 to 2 m thick (Fig. 8). These successions typically consist of pebbly conglomerate or grit at the base, and fine sandstone or siltstone at the top. Lithologic changes within the successions are gradational, although contacts between successive sequences are generally abrupt and locally undulating with approximately 10 to 20 cm relief.

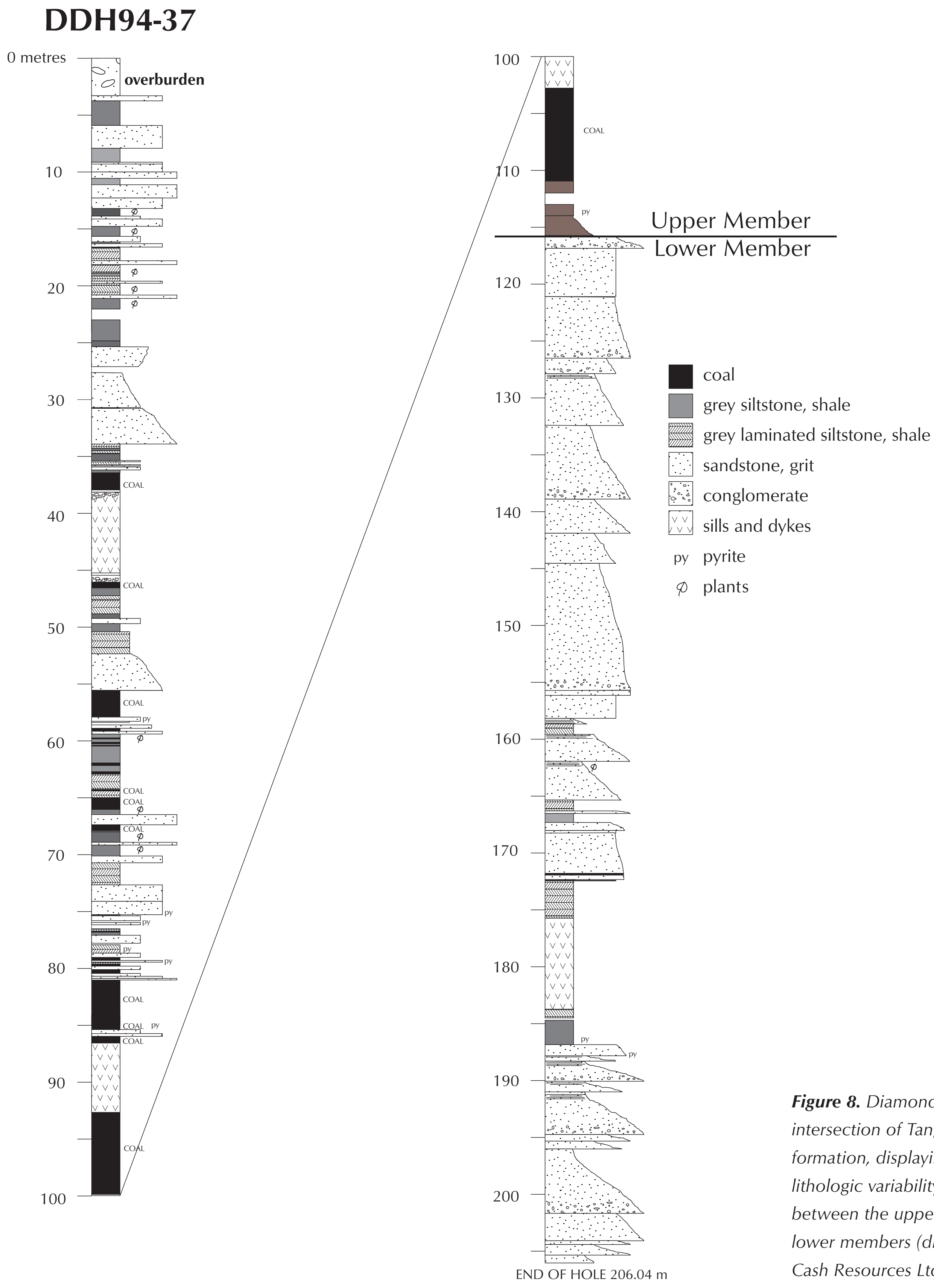

Figure 8. *Diamond drill hole intersection of Tanglefoot formation, displaying lithologic variability between the upper and lower members (drilled by Cash Resources Ltd.).*

The conglomerate is heterolithic with an overall colour of light olive grey to yellowish grey and locally weathers dark brown (Fig. 9). Clasts, ranging from granules up to boulders 30 cm across, including vein quartz, buff to dark grey mudstone, as well as felsic granitic, metamorphic, and volcanic lithologies. Near Red Ridge Canyon, the clasts are generally smaller, ranging between 0.5 and 3 cm. The overall texture of the conglomerate ranges from matrix- to clast-supported with subangular to rounded clasts. The matrix is quartz-rich with lesser amounts of feldspar and minor biotite, similar to the composition of the associated sandstone. The conglomerate is typically very poorly sorted with no obvious imbrication.

Figure 9. *Heterolithic conglomerate of the Tanglefoot formation lower member, Teslin Creek. The conglomerate includes clasts of vein quartz, buff and dark grey mudstone as well as granitic, metamorphic and volcanic lithologies.*

Figure 10. *Cavernous sandstone typical of the Tanglefoot formation lower member, Teslin Creek. A large percentage of the grains are quartz and K-feldspar with lesser amounts of plagioclase feldspar, biotite, and plant debris.*

The sandstone and grit commonly have a cavernous appearance (Fig. 10), notably in exposures at Teslin Creek and Red Ridge Canyon. The sandstone and grit are light olive grey to yellowish grey, friable, and massive to crudely bedded. The sandstone and grit, dominated by quartz grains (50 to 90%), also contains K-feldspar (15 to 20%), and plagioclase feldspar (up to 10%) as well as minor biotite, lithic grains, and carbonaceous plant debris. Finer grained sandstone, at the tops of fining-upward sequences, contains compressed macerated plant debris, subparallel to bedding.

Fine-grained lithologies of the lower member are best exposed at Red Ridge Canyon. The fines consist of laminated olive grey to dark grey siltstone and very fine-grained sandstone. Common sedimentary structures in the fines include starved ripples and parallel- to cross-laminae (1 to 10 cm). Carbonaceous laminae are common and bivalve fossils are locally abundant (Red Ridge Canyon and the east side of Vowel Mountain). Thicker beds, 1 to 25 cm thick, of fine- to medium-grained sandstone are intercalated within the siltstone package, comprising approximately 30% of a section. These sandstone beds are light grey on the fresh surface, weather buff to yellowish grey and are locally iron-stained. They are well indurated with siliceous to calcareous cement and exhibit abrupt bases and planar to rippled abrupt tops. Thin silty bands (4 to 10 mm) are common in these sandstone beds. Coal was not observed in this member.

Upper member

The upper member of the Tanglefoot formation consists of very coarse- to fine-grained sandstone, pebbly grit, siltstone, carbonaceous shale, and coal. The coal seams have previously received extensive study, although little attention has been paid to related strata. Contact relationships with coal seams are difficult to determine as coal is generally removed from drill core and there are no natural exposures. In a road cut on the south side of Cub Mountain, coaly shale is in contact with porphyritic sills and dykes. In a trench along Teslin Creek, carbonaceous root traces are noted in siltstone and sandstone beds directly below an exposed coal seam.

Strata associated with the coal measures are distinctive from other lithologies in the map area, including sandstone, grit, and pebbly conglomerate that are typically bleached white, although locally the matrix is medium to dark grey. On the fresh surface, the grit is light grey. The composition of these lithologies is primarily quartz (60 to 90%) and K-feldspar (10 to 25%) with rare plagioclase. The granules are subangular to round and poorly to well sorted. Within the pebbly grit, grains reach up to 1 cm across and occupy approximately 5% of the rock. The sandstone, medium to light grey on the fresh surface, possesses a white to orange chalky matrix between the grains. A small percentage (1 to 2%) of tiny macerated plant debris (1 to 2 mm) occurs scattered in the sandstone. The grit and sandstone are porous and preferentially

Figure 11. White grit, ubiquitous of the upper member of the Tanglefoot formation. Grains are subangular to subround, poorly to well sorted, with conspicuous quartz and feldspar grains.

weathered with conspicuous grains of quartz and feldspar giving the rock a stuccoed appearance (Fig. 11).

Finer grained lithologies, noted mainly in drill core intersections, include carbonaceous silty mudstone and shale, grey laminated siltstone and light to medium grey, fine- to medium-grained sandstone, and coal. The silty mudstone and siltstone, olive grey to dark grey on the fresh surface, is crumbly to platy and parallel-laminated (1 to 5 mm) with sandstone laminae (2 to 10 mm) comprising up to 80% of the rock. Well-preserved plant debris (grasses, twigs, and ferns) are commonly compressed along bedding planes of the carbonaceous shale and laminated siltstone. Intercalated fine-grained sandstone beds are flaggy and 2 to 5 cm thick. Beds are massive to planar parallel to cross-stratified with shallow dips at approximately ten degrees. Fining upward sequences are noted within the upper member, although not as common as in the lower member.

CONTACT RELATIONSHIPS

The basal contact of the Tanglefoot formation in the study area is not exposed. The contact between the upper and lower members, only observed in drill core intersections from the east side of Division Mountain, is abrupt with no evident interstratification. On the east side of Vowel Mountain and the southwest side of Cub Mountain, the Tanglefoot formation underlies the Tantalus Formation, although the contact is locally obscured by andesite dykes and sills, as well as overburden.

Outside of the map area, the Tanglefoot formation has been recognized in the Laberge map area (Tempelman-Kluit, 1984). The Tanglefoot formation was also recognized in the Whitehorse map area at Flat Mountain, where it was deposited unconformably on top of Lewes River Group strata (Hart, 1997). In the Whitehorse area, the Tanglefoot formation is unconformably overlain by nearly flat-lying Carmacks Group volcanic rocks (Hart, 1997).

THICKNESS

In the map area, the Tanglefoot formation is approximately 2000 m thick, although this is likely an over-approximation due to intense folding of the strata. The Tanglefoot formation attains a thickness of 500 m at Flat Mountain (Hart, 1997), although Hart's Tanglefoot formation includes chert clasts, which here are included in the overlying Tantalus Formation.

AGE

The upper member, as outlined in this study, has not previously been assigned an age. Elsewhere, the lower member of the Tanglefoot formation has been dated as Toarcian to Bajocian (Middle Jurassic; Tempelman-Kluit, 1984). Fossils identified (GSC collections C-18178 and C-18179 and 57186) from Red Ridge Canyon, north of Vowel Mountain, revealed an age of middle Bajocian for the lower member in the Division Mountain area (Tempelman-Kluit, 1974; Poulton, 1979).

TANTALUS FORMATION

Within the map area, the Tantalus Formation forms Division, Vowel (Red Ridge), Corduroy and Cub mountains. The Tantalus Formation occurs as a steeply dipping syncline to form Vowel Mountain and, along strike, a moderately dipping syncline to form Division Mountain. Cub Mountain consists of a syncline and anticline pair of Tantalus Formation. At Corduroy Mountain, the Tantalus forms a steeply dipping homocline(?), that dips to the northeast. The east side of Corduroy Mountain is faulted, otherwise it may have formed a syncline, along strike with Cub Mountain. The only other occurrence of Tantalus Formation visited this season was west of the Nordenskiöld River where the dip is moderate to shallow in a northeastly direction.

The Tantalus Formation occurs as thickly bedded (5 to 30 m), massive to low-angle cross-bedded conglomerate with lesser

Figure 12. Corduroy Mountain, which consists of thickly bedded Tantalus Formation conglomerate.

sandstone, and shale. Coal seams have been reported in the Tantalus Formation in the Carmacks region (Bostock, 1936) and as muddy coal on Corduroy Mountain (D. Long, pers. comm., 1999). The overall colour of the unit is light grey to yellowish grey except where locally bleached or iron-stained. The conglomerate beds are resistant, forming mountains of vertical to near vertical beds with a ribbed (or corduroy) appearance (Fig. 12). Conglomerate beds are typically moderate to well sorted and crudely bedded. Graded beds, as well as fining and less often coarsening up successions, are common in the conglomerate; these characteristics are marked by changes in clast size and abundance. Matrix-supported conglomerate contains up to 40% chert clasts, averaging 0.5 to 4 cm across.

In the Division Mountain area, there are two mappable units within the Tantalus Formation. The lower unit is a recessive weathering, matrix-supported chert-pebble conglomerate, while the upper is a resistant, clast-supported 'typical' chert-pebble conglomerate. Unfortunately, due to its recessive nature, the lower member is exposed only in trenches and intersections in diamond drill core on the east side of Division Mountain. This lower unit contains more sandstone than the overlying clast-dominated portion of the Tantalus Formation. The relationship between the upper and lower members was not observed.

The conglomerate is comprised of moderate to well rounded pebbles of chert, quartz, and a small percentage of quartzite, and felsic porphyry (Fig. 13). Chert clasts are widely variable in colour, including white, black, green, greenish grey, buff, grey, and pink. Grey clasts are generally veined or mottled. Clasts are typically 1 to 5 cm in diameter, although locally range up to 20 cm. The clasts are subround to subangular, with moderate to high sphericity and often egg-shaped. The matrix consists of medium- to very coarse-grained sandstone made up of lithologies similar to the framework clasts, with a siliceous to locally calcareous cement.

Figure 13. *Chert pebble conglomerate, typical of the Tantalus Formation, is clast-supported, with a matrix of medium- to coarse-grained sandstone. Clasts consist of subrounded to well-rounded pebbles of vein quartz, chert and a small percentage of quartzite and felsic porphyritic rocks.*

Discontinuous, interstratified sandstone bands, commonly 5 to 50 cm thick, consist of material similar to the conglomerate matrix. The sandstone is medium- to very coarse-grained, with up to 30% granules and less than 5% entrained small chert pebbles. The sandstone is moderately to well sorted, quartz-rich (40% to 50%) with lesser amounts of feldspar and chert and rare carbonaceous plant debris in a white chalky cement. The overall colour of the sandstone is light grey to light olive grey or buff and locally iron-stained. Grains are subangular to subround and moderately to well sorted. Individual sandstone beds are commonly 0.5 to 20 cm thick and massive to cross-bedded.

Another lithology associated with the chert pebble conglomerate, less common than the previous, is a greyish red to medium greyish brown fine-grained sandstone. The sandstone is quartz-rich, well sorted, and characterized by its fine grain size and abundance of well preserved plant material (ferns and grasses). The thickness of this sandstone is unknown as there were only two occurrences noted, both on the east side of Division Mountain, one in a trench and one in a road cut.

In drill core, carbonaceous mudstone as well as parallel-laminated siltstone occur interbedded with the matrix-supported chert pebble conglomerate.

CONTACT RELATIONSHIP

In the Division Mountain area, the only visible contact between the Laberge Group and the overlying Tantalus Formation is intersected in drill core. The observed contact, from the east side of Division Mountain, is abrupt and marked by the appearance of chert. West of the Nordenskiöld River, the contact with the underlying Tanglefoot formation is not observed.

In the Whitehorse area, the Tantalus Formation conformably overlies the Laberge Group (Cockfield and Bell, 1926; Wheeler, 1961). In the Indian River area, the Tantalus Formation unconformably overlies Palaeozoic (?) metamorphic rocks and is intruded and unconformably overlain by andesitic dykes and sills of the Carmacks Group (Lowey and Hills, 1988).

THICKNESS

In the study area, the Tantalus Formation ranges from 745 m on Corduroy Mountain to 1270 m thick on Vowel Mountain, consisting predominantly of conglomerate (D. Long, pers. comm., 1999). Outside the study area, the Tantalus Formation ranges in thickness from 300 m in the Carmacks area (Lowey and Hills, 1988), to 1525 m exposed near Double Mountain (Whitehorse area; Wheeler, 1961).

AGE

No fossils have been obtained from the Tantalus Formation in the Division Mountain area. The age of the Tantalus Formation in other areas is somewhat unconstrained, ranging from Jurassic to Early Cretaceous. Fossils examined from the Tantalus Mine (Carmacks) suggested that the formation is as young as Lower Cretaceous (Cairnes, 1910). Fossils retrieved from the conglomerate in the Wheaton district suggested the formation is as old as Jurassic (Cairnes, 1916). In the Whitehorse region the age was determined as Upper Jurassic (?) and Lower Cretaceous based on plant fossils documented by Cairnes (1916) from Mount Bush (Wheeler, 1961). A Neocomian (early Lower Cretaceous) age was determined in the Aishihik Lake area based on a collection of plant fossils (Tempelman-Kluit, 1974). Palynomorphs collected from the Indian River area indicated an Early Cretaceous (Albian) age (Lowey, 1984; Lowey and Hills, 1988). Hunt and Hart (1994) concluded that the Tantalus Formation of the Whitehorse coal deposit ranges in age from Late Jurassic to Late Cretaceous, based on palynology results.

CARMACKS GROUP

The Carmacks Group is divisible into five mappable units in the Division Mountain area.

Unit 1 is here emphasized as it is intimately associated with the coal-bearing strata. The remaining four units are considered less important as they do not occur with the coal.

Unit 1 consists of feldspar-hornblende andesitic sills and dykes that intrude coal-bearing and underlying strata along south Cub Mountain, west to Division and Vowel mountains (Fig. 4). A large portion of the outcrop exposed between Cub and Vowel mountains consists of these sills and dykes with few sedimentary rock exposures. Diamond drill hole intersections and road cut exposures indicate sills and dykes preferentially occur along or within coaly intervals. Brecciated contacts are commonly observed between the porphyry and neighbouring strata in drill core. The relationships observed of the porphyritic rocks with the neighbouring strata suggest that the sills and dykes post-date deposition of the Laberge Group.

The andesite is relatively fresh to moderately weathered, ranging from well indurated with sharp mineral boundaries, to crumbly and blocky with crystals weathered out. The andesite ranges from medium greenish grey, to dark brownish grey to light grey depending on the degree of alteration.

Phenocrysts, comprising up to 50% of the rock, include predominantly feldspar with lesser hornblende. Feldspar occurs as stubby to elongate euhedral laths and anhedral blebs, generally 1 to 3 mm, although up to 10 mm across. Hornblende occurs as randomly oriented laths (3 to 5 mm) and generally comprises 5 to 10% of the rock. In drill core, buff to white calcite amygdules (<5%) were noted, averaging 1 to 4 mm across, rarely up to 10 mm, and irregularly shaped. In drill core, the andesite was noted as aphanitic near contacts with neighbouring strata and brecciated over a 10 to 40 cm interval.

Due to poor exposure of sedimentary rocks in the map area, the occurrence of these andesites is a useful tool in mapping as they generally occur with the recessive Tanglefoot formation. The sills and dykes rarely intrude the resistant chert pebble conglomerate of the Tantalus Formation.

Unit 2, noted only on the west side of Belleview Mountain, consists of dark maroon, andesitic feldspar porphyry. Plagioclase (2 to 4 mm) comprises 30 to 40% of the rock and hornblende (1 to 2 mm) less than 5%, within a glassy groundmass.

Unit 3 crops out along the south side of Division Mountain. The common lithology of Unit 3 is greyish red feldspar porphyry with 15 to 20% phenocrysts (< 2 mm) in an glassy groundmass. Some exposures are dominated by fragments up to 4 cm across. The fragments are buff weathered, very fine grained, angular to rounded, with sharp contacts. The matrix weathers preferentially.

Unit 4, exposed southwest of Red Ridge Canyon, includes a dark brown weathering greyish black, medium- to coarsely crystalline monzodiorite.

Unit 5 includes exposures in the canyon south of Vowel Mountain and west of the Nordenskiöld River (Fig. 4). The unit consists of dark grey to dark brown resistant weathering flows characterized by the presence of vesicles and calcite amygdules, that locally contain pyroxene and feldspar phenocrysts (5 x 10 mm), comprising 5-40% of rock.

STRUCTURE

The Laberge Group occurs as several northwest-trending syncline-anticline pairs sandwiched between the more resistant Tantalus Formation that forms local uplands. The folds have wavelengths on the order of 2 to 7 km, although as small as 3 m (Carne and Gish, 1996). Northwest- and northeast-trending normal faults with minor dip-slip displacement crosscut the folds (Carne and Gish, 1996). The folded strata are crosscut and locally overlain by porphyritic andesite sills and dykes.

COAL OCCURRENCES

Coal occurrences in the Division Mountain area occur within the Tanglefoot formation, approximately 210 m to 240 m stratigraphically below the base of the Tantalus Formation (Long, 1986). Natural exposures of coal do not occur within the map area, although muddy coal is visible in a road cut near Division Mountain and in a trench above Teslin Creek. Coal occurrences identified by trenching and drilling in the map area occur on the east side of Division Mountain, at Teslin Creek, Cub Mountain, Vowel Mountain (Red Ridge), and Corduroy Mountain. Coal was also reported at Klusha Creek by Peach (1993).

On the east side of Division Mountain, over 30 seams have been identified within the upper member of the Tanglefoot formation, with the thickest and most continuous accumulations of coal present near the base of the unit (Gish and Carne, 1998). Aggregate coal thickness ranges from approximately 10 m in the discovery area (Teslin Creek), to 32 m, 4 km to the southeast (Gish and Carne, 1998). There are fourteen major coal seams ranging from 1.7 m to 17.3 m thick and numerous subordinate seams ranging from 0.10 m to 1.7 m.

The Cairnes Seam, visible in a trench in the discovery area on the north side of Teslin Creek, is the best documented coal seam at Division Mountain (Phillips, 1973; Beaton et al., 1992; Wengzynowski and Carne, 1993). The Cairnes Seam, 12.5 m thick, has two clay and sand partings measuring 92 cm and 54 cm thick (Carne, 1992) and extends for a minimum of 1500 m along strike (Peach, 1993).

Allen (1975) noted coaly fragments in gopher diggings on the southeast side of Cub Mountain and suggested that the coaly material was part of the Tantalus Formation. A 30-m-hand trench on the south side of Cub Mountain intersected numerous patches of coal float in the Laberge Tanglefoot formation (Gish and Carne, 1998).

Coal was originally documented on the east side of Vowel Mountain (Red Ridge), approximately 245 m stratigraphically below the base of the Tantalus Formation (Kirker, 1971) by Cairnes (1908; Yukon Minfile, 1997, 115H 012). A 60-m-long hand trench on Red Ridge intersected coal fragment horizons 1.2 m, 1.4 m, and 1.8 m thick within the Tanglefoot formation (Wengzynowski and Carne, 1994).

A 360-m-long trench on the west side of Corduroy Mountain, intersecting the upper Tanglefoot formation, exposed 23 m of coal in 25 seams, the thickest being 3 m (Gish and Carne, 1998).

COAL QUALITY

The coal at Division Mountain is ranked as high volatile bituminous B to C (0.60-0.64% R_{omax}; Gish and Carne, 1998; Beaton et al., 1992). Coal seams analyzed from within 13 m of the sills and dykes demonstrate higher reflectance values, ranking as anthracite. Calculated averages for raw coal include 2.42% residual moisture, 28.45% ash content, 25.79% volatile matter, 43.18% fixed carbon, 0.43% sulphur and a calorific value of 5216 cal/g (9328 Btu per lb.; Mineral Resources Branch, 1998).

Maceral compositions identified within the Cairnes Seam (Teslin Creek) include: 54% vitrinite (telocollinite, desmocollinite, and vitrodetrinite); 10% liptinite (sporinite, resinite, lipodetrinite, and cutinite); and 36% inertinite (fusinite and semifusinite; Beaton et al., 1992). Beaton and others (1992) concluded that the maceral composition reflected a plant community with abundant grasses and reeds, perhaps of a low-lying wetland flora.

Macerals identified in silty shale from the Richthofen formation of Joe Creek include vitrinite, inertinite and abundant framboidal pyrite (Stasiuk and Fowler, 1999). Macerals identified in silty shale from the lower member of the Tanglefoot formation at Vowel Mountain include abundant inertinite as well as reworked vitrinite and liptinite (liptodetrinite, cutinite and resinite) (Stasiuk and Fowler, 1999).

Regional correlation

The only other reported economic coal seams of the Laberge Group (0.2 m, 1.2 m, 1.1 m, 1.2 m) were worked underground north of Carmacks between 1900 and 1908 at Five Fingers mine (Cairnes, 1908; Long, 1986). Numerous small occurrences of coal within the Jurassic Laberge Group have been reported in the Whitehorse Trough (Yukon Minfile, 1997). Traditionally, economic coal seams in the Whitehorse Trough have been recognized in the Jura-Cretaceous Tantalus Formation. Tantalus coal seams were previously mined at Tantalus Butte (seam 2.4 m to 6 m) and the Tantalus Coal mine (seams 2.3 m, 2.0 m, 0.9 m) near Carmacks, as well as near Whitehorse at the Whitehorse Coal mine (Yukon Minfile, 1997). The Tantalus coal seams also have very low sulphur and high ash contents.

SOURCE ROCK POTENTIAL

Rock-Eval pyrolysis was used to determine thermal maturation (T_{max}) and hydrocarbon potential (total organic carbon (TOC), hydrogen, oxygen, and production indices) of strata in the Division Mountain area. Results from previous Rock-Eval analysis of the Cairnes Seam suggested that the coal has a low petroleum potential (Beaton et al., 1992). One other study of hydrocarbon potential involved reconnaissance sampling of strata in the Whitehorse Trough by the Petro-Canada Whitehorse Field Party (Gilmore, 1985). Analyses of the two samples from the Division Mountain area, indicated some gas potential, but little for oil.

Samples collected for this study were analyzed on a Rock-Eval 6.0 pyrolysis system with results displayed in Table 2.

Total organic carbon contents determined for non-coaly samples ranged from 0.34 to 3.48 wt%, although averaged between 1.2 and 2.2 wt%. Coal and carbonaceous shale total organic carbon ranged from 6.66 wt% for the shale to 63.41 wt% for the coal. Typically, the cut off percentile for source rock potential, in respect to total organic carbon content is 0.5 wt% (refer to Table 3), suggesting that the TOC values represent fair to very good generative source rock potential.

The type of organic matter within the coals and related strata was determined by plotting the following Rock-Eval pyrolysis products: the hydrogen index versus the oxygen index (Fig. 14). Samples with no obvious coaly material plotted along the Type III kerogen evolutionary pathway. This suggests the organic matter in the shale and siltstone is terrestrially derived. Type III kerogen yields low hydrocarbon amounts in the form of oil, and are more likely to generate gas. Coal and carbonaceous shale samples plotted along the Type I and III evolutionary paths (oil- to gas-prone). Type I kerogen is typically oil-prone.

The petroleum potential or genetic index, calculated from Rock-Eval pyrolysis data (S1+S2), suggests that the non-coaly samples analyzed are not oil source rocks (Table 3). The genetic index

Table 2. *Summary of total organic carbon content (TOC), Rock-Eval pyrolysis, and vitrinite reflectance results for the Division Mountain area (from Stasiuk and Fowler, 1999).*

Sample	TOC[1]	S1[2]	S2[3]	S3[4]	S1+S2	PI[5]	HI[6]	OI[7]	RoR%[8]	T_{max}[9]	Lithology	Unit	Easting[10]	Northing
99TLA033	2.27	0.00	0.76	3.19	0.76	0.00	34	141	0.50	430	dark grey mudstone, blocky-crumbly	Tanglefoot fm.	443125	6800880
99TLA044	2.32	0.01	1.31	1.56	1.32	0.01	58	67	0.80	438	dark grey silty shale, carbonaceous	Tanglefoot fm.	442128	6801623
99TLA077	1.83	0.13	0.66	1.15	0.79	0.16	37	63	1.54	475	dark grey silty shale, laminated	Richthofen fm.	454862	6804369
99TLA078	0.79	0.03	0.17	0.38	0.20	0.17	22	48	1.36	482	dark grey silty shale, laminated	Richthofen fm.	454862	6804369
99TLA082	1.67	0.04	0.40	2.45	0.44	0.10	25	147	1.57	484	olive grey silty mudstone	Richthofen fm.	455062	6803958
99TLA112	1.10	0.00	0.03	1.73	0.03	0.00	3	157	1.93	578	medium grey silty shale, laminated	Tanglefoot fm.	440130	6809100
99TLA121	3.48	0.00	1.57	0.73	1.57	0.00	46	21	0.54	438	medium grey silty shale	Tanglefoot fm.	438160	6814310
99TLA122	1.48	0.01	0.35	0.52	0.36	0.02	24	35	0.57	441	olive grey silty shale, laminated	Tanglefoot fm.	438160	6814310
DDH97-63A	1.34	0.00	0.43	0.28	0.43	0.00	32	21	0.60	432	medium grey silty mudstone	Tantalus fm.	445250	6796830
DDH97-63B	0.81	0.00	0.66	0.33	0.66	0.00	81	41	0.66	431	medium grey shaly mudstone	Tanglefoot fm.	445250	6796830
DDH94-37B	2.76	0.21	0.33	0.25	0.54	0.38	12	9	2.01	333	medium grey siltstone, laminated	Tanglefoot fm.	444240	6798550
DDH95-52A	1.09	0.00	0.96	0.29	0.96	0.00	89	27	0.65	432	medium grey siltstone	Tantalus fm.	444720	6797525
99TLA023	63.41	0.00	10.44	31.34	10.44	0.00	17	49	0.54	432	coal	Tanglefoot fm.	443630	6798855
99TLA024	47.79	0.00	7.72	25.93	7.72	0.00	16	54	0.53	432	coal	Tanglefoot fm.	443663	6798884
99TLA031	58.20	0.13	33.50	34.97	33.63	0.00	59	60	0.55	430	coal	Tanglefoot fm.	444158	6799525
99TLA042	46.75	0.00	16.05	46.81	16.05	0.00	35	100	0.45	438	coal	Tanglefoot fm.	442234	6801702
99TLA043	55.02	0.00	34.55	36.28	34.55	0.00	64	66	0.53	433	coal	Tanglefoot fm.	442234	6801702
99TLA051	57.46	0.00	23.38	40.59	23.38	0.00	41	71	0.49	428	coal	Tanglefoot fm.	441841	6801742
99TLA053	6.66	0.07	12.27	13.26	12.34	0.01	189	199	0.56	438	carbonaceous shale	Tanglefoot fm.	441550	6801678
DDH94-37A									2.82		carbonaceous shale	Tanglefoot fm.	444240	6798550
DDH97-63C	57.94	0.00	97.28	3.34	97.28	0.00	169	6	0.59	425	coal	Tanglefoot fm.	445250	6796830
DDH97-63D	52.89	0.13	181.18	2.39	181.31	0.00	344	5	0.63	430	coal	Tanglefoot fm.	445250	6796830
DDH97-63E	19.57	0.04	43.95	2.46	43.99	0.00	226	13	0.65	430	coal	Tanglefoot fm.	445250	6796830
DDH95-52B	61.32	0.14	50.56	4.54	50.70	0.00	84	7	0.68	432	coal	Tanglefoot fm.	444720	6797525

[1]wt % of total organic carbon
[2]mg hydrocarbons/g rock
[3]mg hydrocarbons/g rock
[4]mg CO_2 /g rock
[5](S1/S1+S2)
[6]Hydrogen Index (S2/TOC x 100)
[7]Oxygen Index (S3/TOC x 100)
[8]per cent random reflectance in oil
[9]T_{max} - °C
[10]North American Datum 1983, Zone 8

should be above 2 kg HC/t of rock to qualify as a oil-source rock (Tissot and Welte, 1984). All of the coal and carbonaceous shale genetic indices were above 2 kg HC/t of rock, suggesting that if all parameters are met, they could be viable source rocks for oil.

Four samples analyzed in this study showed high hydrogen indices (two above 200 mg HC/t rock) and contain abundant liptinite. Hunt (1991) suggests that as the liptinite content of organic matter increases so does the hydrogen content and potential for oil generation. Samples with hydrogen index values above 200 are generally considered capable of generating some liquid hydrocarbon (Hunt, 1991).

THERMAL MATURITY

The thermal maturity of the coals and neighbouring strata has been determined with the use of vitrinite reflectance and Rock-Eval pyrolysis.

Vitrinite reflectance is useful for defining zones of potential hydrocarbon generation and provides information on maturation within a basin. Maximum reflectance values of six samples of the Cairnes Seam previously analyzed by Beaton et al. (1992) range from 0.60 to 0.62% R_{omax}. Random reflectance measurements obtained for samples collected in this study range from 0.45 to 2.82% $R_{orandom}$ (Table 2). The highest values obtained are in close proximity of porphyritic to aphanitic sills or dykes. The values between 0.5 and 1.3% $R_{orandom}$ are within the oil window while values between 1.3 and 2.0% $R_{orandom}$ are in the gas window. Samples overmature in terms of source rocks (above 2.0%) are in close proximity of sills and dykes.

T_{max}, a value obtained during Rock-Eval pyrolysis, is an indicator of thermal maturity, assuming that as maturity increases, T_{max} increases. The T_{max} value is partially dependent on the type of organic matter present in the sample, and thus, should be confirmed with additional techniques such as vitrinite reflectance or thermal alteration indices. T_{max} values obtained by Beaton and others (1992) for six samples of the Cairnes Seam ranged from 443-448°C. T_{max} values obtained for samples in this study range from 333° to 484°C. The 333°C value is anomalous and when removed T_{max} ranges from 425° to 484°C. The highest T_{max} values (475° to 484°C) correspond to strata on Joe Creek (underlying the Nordenskiöld strata), and are beyond the oil window in terms of thermal maturation, although within the gas zone. The remaining T_{max} values, 425° to 432°C, indicated that the strata are just below the beginning of the oil window, which is typically 435° to 470°C depending on the type of organic matter present (Peters, 1986).

Table 3. *Rock-Eval interpretative guidelines (modified from Peters, 1986).*

Source rock generative potential			
Quality	TOC (wt%)	S1 (mg HC/g rock)	S2 (mg HC/g rock)
poor	0-0.5	0-0.5	0-2.5
fair	0.5-1.0	0.5-1.0	2.5-5.0
good	1-2	1-2	5-10
very good	>2	>2	>10
Type of hydrocarbon generated			
Type	HI (mg HC/g TOC)	S2/S3*	
gas	0-150	0-3	
gas and oil	150-300	3-5	
oil	>300	>5	
		*assumes Ro = 0.6%	
Level of thermal maturation			
Maturation	PI (S1/S1+S2)	Tmax (ºC)	Ro (%)
top oil window	~0.1	430-445*	~0.5
bottom oil window	~0.4	~465	~1.3
		*varies with type of organic matter	

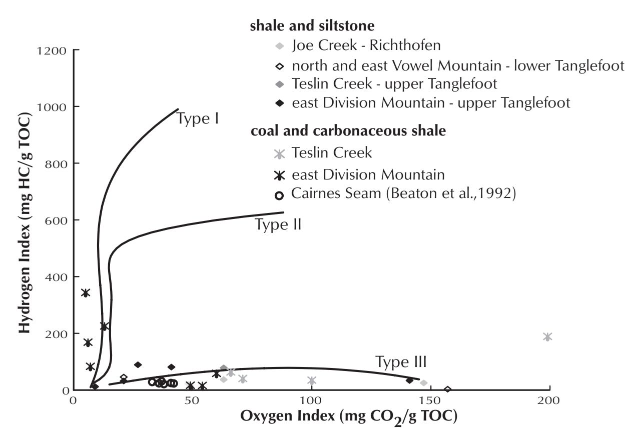

Figure 14. *Hydrogen versus oxygen index cross plot of samples analyzed from the Division Mountain area. Note that a majority of the samples plot around the Type III evolutionary path, suggesting that the organic matter within the strata at Division Mountain is largely derived from terrestrial plants, thus gas prone. A few samples plot along the Type I pathway, suggesting that these samples are more likely oil prone.*

DISCUSSION OF SEDIMENTARY ENVIRONMENT

Several interpretations have been presented for the depositional environment of the Tanglefoot formation including a shallow marine (lower member) to a complex fluvial-deltaic (upper member) environment (Carne and Gish, 1996). Long (1986) suggested that the upper member was deposited on a broad coastal plain where extensive coals accumulated within strandline and high constructive elongate delta deposits. Hart (1997) proposed that the Tanglefoot formation may represent a transition from dominantly fine-grained marine sediments to dominantly coarse-clastic terrigenous sediments, reflecting a dramatic change in the depositional environment from near-shore marine to deltaic or gravely shoreface.

Strata of the Tanglefoot formation is indicative of a shoaling up from shallow marine to a possible non-marine environment. The transition from the lower member to the overlying upper member of the Tanglefoot formation indicates an overall fining upward (Fig. 8). The lower member is much coarser grained and of a different composition than the upper member. The lower member sandstone and conglomerate are quartz-rich with ubiquitous biotite scattered throughout. The conglomerate contains clasts of vein quartz, as well as granitic and lesser volcanic clasts. The granitic clasts in the conglomerate may be indicative of the source for biotite and other minerals in the sandstone and grit. The lower member locally contains marine fossils including Trigoniids and corals. Repeated fining-upward sequences, coupled with the presence of marine fossils in the lower member, suggest deposition in a marine environment. A section at Red Ridge Canyon, over 300 m thick, displays progressive coarsening upward of the lower member that is characteristic of a deltaic environment.

The overlying upper member sandstone contains no obvious biotite and consists largely of quartz and feldspar, suggesting a change in source for the sediments. Faunal records are absent in the upper member, thus there is no direct evidence for a marine versus non-marine argument for these deposits. The presence of thick coal seams in the upper member suggests a periodically stagnant environment with very little sediment influx. Coals typically originate in swamps on low-lying delta plains, alluvial plains, or coastal areas (McCabe, 1984). Vitrinite varieties of the upper Tanglefoot coal seams imply that the coal may have originated in an environment with a significant proportion of grasses and reeds of a low-lying wetland flora (Beaton et al., 1992). Very low sulphur content of the coal suggests the environment of deposition was unaffected by marine waters. Therefore, the upper member was not likely formed in a coastal zone. The presence of abundant laminated fines, and coal seams with intercalated fining upward sequences, suggests that deposition occurred in an alluvial-dominated setting.

Finally, the influx of chert pebbles and cobbles of the Tantalus Formation over the Laberge Group suggests a dramatic change in source. The upper portion of the Whitehorse Trough (Upper Jurassic to Lower Cretaceous) is apparently derived from the northeast, but contains mostly chert clasts for which a northeastern source is unknown (Tempelman-Kluit, 1979), other than the Cache Creek Terrane (Hart, 1997), which is to the south.

The system that deposited Tantalus Formation sediments was much more active than the systems that deposited underlying strata, as indicated by the coarseness of material preserved. Several interpretations have been presented for the origin of the Tantalus Formation, including a continental fluvial origin (Tempelman-Kluit, 1974; Hughes and Long, 1980), braided river or alluvial fan (Bremner, 1988), a fan delta that prograded into a paralic environment (Lowey and Hills, 1988), and a fluvial to marine shoreface transition (Hart and Pelletier, 1989). The uncommon presence of dinoflagellates within lower Tantalus strata attests to the fact that sediments were deposited, at least in part, in a marine environment (Lowey, 1984; Lowey and Hills, 1988; Hunt and Hart, 1994).

In the Whitehorse Trough, economic coal seams of the Tantalus Formation have very low sulphur contents. Low sulphur contents, coupled with an absence of marine fossils, suggest a predominantly non-marine depositional setting for the Tantalus Formation.

CONCLUSIONS

Two members have been recognized within the Tanglefoot formation in the Division Mountain area. The underlying lower member is characterized by quartz-rich sandstone with minor biotite, heterolithic conglomerate, and intercalated laminated siltstone. The upper member is characterized by bleached quartzofeldspathic sandstone and grit with interbedded carbonaceous shale and coal seams.

Traditionally, the Tantalus Formation has been recognized as containing coal seams, but not the older, underlying Tanglefoot formation. The coal seams in the Division Mountain area occur within the Laberge Group Tanglefoot formation. The Tantalus Formation, forming resistant highlands, may be very useful in determining where recessive coal-bearing strata of the underlying Tanglefoot formation occur.

The source rock evaluation completed in this study indicates that there is potential for gas, and perhaps modest amounts of oil source rocks in the upper Laberge Group. Thermal maturity indicators (T_{max} and vitrinite reflectance) suggest that the strata lie at the beginning of the oil window and thus are slightly immature to produce hydrocarbons. Assuming the proper parameters are met, the upper Laberge Group could prove a viable gas, and maybe, oil source.

ACKNOWLEDGEMENTS

I would like to thank Leyla Weston and Panya Lipovsky for their assistance, knowledge and for enduring the "tanglewood" in the field. Thanks are extended to Cash Resources Ltd. for use of their Division Mountain field camp, access to drill core, and company reports. Craig Hart and Frank Gish are acknowledged for helpful discussions. The manuscript was improved by comments from Grant Abbott and Leyla Weston. Safe and reliable helicopter support was provided by Trans North Helicopters out of Whitehorse. Vern Stasiuk and Martin Fowler of the Geological Survey of Canada processed the samples for vitrinite reflectance and source-rock geochemistry.

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APPENDICES

Appendix A. *Summary of geological mapping in the Division Mountain area (refer to Figure 2 for limits of previous maps).*

Author (year)	Scale	Map
Cairnes (1910)	1:126 720 (2 miles:1 inch)	Braeburn-Kynocks coal area; Cairnes located coal seams on Teslin Creek and base of Vowel Mountain (Red Ridge).
Lees (1934)	1:253 440 (4 miles:1 inch)	Geology of the Laberge area.
Cockfield et al. (1936)	1:253 440 (4 miles:1 inch)	Geology of Laberge map sheet.
Bostock and Lees (1938)	1:253 440	Laberge map area geology report.
Tempelman-Kluit (1974)	1:250 000	Geology of the Aishihik Lake map area.
Tempelman-Kluit (1984)	1:250 000	Geology of the Laberge map area.
Carne and Gish (1996)		Outline of geology of Division Mountain area.

Appendix B. *An outline of exploration activity in the Division Mountain area.*

Date	Exploration cbompany	Work performed and highlights	Reference
1903	John Quinn and H.E. Porter	• staked coal near Division Mountain	Yukon Minfile (1997)
1970	Norman H. Ursel Associates Ltd.	• Cub Mountain area; geological mapping, no coal found (NW corner of NTS block 105E/5)	Hunt (1994)
1970, 1971	Arjay Kirker Resources Ltd. for Teslin Exploration Ltd.	• Division and Vowel mountains – bulldozer trenching (7 trenches totalling 167 m near Teslin Creek), mapping, sampling and test I.P. survey over coal outcrops near Teslin Creek • reconnaissance geological mapping, road building • estimated reserves at 41 million tons • exposed aggregate thickness of 18.6 m of coal over an interval approximately 305 m • explored Corduroy Mt, no coal located	Kirker (1971); Craig and Laporte (1972)
1972	Arjay Kirker Resources Ltd. (Archer, Cathro and Associates Ltd.)	• drilled 6 diamond drill holes in Teslin Creek area (totalling 1047 m) • coal seams intersected vary from 4.6 to 5.9 m • 24.8 m aggregate thickness of coal seams > 0.5 m • reserves calculated as 2.8 million tons	Phillips (1973)
1975	Allen Resource Consultants Ltd. (Resoursex Ltd.)	• located coal float on Cub Mountain in gopher holes, believed to be within the Tantalus formation	Allen (1975)
1977	Hill for Cyprus Anvil Mining Corp.	• collected coal samples for analysis	Hunt (1994)
1978	Hill for Utah Mines Ltd.	• collected coal samples for analysis	Hunt (1994)
1978	Manalta Coal Ltd.	failed to locate any additional coal seams	Hunt (1994)
1990-1991	All-North Resources Ltd. and W4 Joint Venture	• trenching and mapping near Teslin Creek	Yukon Minfile (1997)
1990	Geological Survey of Canada	• one 1972 bulldozer trench was remapped and carefully sampled (Teslin Creek) for Beaton et al. report	Beaton et al. (1992)
1992	Beaton et al. (University of Western Ontario)	• petrography, geochemistry and utilisation potential of the Division Mountain coal occurrence (Cairnes Seam)	Beaton et al. (1992)
1993	Cash Resources Ltd. (Allister Peach Geo-Consulting Ltd.)	• drilled 16 holes totalling 1810 m near Teslin Creek • intersected over 28 coal seams > 0.5 m thick • total in situ reserves estimated at 11 139 920 tonnes • hand trenching at Red Ridge exposed 11.4 m coal	Peach (1993); Wengzynowski and Carne (1993, 1994)
1994-1995	Cash Resources Ltd. (Archer, Cathro and Associates Ltd.)	• 5.2 km of excavator trenching • 6034 m of HQ-size diamond drilling in 32 holes • aggregate coal thickness 10 to 32 metres • estimated open pit reserves of 31.7 million tonnes	Carne and Gish (1996)
1996-1997	Cash Resources Ltd. (Archer, Cathro and Associates Ltd.)	• 1667 m of HQ-size diamond drilling in 10 holes • 21 excavator trenches totalling 2695 m at Division and Corduroy mountains • hand trenches southwest of Cub Mountain • raw coal reserves estimated at 54.7 million tonnes	Burke (1998); Gish and Carne (1998)
1998	Cash Resources Ltd. (Archer, Cathro and Associates Ltd.)	excavator trenching at Cub Mountain	Burke (1999)
1999	Cash Resources Ltd. (Archer, Cathro and Associates Ltd.)	RC drilling program	

Glaciation, gravel and gold in the Fifty Mile Creek area, west-central Yukon

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Lowey, G.W., 2000. Glaciation, gravel and gold in the Fifty Mile Creek area, west-central Yukon. *In:* Yukon Exploration and Geology 1999, D.S. Emond and L.H. Weston (eds.), Exploration and Geological Services Division, Yukon, Indian and Northern Affairs Canada, p. 199-209.

ABSTACT

Previously unrecognized glacial erosional landforms (i.e., cirques, u-shaped troughs, truncated spurs and arêtes, in order of increasing doubt), and glacial depositional landforms (i.e., end moraine and possibly ground moraine) occur in the Fifty Mile Creek area, west of the pre-Reid Cordilleran glacial limit. The cirques and end moraine, representing the best evidence of glaciation, are similar to landforms in the adjacent Yukon-Tanana uplands of Alaska and formed during the Eagle glaciation (>40 ka, or Reid in age). Glaciation caused climate-controlled variations in runoff and cycles of aggradation and incision in the Fifty Mile Creek drainage. This resulted in the formation of upper- and lower-level terraces along Fifty Mile Creek and its tributaries. The terraces are composed of slightly muddy, sandy gravel of locally derived lithologies, and are fluvial in origin. Placer gold occurs along Fifty Mile Creek and several of its tributaries, as well as in the lower-level terraces. The upper-level terraces are potentially placer-gold bearing.

RÉSUMÉ

Des formes de terrain nouvellement reconnues, caractéristiques de l'érosion glaciaire (p. ex. des cirques, des vallées en U, des éperons et des arrêtes rocheuses tronquées, en ordre décroissant de confiance) et des formes de terrain associées aux dépôts glaciaires (p. ex. une moraine terminale et possiblement de la moraine de fond) sont présentes dans la région du ruisseau Fifty Mile, à l'ouest de la limite définie pour les glaciations qui ont précédé la période glaciaire de Reid dans la Cordillère. Les cirques et la moraine terminale, qui constituent les meilleurs indices de glaciation, sont similaires aux formes de terrain modelées pendant la glaciation de Eagle (il y a plus de 40 000 ans, soit d'âge Reid) dans les hautes terres du Yukon-Tanana de l'Alaska. La glaciation a causé des variations de ruissellement déterminées par le climat et la formation de cycles d'accumulation et d'érosion de sédiments dans le bassin versant du ruisseau Fifty Mile. Ces variations ont formé les terrasses supérieure et inférieure qui longent le ruisseau Fifty Mile et ses tributaires. Les terrasses, composées de graviers sableux et boueux d'origine locale, ont été formées en milieu fluvial. De l'or placérien est présent le long du ruisseau Fifty Mile, de plusieurs tributaires et dans les terrasses inférieures. Les terrasses supérieures pourraient renfermer de l'or placérien.

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INTRODUCTION

The Fifty Mile Creek area, located southwest of Dawson City in west-central Yukon (Fig. 1), forms the northwest corner of the Stewart River map sheet (115 O and N). The area lies west of the pre-Reid Cordilleran glacial limit and is adjacent to the Sixty Mile River placer area. Ralph, Cheryl and Al creeks are informally named (Fig. 2) and are all tributaries to Fifty Mile Creek. Despite the area's proximity to the Sixty Mile River area, no placer mining has occurred in the Fifty Mile Creek area and only limited exploration for placer deposits has been undertaken. Rudis (1998) reported that the area was prospected for placer gold during the 1960s and 1970s. This was followed by exploratory drilling (Woodsend, 1990) and several geophysical surveys along Fifty Mile Creek (Mollot, 1988a, 1988b, 1988c; McIntyre, 1989a, 1989b) with no success. Recently, RJAS Minerals conducted a trenching and bulk sampling program of gravel in the area. The Fifty Mile Creek area is characterized by previously unrecognized glacial landforms, terraces, and placer gold. This study represents the first systematic and detailed investigation of the Fifty Mile Creek drainage basin. The purpose of the study is to document evidence of glaciation, describe the gravel deposits comprising the terraces, and evaluate the placer potential of the area.

BEDROCK GEOLOGY

Tempelman-Kluit (1974) and Mortensen (1996) provide the most complete coverage of the bedrock geology in the Fifty Mile Creek area. The report by Cockfield (1921) is dated, but contains useful historical information. In the adjacent Sixty Mile River area, Glasmacher (1984) concluded that epithermal type and vein type mineralization were the primary sources of placer gold. The Yukon Minfile contains brief descriptions of the bedrock geology and lode mineral deposits in the Fifty Mile Creek area.

The Fifty Mile Creek area is underlain by mainly Paleozoic metasedimentary (i.e., Kondike Schist and Nasina Assemblage) and meta-igneous rocks belonging to the Yukon-Tanana Terrane (Mortensen, 1996). Minor amounts of altered ultramafic rocks occur locally and are assigned to the Slide Mountain Terrane. According to Mortensen (1990, 1996), these two pre-accretionary units were juxtaposed by regional-scale thrust faulting in Early Mesozoic time. The area was unconformably overlain by post-accretionary sedimentary and volcanic rocks during mid- to Late Cretaceous time.

SURFICIAL GEOLOGY

Bostock (1966) and Hughes et al. (1969) provide a regional framework for the surficial geology and glacial history of the Stewart River map sheet. No surficial geology mapping has been done in the Fifty Mile Creek area, although mapping is planned as part of a proposed NATMAP project (Lionel Jackson, pers. com., 1998). In the adjacent Sixty Mile River area, Cockfield (1921) provides a historical account of the surficial geology and placer deposits, while Hughes (1986) describes the sedimentology of the placer deposits. Limited information on the type of surficial geology units present in the area can be obtained from the Dawson map sheet (located immediately to the north of the Stewart River map sheet), which was mapped by Vernon and Hughes (1966) and more recently by Duk-Rodkin (1996).

The Fifty Mile Creek area, thought to be a mature, subdued landscape by Miocene time, underwent a period of uplift and erosion in the Pliocene (Tempelman-Kluit, 1980). The area was not covered by glacial ice during the Cordilleran pre-Reid (latest Pliocene in age) or later glaciations, although there is evidence of alpine and valley glaciation.

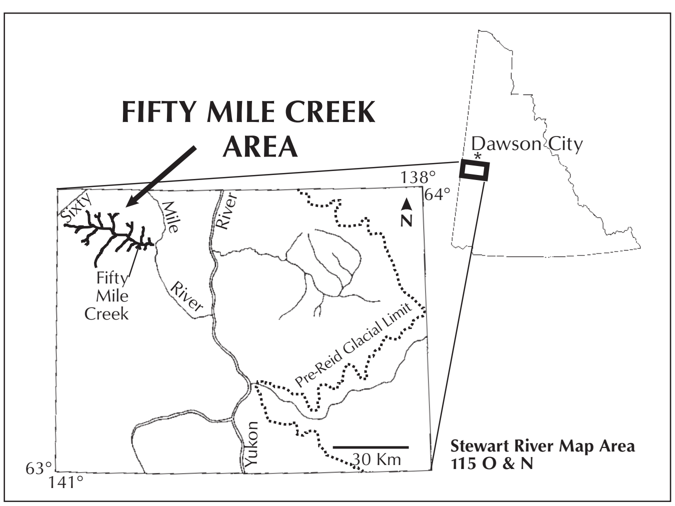

Figure 1. *Location map of the Fifty Mile Creek area, west-central Yukon.*

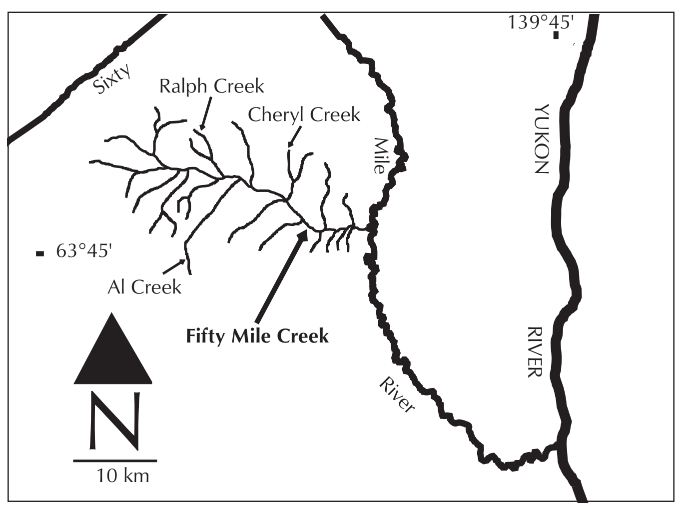

Figure 2. *Principal streams in the Fifty Mile Creek area.*

METHODS

This study is based on fieldwork and preliminary laboratory analyses. Seven days of fieldwork were spent in the Fifty Mile Creek area in August, 1999. During this time, outcrop profiles of the deposits were constructed according to the method outlined by Miall (1996), and representative samples were collected for grain size, heavy mineral, palynological, and radiometric analysis. Ongoing laboratory work includes determining grain size distribution (following the classification of Blair and McPherson, 1999) and clast lithology of gravel samples, heavy mineral analysis of panned concentrates, palynological analysis of fine-grained sand and silt samples, and radiometric age dating of tephra and organic samples. Outcrop profiles are tentatively correlated by lithocorrelation (c.f., Schoch, 1989) which will be confirmed by chronocorrelation once radiometric age dates are available.

GLACIATION

The Fifty Mile Creek is located within the Klondile Plateau, west of the Cordilleran glacial limits (i.e., the pre-Reid, Reid and McConnell). Bostock (1948, p. 69) describes the plateau as "cut into segments by the valleys of the master streams that traverse it, and its striking characteristic is the topographic similarity of all these segments, a similarity that may largely be due to the lack of glaciation of the plateau...The topography is a maze of deep, narrow valleys, separated by long, smooth-topped ridges whose elevations are very uniform...". However, the headwaters of Fifty Mile Creek are an exception to this generalization: approximately 140 km^2, or one-fifth of the Crag Mountain map sheet (115N/15) is above 1200 m in elevation with peaks up to 1820 m in elevation; similarly, approximately 140 km^2, or one-fifth of the Borden Creek map sheet (115N/10) is above 1200 m in elevation with peaks up to 1862 m in elevation. Both glacial erosional landforms and glacial depositional landforms occur within these mountainous uplands.

GLACIAL LANDFORMS

The glacial erosional landforms include cirques, u-shaped troughs, truncated spurs and arêtes, in order of increasing doubt. The cirques are located near the headwaters of Fifty Mile Creek at approximately 63°45'N, 140°35'W and 63°51'N, 140°53'W and their morphometric characteristics are summarized in Table 1. Generally, the cirques are well defined (Fig. 3) and face north-northeast (Fig. 4). The cirques typically occur at an elevation of 1415 m, and are 140 m high, 750 m wide and 1760 m long. The altitude, orientation and form of the cirques provide information on the paleoenvironmental conditions at the time of their formation. For example, using an atmospheric lapse rate of 6°C/1000 m (Hidore and Oliver, 1993) and assuming a current July freezing isotherm at 2700 m altitude in west-central Yukon, the formation of cirque glaciers in

Figure 3. *Photograph of cirque #7, looking east.*

Figure 4. *Photograph of cirque #7 headwall, looking south.*

Figure 5. *Photograph of u-shaped trough (in foreground), looking east.*

the Fifty Mile Creek area would have required a summer temperature depression of approximately 8°C below modern day values. Several u-shaped troughs (Fig. 5) are located down-stream from cirques and in valleys oriented east-west at approximately 63°45'N, 140°35'W. Landforms interpreted as truncated spurs (Fig. 6) occur along Al Creek at approximately 63°45'N, 140°35'W and arêtes(?) occur along the headwalls of several of the cirques.

The glacial depositional landforms include an end moraine and possibly ground moraine. The end moraine (Fig. 7) is located in a u-shaped trough and downstream from a cirque at approximately 63°45'N, 140°30'W. It is sharp-crested, approximately 3 m high, and partly eroded (Fig. 8). The ground moraine(?), preserved as a concentration of large lag boulders, is located in the valley of Al Creek at approximately 63°47'N, 140°35'W.

Table 1. *Cirque morphometric characteristics, Fifty Mile Creek area, west-central Yukon.*

Cirque	Location (Latitude, Longitude)	Grade[1]	Aspect[2] (°)	Altitude[3] (m)	Height[4] (m)	Width[5] (m)	Length[6] (m)	Headwall slope[7] (°)	Floor inclination[8] (°)	Length: Height Ratio	Length: Width Ratio	Headwall: Floor Slope Ratio	Cirque Volume[9] (km^3)
1	63°51'30" 140°53'50"	4	55	1395	120	600	1500	11	6	12.5	2.5	1. 8	0.05
2	63°51'10" 140°52'10"	4	5	1365	150	750	1250	17	9	12.5	2.5	1.9	0.07
3	63°47'30" 140°44'30"	3	30	1305	150	1000	1750	17	5	11.6	1.7	3.4	0.13
4	63°47'10" 140°40'30"	3	35	1485	90	750	1600	14	7	17.8	2.2	2.1	0.05
5	63°45'50" 140°39'30"	2	15	1375	45	750	1250	8	4	27.8	1.7	1.9	0.02
6	63°45'30" 140°37'40"	1	-25	1455	240	650	2000	18	8	8.3	3.1	2.2	0.16
7	63°44'30" 140°38'30"	1	-40	1455	180	700	2500	20	4	13.9	3.6	5.0	0.15
8	63°44'50" 140°35'00"	1	60	1515	150	800	2250	17	6	15.0	2.8	2.8	0.13
	Total												**0.76**
	Average	2	10	1415	140	750	1760	15	6	-	-	-	-

[1]Grade follows classification of Evans and Cox (1995), whereby 1 = classic, with all textbook attributes, 2 = well-defined, with headwall and floor clearly developed and headwall curves around cirque floor, 3 = definite, with no debate over cirque status, but one characteristic may be weak, 4 = poor, some doubt, but well-developed characteristics compensate for weak ones, 5 = marginal, with cirque status and origin doubtful.
[2]Aspect is direction faced by central headwall perpendicular to long axis of cirque measured to nearest 5° azimuth (negative values from 360° to 180°).
[3]Altitude measured as most obvious break in slope denoted by contour lines.
[4]Height measured from top of headwall to break in slope denoted by contour lines (to nearest 5 m).
[5]Width measured from top of sidewall to top of opposite sidewall (to nearest 5 m).
[6]Length measured from top of headwall to cirque mouth, or where sidewalls abruptly end or drop in altitude (to nearest 5 m).
[7]Headwall slope measured from top of headwall to break in slope denoted by contour lines (to nearest 5°).
[8]Floor inclination measured from break in slope denoted by contour lines to cirque mouth, or where sidewalls abruptly end or drop in altitude (to nearest 5°).
[9]Volume calculated by: (height x width x length)/2.

Figure 6. *Photograph of truncated spurs along Al Creek, looking north.*

AGE AND CORRELATION OF GLACIATION

The cirques and end moraine, representing the best evidence of glaciation, are similar to landforms in the adjacent Yukon-Tanana uplands of Alaska (Weber, 1986) that formed during the Eagle glaciation (>40 ka; Hamilton, 1994). The Eagle glaciation is generally correlated with the penultimate or Reid glaciation in the Yukon. A detailed examination of the end moraine is planned for next year; organic matter (if present) will be collected for radiocarbon dating, in order to obtain a precise age estimate of the glaciation.

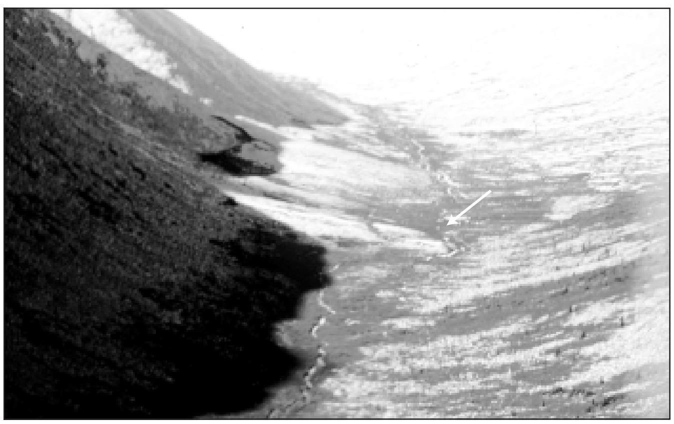

Figure 7. *Photograph of end moraine, looking west.*

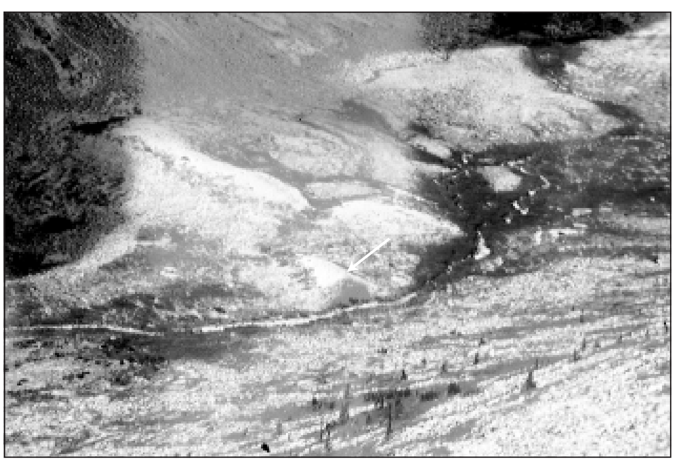

Figure 8. *Photograph of end moraine, looking south.*

AFFECT OF GLACIATION ON BASE LEVEL

The documentation of alpine and valley glaciation in the Fifty Mile Creek area is important from the perspective of placer geology since this glaciation controlled the base level of Fifty Mile Creek. Base level is the level to which a stream erodes its base and this determines the accommodation space, or space made available for potential sediment accumulation (Miall, 1996). Changes in base level (and related changes in accommodation space) are caused by changes in tectonics, sea level and climate. Very little is known about the neotectonics of the Fifty Mile Creek area, and the area is considered too far inland to have been affected by changes in sea level. However, Vandenberghe (1993) has shown that climate-controlled variations in runoff and sediment supply, due to cycles of glacial and interglacial phases, result in cycles of stream aggradation and incision. For example, a change from the initiation of glaciation to the maximum glacial phase causes a relative increase in runoff and a dramatic increase in sediment supply (as vegetation disappears and slopes become unstable), resulting in aggradation (Vandenburghe, 1993). As another example, a change from a glacial to interglacial phase causes a dramatic increase in runoff and a decrease in sediment supply (as limited amounts of vegetation reappear and slopes become stabilized), resulting in incision (Vandenburghe, 1993). Hence, glaciation in the Fifty Mile Creek area led to a relative increase in runoff and an increase in sediment supply, corresponding to a rise in base level and an increase in accommodation space. This resulted in aggradation or deposition of the gravel and

Figure 9. Photograph of terraces along Fifty Mile Creek, looking southeast.

accompanying placer gold. Conversely, deglaciation in the Fifty Mile Creek area led to an increase in runoff and decrease in sediment supply, corresponding to a lowering of base level and a decrease in accommodation space. This resulted in incision or erosion of the gravel and subsequent formation of the terraces.

GRAVEL

Deposits of gravel occur along Fifty Mile Creek, its tributaries, and on several levels of terraces. This report deals only with the terraces, which are assigned to an upper- and lower-level. Upper-level and lower-level terraces occur along Fifty Mile Creek (Fig. 9); lower-level terraces also occur along several tributaries to Fifty Mile Creek (i.e., Ralph and Cheryl creeks; Fig. 2). All of the terraces are cut into bedrock and are capped by a relatively thin veneer of gravel (Fig. 10). The upper-level terraces have scarps up to 20 m high and treads up to 100 m wide; lower-level terraces have scarps up to 2 m high and treads up to 300 m wide.

UPPER-LEVEL TERRACES

The upper-level terraces are restricted to the right limit of Fifty Mile Creek where they are cut into granitic orthogneiss (Fig. 11) of the Fifty Mile batholith (Mortensen, 1996). The terraces have not been extensively explored and no trenches are present, however several trails cut by bulldozers provide limited exposure of the gravel capping the terraces (Fig. 12). The gravel is up to 2 m thick, poorly horizontally bedded, and is classified as lithofacies Gh (Fig. 13). Texturally, it is a clast supported, rounded, moderately sorted, muddy, sandy, cobbly, medium to very coarse pebble gravel. The gravel, dominated by metamorphic clasts locally derived from the Fifty Mile batholith, was deposited by a paleocurrent flowing towards the east.

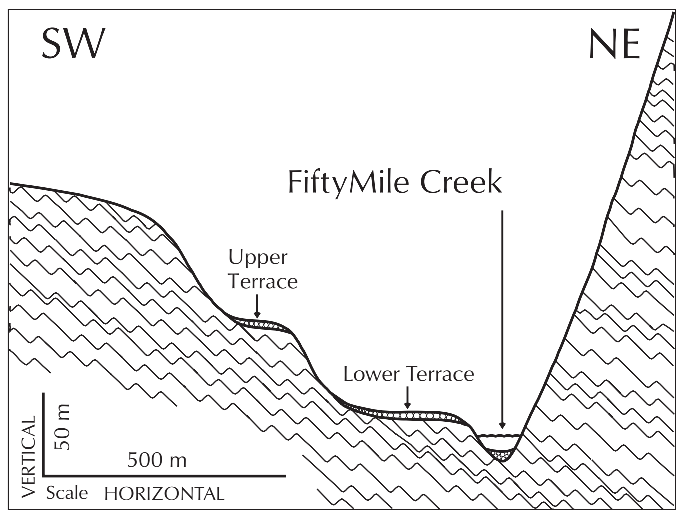

***Figure 10.** Schematic cross-section of terraces along Fifty Mile Creek.*

***Figure 11.** Photograph of the upper-level terrace and exposed bedrock, looking southeast.*

LOWER-LEVEL TERRACES

The lower-level terraces are restricted also to the right limit of Fifty Mile Creek. The terraces are cut into quartz-muscovite schist of the Nasina Assemblage (Fig. 14) and granitic orthogneiss of the Fifty Mile batholith (Mortensen, 1996). The terraces have been extensively explored and several trenches provide limited exposure of the gravel capping the terraces (Fig. 15). The gravel is up to 3 m thick, poorly horizontally bedded, and is classified as lithofacies Gh (Fig. 16). Texturally, it is a clast-supported, slightly organized (i.e., a/t, b/i, with the long axis of clasts horizontal and transverse to slope, and the intermediate axis of clasts imbricate), rounded, moderately sorted, slightly sandy, cobbly, medium to very coarse pebble gravel. The gravel, dominated by metamorphic clasts locally derived from the Nasina Assemblage and Fifty Mile batholith, was deposited by paleocurrents flowing towards the east. Minor amounts of planar bedded sand (lithofacies Sp) also occur in the gravel.

Figure 14. *Photograph of the lower-level terrace and exposed bedrock, looking south.*

Figure 12. *Photograph of a bulldozer trail exposing gravel on the upper-level terrace, looking south.*

Figure 15. *Photograph of an exploration pit in the lower-level terrace, looking southeast.*

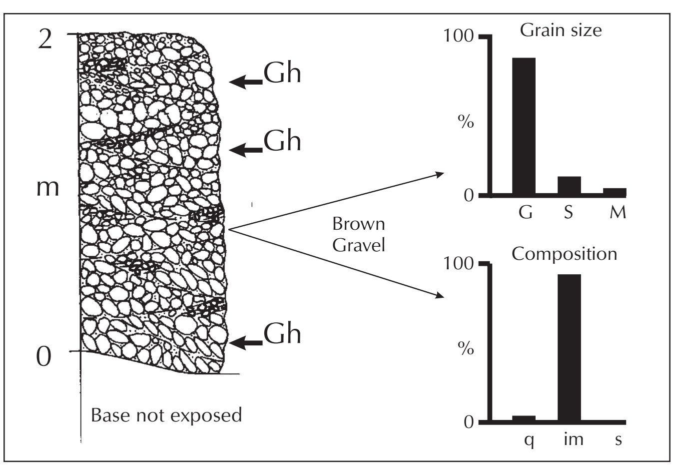

Figure 13. *Sedimentological section of the upper-level terrace (Gh=horizontally bedded gravel) and typical grain size distribution and composition of gravel (G=gravel, S=sand, M=mud, q=quartz vein clasts, im=igneous and metamorphic clasts, s=sedimentary clasts).*

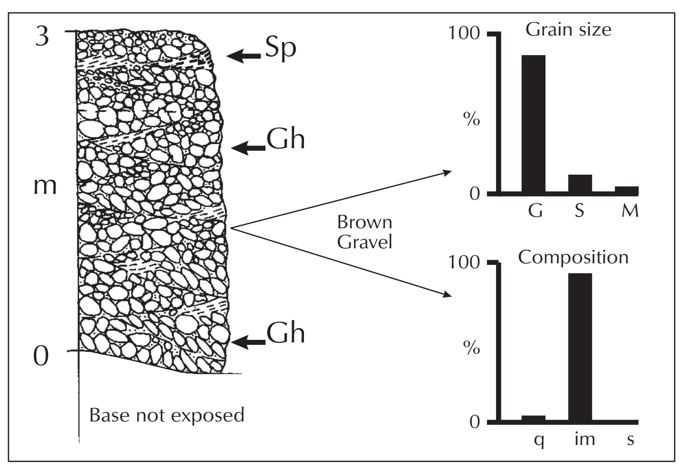

Figure 16. *Sedimentological section of the lower-level terrace (Gh=horizontally bedded gravel, Sp=planar bedded sand), and typical grain size distribution and composition of gravel (abbreviations in Figure 13).*

TRIBUTARY CREEK TERRACES

Lower-level terraces also occur along Ralph and Cheryl creeks and several other unnamed tributaries. They are cut into quartz-muscovite schist and amphibolite (Fig. 17) of the Nasina Assemblage (Mortensen, 1996). Several of the terraces have been explored and trenches provide limited exposure of the gravel capping the terraces (Fig. 18). The gravel is up to 1 m thick, poorly horizontally bedded, and classified as lithofacies Gh (Fig. 19). Texturally, it is a clast supported, slightly organized (i.e., a/t, b/i, with the long axis of clasts horizontal and transverse to slope, and the intermediate axis of clasts imbricate), rounded, moderately sorted, muddy, sandy, medium to very coarse pebble gravel. The gravel, dominated by metamorphic clasts locally derived from the Nasina Assemblage, was deposited by paleocurrents flowing towards the south. The gravel is overlain by interbedded sand (lithofacies Sh) and mud (lithofacies Fl) that are horizontally laminated.

Figure 17. *Photograph of the tributary creek terrace and exposed bedrock, looking north.*

Figure 18. *Photograph of an exploration pit in the tributary creek terrace, looking southeast.*

ENVIRONMENT OF DEPOSITION

The deposits of gravel comprising the terraces are characterized by a vertical assemblage of lithofacies Gh. This assemblage is classified as element GB and interpreted as gravel bars. The gravel bars formed in a fluvial system, most likely a braided river environment. Lithofacies Sp is interpreted as small sand bars within the gravel, and lithofacies Sh and Fl are interpreted as overbank deposits.

GOLD

HEAVY MINERAL ANALYSIS

A panned sample of gravel (approximately 1/150th of a cubic metre) from the lower-level terrace contained a heavy mineral assemblage dominated by magnetite, garnet, hornblende, hematite and pyroxene (enstatite; Fig. 20). Approximately 15 gold colours were recovered in the assemblage and classified as follows (Macdonald, 1983): 2 fine-grained colours (the largest gold particle was 1 mm long), 9 very fine-grained colours, and at least 5 flour-sized colours. According to the method outlined by Macdonald (1983), the colours are estimated to weigh 6.16 mg, or represent almost 1 gram of gold per cubic metre of gravel (equivalent to 0.024 oz/yd). The heavy mineral assemblage is consistent with derivation from magnetite-pyroxene skarns present in the area (i.e., Yukon Minfile, 1997, 115N 042). Gold has not been reported from the skarns, but up to 4.0 g/t Au was

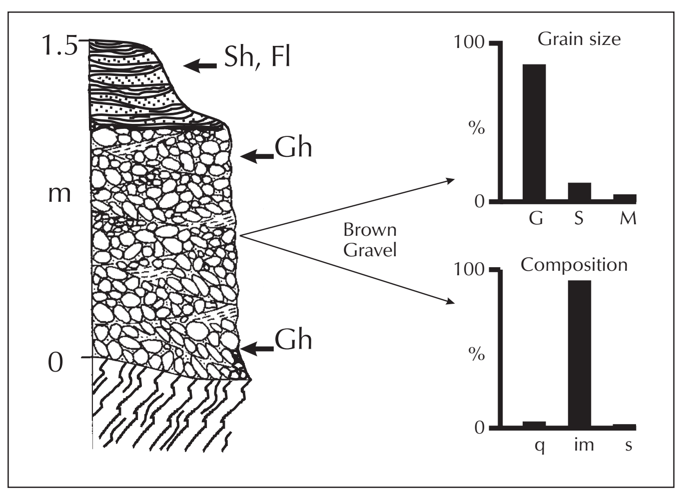

Figure 19. *Sedimentological section of the tributary creek terrace (Gh=horizontally bedded gravel, Sh=horizontally bedded sand, Fl=laminated mud), and typical grain size distribution and composition of gravel (abbreviations in Figure 13).*

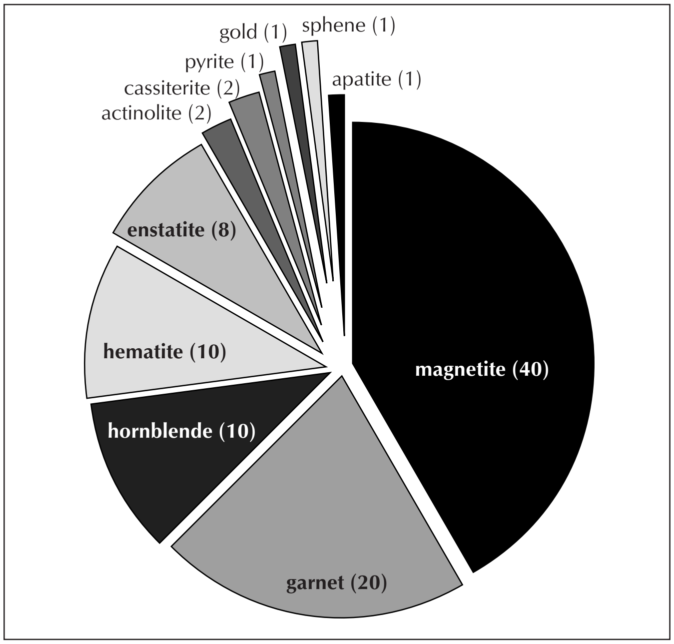

Figure 20. *Heavy mineral analysis of a panned sample (GL99-55) from the lower-level terrace (values in percent run clockwise from 40%=magnetite, garnet=20%, etc.)*

reported from galena-carbonate veins that are occur in the study area (i.e., Yukon Minfile, 1997, 115N 040 and 042). Although paleoplacer gold has been reported from Cretaceous and/or Tertiary conglomerate exposed in the area (Tempelman-Kuit, 1972), subsequent exploration has failed to find any gold in this unit (Yukon Minfile, 1997, 115N 044).

DISTRIBUTION

Placer gold occurs along Fifty Mile Creek and several of its tributaries (Ralph and Cheryl creeks), but the occurrence of this gold was not systematically investigated. Placer gold occurs also in the lower-level terraces along the right limit of Fifty Mile Creek (Fig. 21) and in the lower-level terraces along several tributaries to Fifty Mile Creek (i.e., Ralph and Cheryl creeks). The upper-level terraces along Fifty Mile Creek are similar (in terms of origin and composition) to the lower-level terraces, and therefore, they are potentially placer gold bearing. However, the lower-level terraces represent a larger volume of gravel than the upper-level terraces. In addition, placer gold, if it is present in the upper-level terraces, would probably be of lower grade than that in the lower-level terraces due to the erosion and re-concentration of gold from the upper-level terraces into the lower-level terraces. Hence, the lower-level terraces represent the best exploration target for large-scale placer mining.

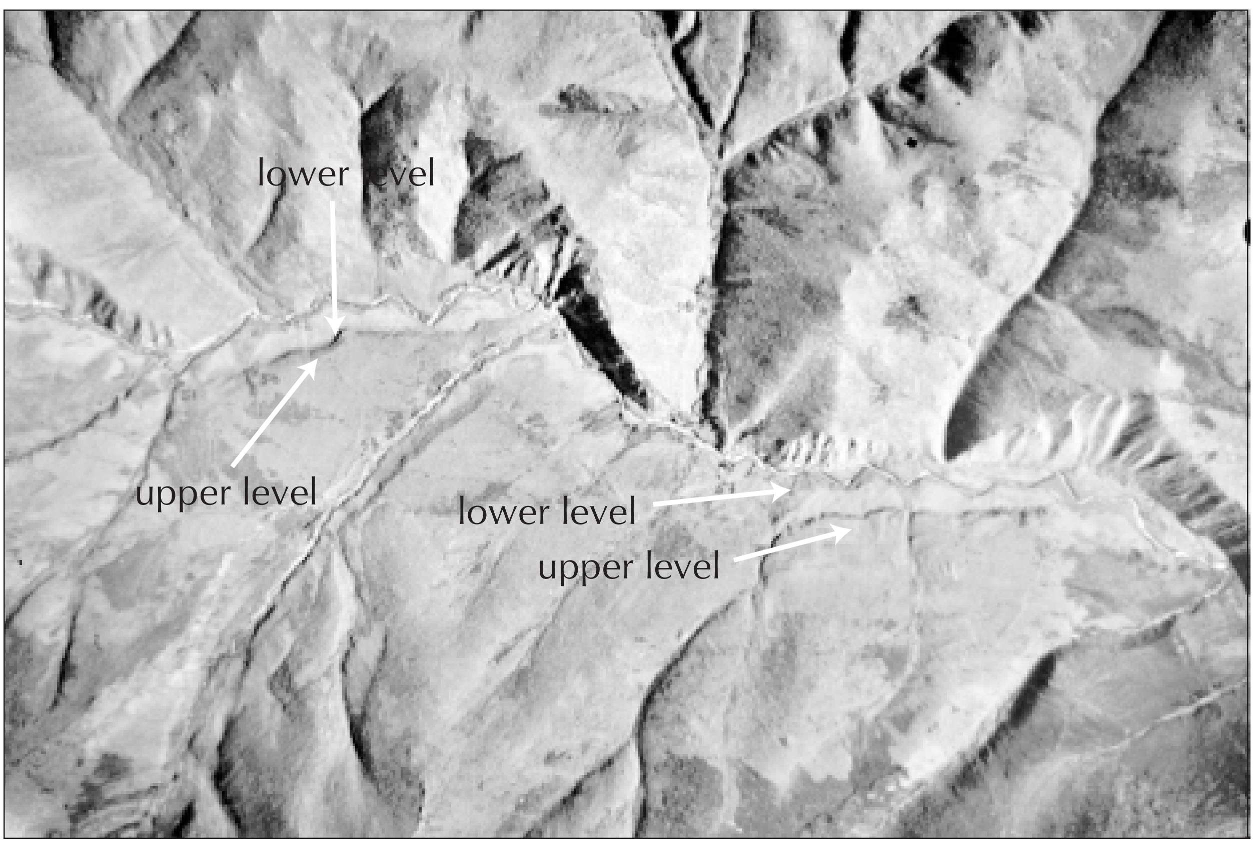

Figure 21. *Air photograph of terraces along Fifty Mile Creek.*

CLASSIFICATION OF PLACER DEPOSITS

Placer gold deposits in gravel capping the terraces are classified as alluvial bench placers (Table 2), and those in the present day Fifty Mile Creek and its tributaries are classified as creek placers.

CONCLUSIONS

Alpine and valley glaciation in the Fifty Mile Creek area, based mainly on the identification of cirques and an end moraine, is likely Reid in age. This glacial event caused fluctuations in runoff and sediment supply, thereby controlling the base level of Fifty Mile Creek. As a result, cycles of aggradation and incision ensued, resulting in the formation of terraces along Fifty Mile Creek and several of its tributaries. The terraces are capped by a relatively thin veneer of gravel that is pebbly to cobbly, locally derived, and fluvial in origin. Placer gold occurs in lower-level terraces located along Fifty Mile Creek and along several tributaries to Fifty Mile Creek. There is also potential for placer gold in upper-level terraces located along Fifty Mile Creek.

ACKNOWLEDGEMENTS

I am grateful to Albert Rudis, Ralph Nordling and Bonnie Nordling for their hospitality during my study of the Fifty Mile Creek area, and thank Rachel Pugh for her help and enthusiasm during the fieldwork.

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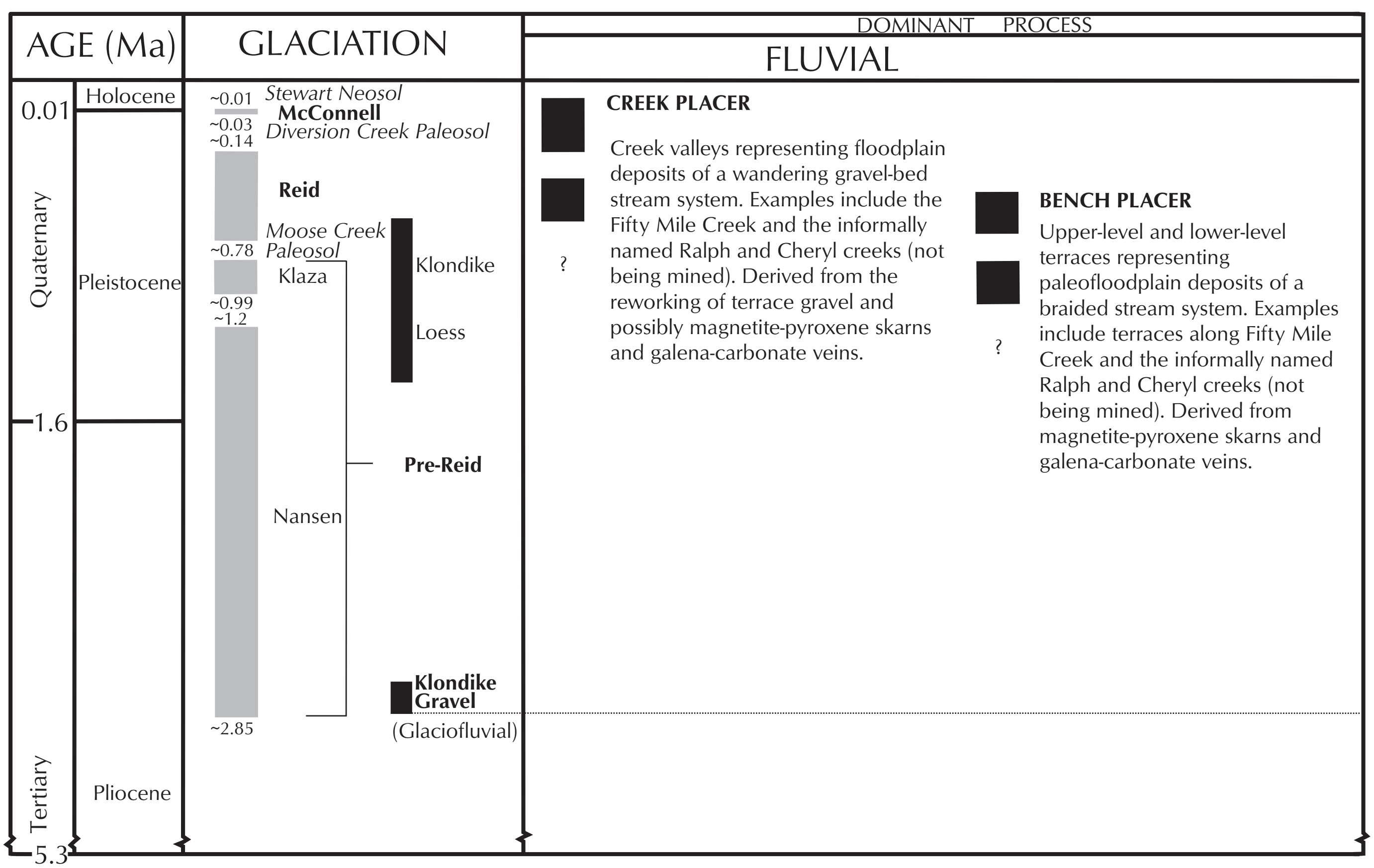
Table 2. *Classification of placer deposits in the Fifty Mile Creek area, west-central Yukon.*



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Ground penetrating radar investigation of the upper Yukon River valley between White River, Yukon and Eagle, Alaska

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Froese, D.G. and Smith, D.G., 2000. Ground penetrating radar investigation of the upper Yukon River valley between White River, Yukon and Eagle, Alaska. *In:* Yukon Exploration and Geology 1999, D.S. Emond and L.H. Weston (eds.), Exploration and Geological Services Division, Yukon, Indian and Northern Affairs Canada, p. 211-216.

ABSTRACT

Ground penetrating radar (GPR) profiles were collected along mid-channel and side-channel bars from the confluence of the Yukon and White rivers in the Yukon, to Eagle, Alaska, a distance of 270 km. These profiles, although preliminary, demonstrate little variation in the thickness of valley-fill gravel (depth to bedrock) over that distance. Surveys show little difference in gravel thickness between the largest sediment source (White River) and more distal downstream reaches. The average thickness is approximately 10 m, which is equivalent to the maximum scour depth of the river. GPR surveys across the Tintina Fault along the Yukon River indicate a similar depth of fill compared to the upstream and downstream reaches from the fault zone, suggesting no significant recent vertical movement. These observations, when combined with the uplift history of the region (rates of 50-70 mm/ka determined in the Klondike area), suggest the region is likely undergoing either very slow uplift or is stable. No differential uplift is detectable within the error limits and sampling density of the GPR valley-fill method used in this study.

RÉSUMÉ

Des profils géoradar (PG) ont été recueillis sur les barres de mi-chenal et riveraines entre la confluence du fleuve Yukon et de la rivière White, au Yukon, et Eagle, en Alaska, soit sur une distance de 270 km. Bien que préliminaires, ces profils montrent que l'épaisseur du gravier comblant la vallée (profondeur au socle rocheux) varie peu sur cette distance. Les relevés indiquent que l'épaisseur du gravier varie peu entre la plus importante source de sédiments (la rivière White) et les tronçons aval plus éloignés. L'épaisseur moyenne est approximativement de 10 m, ce qui est équivalent à la profondeur d'affouillement maximale du cours d'eau. Les levés d'établissement de PG sur la faille de Tintina, le long du fleuve Yukon, indiquent une profondeur de comblement similaire à celles observées en amont et en aval de la zone faillée, ce qui suggère qu'il n'y a eu récemment aucun déplacement vertical important. Lorsque combinées à l'histoire du soulèvement de la région (vitesses de 50 à 70 mm/ka déterminées dans la région du Klondike), ces observations suggèrent que la région subit vraisemblablement un soulèvement très lent ou bien qu'elle est stable. Aucun soulèvement différentiel n'est détectable, au delà des limites d'erreur et de la densité d'échantillonnage, au moyen de la méthode PG utilisée dans la présente étude.

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INTRODUCTION

Timing and magnitude of late Cenozoic crustal movements in west-central Yukon have been poorly understood when reconstructing the geomorphic history of the Yukon River valley and its gold-bearing tributaries. Whether terraces along the Yukon River and its tributaries were produced by either large-scale regional uplift, or more localized uplift or subsidence (e.g., normal faulting, Tintina graben) has significant implications for the construction of new exploration models of placer gold deposits. This paper is a summary of GPR data collected along the Yukon River in west-central Yukon as part of a Ph.D thesis on the Plio-Pleistocene history of the Yukon River in western Yukon and central Alaska.

Previous investigations of the upper Yukon River in west-central Yukon have suggested that large-scale regional uplift downstream of the Dawson area during the Pleistocene may have resulted in the displacement of terraces by as much as 240 m (Hughes, 1970; Hughes et al., 1972; Fuller, 1995). This hypothesized regional tilting has been suggested to explain the presence of downstream terraces which occur at higher levels, than what have been argued to be their upstream equivalents (Hughes et al., 1972; Fuller, 1995). Alternatively, models of a southerly flowing Yukon River (opposite to the present-day flow direction), rerouted to the northwest by an advancing southern ice sheet, has been suggested to account for these terrace elevation differences (Tempelman-Kluit, 1980). This paper is a preliminary report of results of a geophysical survey of the modern Yukon River valley-fill between the White River/Yukon River confluence and Eagle, Alaska. The purpose of this survey was to determine the present influence of tectonics on the modern Yukon River, and in particular, whether evidence of past regional tectonism was present in the form of mappable variations in the valley-fill of the upper Yukon River.

REGIONAL SETTING

The study reach of the Yukon River is located within the Yukon-Tanana upland, corresponding to the Yukon-Tanana Terrane in western Yukon. The study reach begins at the confluence of the Yukon and White rivers, and continues to where the Yukon River intersects the Tintina Fault, near the border of Alaska (Fig. 1). The Tintina Fault is a zone of Late Cretaceous to early Tertiary dextral strike-slip displacement by as much as 450 km (Gabrielse, 1985). This fault separates highly metamorphosed rocks of the Yukon-Tanana Terrane to the southwest, from sedimentary strata of the Selwyn Basin to the northwest (Tempelman-Kluit, 1980). The Tintina Trench is a more recent (late Tertiary) graben developed along the Tintina Fault (Tempelman-Kluit, 1980).

Physiographically, the Yukon-Tanana upland is a largely unglaciated, gently sloping plateau, consisting of concordant summits, which are connected by ridges and separated by deeply incised v-shaped valleys. This plateau is considered an uplifted erosional surface produced from extensive sub-aerial erosion in the early-mid Tertiary. Tempelman-Kluit (1980) hypothesized that during this time, a south-flowing paleo-Yukon River existed, connecting the area north of the Tintina Trench with the Pacific Ocean. He argued that southerly drainage of the plateau may have persisted through uplift of the southwestern Yukon ranges, and was likely diverted to the northwest by the advance of late Cenozoic ice sheets.

APPROACH TO CHARACTERIZING RECENT CRUSTAL MOVEMENTS

The approach adopted in this study to characterize vertical movements along the Yukon-Tanana upland is based on the simple assumption that relative uplift or subsidence along the river valley will result in variable thickness of the alluvial fill. That is, the valley-fill will be thinnest over areas of active uplift and thickest over areas of subsidence; furthermore, the influence of these variations may be mapped using ground penetrating radar (GPR) in order to examine any upstream or downstream influences. A second objective was to use the GPR valley-fill data to determine whether the modern valley might intersect a portion of the southerly flowing pre-glacial Yukon River valley. This would be indicated by a deepening valley-fill to the south. The third objective was to look for vertical displacement of the Tintina Fault where it crosses the Yukon River.

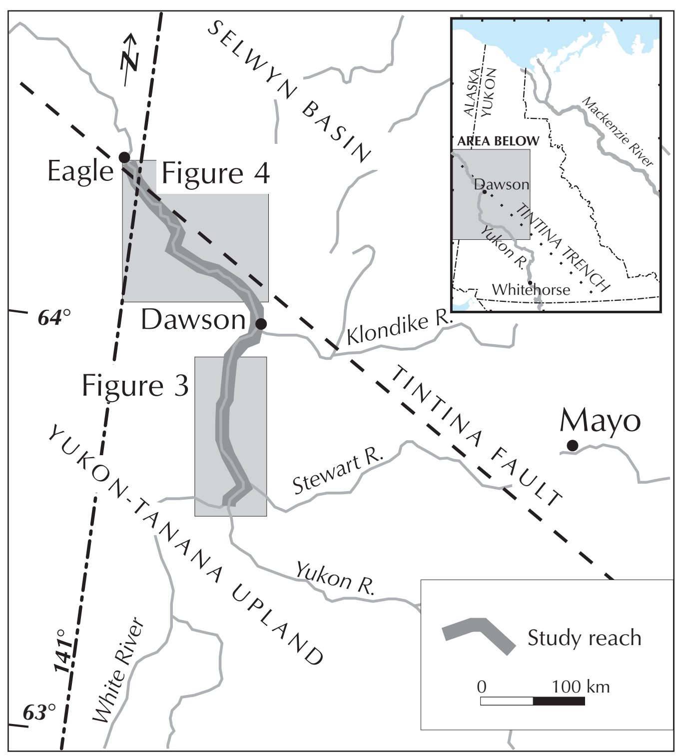

Figure 1. *Study reach of Yukon River in west-central Yukon. Grey boxes correspond to more detailed maps in Figures 3 and 4.*

YUKON RIVER

The Yukon River drains an area of nearly 300 000 km^2 (upstream of Eagle, Alaska), representing roughly 60% of the Yukon Territory (Fig. 1). The Donjek and White rivers, originating in the St. Elias Range, provide the largest single sediment source in the upper Yukon River basin. In contrast to most rivers in Canada, the Yukon River has a relatively simple valley morphology. Most valleys in the Canadian Cordillera were strongly affected by late Quaternary glaciation, resulting in diversion of drainages (e.g., Duk-Rodkin and Hughes, 1994), complex valley fills with multiple depositional environments, or distribution of Quaternary sediments that the rivers may still be adjusting to (e.g., Church and Slaymaker, 1989). The study reach of the Yukon River, between the White River/Yukon River confluence, and the Alaska border, has been in its present position for at least the last 2.6 Ma (Froese et al., in press), and in addition, is outside the furthest limit of glaciation in western Yukon (Duk-Rodkin, 1999).

Rates of Quaternary uplift are poorly understood in the Cordillera, but have been documented from the record of fluvial incision in the Dawson area. On the basis of incision of terraces by the Klondike River near its junction with the Yukon River, rates of 40-50 mm/ka are estimated over the last 2.6 Ma and an average rate of <75 mm/ka over the last 40 ka (Froese, 1997). These rates would suggest that if the rate of lateral migration and erosion by the river is even moderate, the valley fill should be relatively uniform, and bedrock relief should be low. This would indicate that variations in the bedrock profile (a potential source of error in using valley-fill thickness as an indicator of uplift/subsidence) should be minimized. This last assumption appears to hold true, since reports from drilling of the Yukon River channel near the Dawson area show relatively uniform valley depth (2 m of relief). Vertical relief in any GPR profile in a main valley setting did not exceed that value (Yukon Territorial Government, Geotechnical Services report, unpublished; McKinney, 1974).

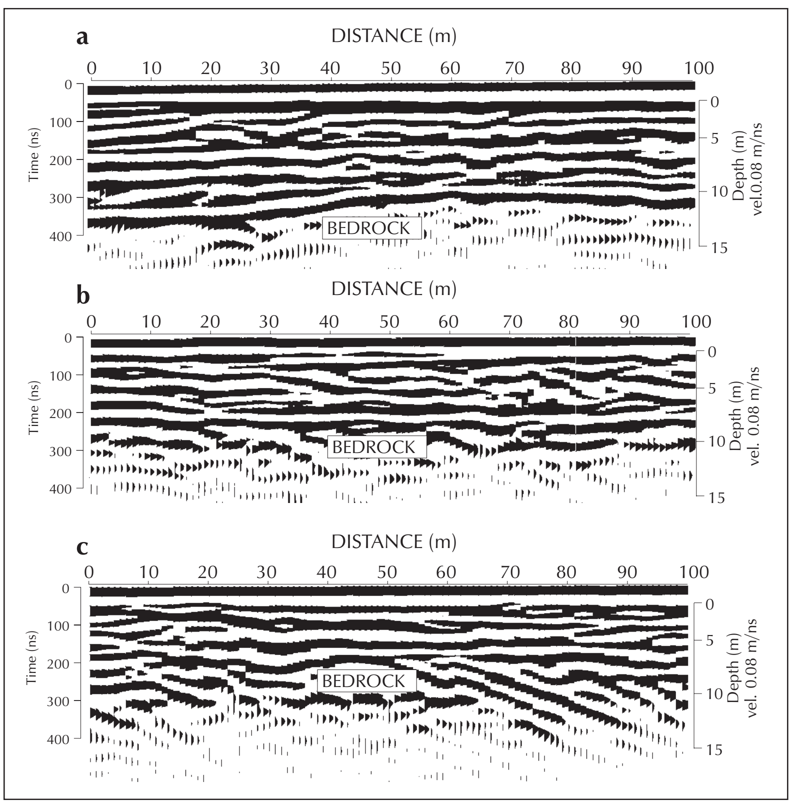

***Figure 2**. Typical bedrock profiles imaged with GPR along the Yukon River. a) 25 MHz survey along mid-channel bar upstream of Fortymile River (km 75, Fig. 4). Profile shows prominent reflector (bedrock) at 350 ns, ~11-12 m depth. b) 25 MHz profile at mouth of Coal Creek (within the Tintina Fault zone). Profile shows prominent reflector at 225-250 ns, ~8 m depth. c) 25 MHz survey along mid-channel bar near km 40, immediately downstream of Tintina Fault intersection with Yukon River. Profile shows prominent reflector at approximately 200-225 ns, with refracted reflections below ~7-8 m depth.*

METHOD

A pulseEKKO IV radar system in reflection survey mode with antennae frequencies of 25, 50, and 100 MHz were used with a 1000-volt transmitter. Profiles 100 to 500 m long were collected at mid-channel bars and along channel edges within 0.5 m of the water table. Each location (vertical trace on profiles) was vertically stacked 64 times with a sampling rate of 1600 picoseconds. Profiles were processed and plotted using pulseEKKO IV (software with constant gain), and an average near-surface velocity of 0.08 m/nanosecond was determined by common mid-point survey at all profiles. Surveys were conducted during 1998 and 1999 field seasons.

GPR works similar to seismic methods with the major difference being that it uses an electromagnetic (EM) rather than an acoustic energy source. A number of detailed accounts provide a review of the theory and methodology behind GPR that is beyond the scope of this paper (Annan and Davis, 1976; Ulriksen, 1982; Daniels et al., 1988). In a GPR survey, short bursts of high frequency EM energy (generally 10-1000 MHz) are transmitted into the ground. Where there are changes in the electrical properties of subsurface materials, reflections of energy are returned which are detected at the surface. This effect enables subsurface stratigraphy to be inferred from the character of the radar return signals. Variations in the dielectric properties of the subsurface results in a return signal that is proportional to the electrical contrast, allowing the contact between bedrock and the alluvial gravel of the Yukon River to be generally well-defined (Fig. 2).

In resistive, coarse-grained materials (e.g., coarse gravel free of silt or clay matrix), depths of penetration up to 70 m may be attained at low frequencies (12.5 MHz; Smith and Jol, 1995).

Three typical profiles collected with 25 MHz antennae are shown in Figure 2. Each profile is processed using a deconvolution filter and amplified by a constant gain. In each profile, bedrock can be reliably interpreted from a high-amplitude reflector occurring between 200 and 350 ns. Below the high amplitude reflector, the signal is refracted and loses its flat-lying to low-angle character.

LONGITUDINAL TRENDS ABOVE DAWSON CITY (WHITE RIVER TO DAWSON CITY)

From the confluence of the White and Yukon rivers, to the mouth of the Klondike River (a distance of approximately 120 km; Fig. 1), the Yukon River shows a changing surface morphology with distance from the White River. The upstream reach consists of unstable gravel braid bars and channels, changing to more stable forest-covered islands separated by braided channels. In this reach we wanted to know: (1) what is the variability in valley-fill thickness; and (2) could the pre-glacial (hypothesized south-flowing) Yukon River valley be imaged below the modern river channel bed.

GPR profiles were collected from the Yukon River above the White River (km 265), at the mouth of White River, and 7 more downstream between kilometres 250 and 160 (Fig. 3). Rather than a downstream thinning of gravel from the mouth of White River, sediment thickness was relatively uniform and within the error limit of the GPR method (discussed below). These depths coincide approximately with the maximum scour depth of the river in each reach. The only significant sediment thickness variation (about 6 m) occurs at the mouth of the Stewart River, immediately below the confluence of the Stewart and Yukon rivers at km 240. This sort of variation was anticipated because deep scour holes commonly occur at channel confluences. Other than the Stewart River, the other main gold-bearing tributaries (Sixtymile, Indian and Klondike rivers) show no variations in their base level control.

The hypothesized paleo-divide of the pre-glacial Yukon River has been suggested to occur within western Yukon between the Fortymile and Fifteenmile rivers, located approximately 150 km northwest of the White River/Yukon River confluence (Tempelman-Kluit, 1980; Duk-Rodkin, 1997). Assuming a conservative slope of 1m/km for the paleo south-flowing Yukon River, this would suggest a decrease in elevation of the ancient valley floor toward the White River. Near Dawson City, the Pliocene bedrock surface is about 100 m above the present river level. This suggests that 100 km to the south, it should be near the intersection point with the modern river valley floor (assuming no differential uplift of the southerly region relative to Dawson City). If this was the case, and the paleo Yukon River valley were encountered, a deepening of the valley-fill in the direction of the paleo river would be expected (to the south). The GPR data show no evidence of any deeper fill to the south, suggesting that either the slope assumption of the river is too high, or differential uplift has occurred during the Plio-Pleistocene relative to Dawson City. Additional data from further south, and/or independent age control of terraces near the junction is required to resolve this question.

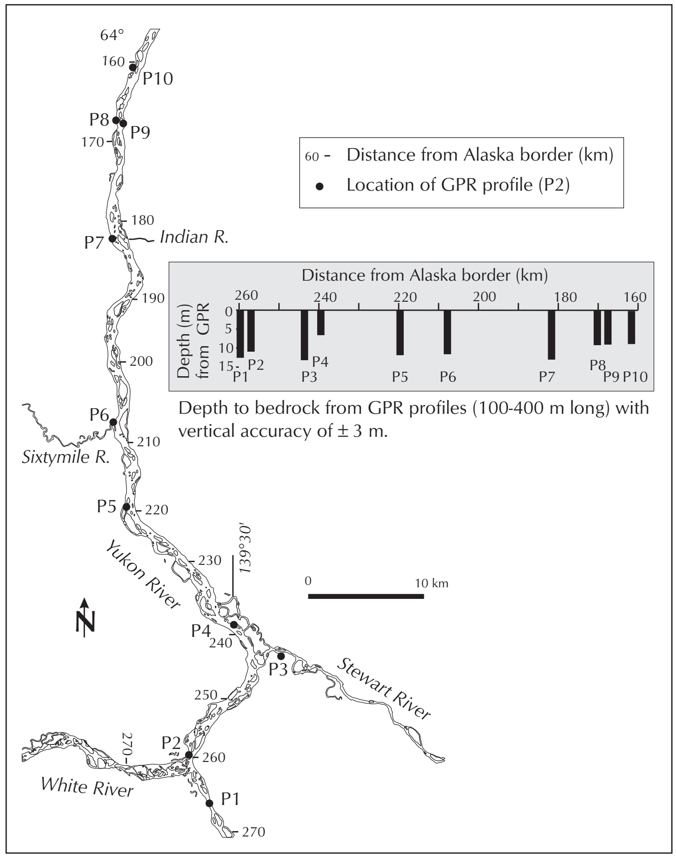

__Figure 3.__ Location of White River confluence with Yukon River, and GPR survey positions along the upstream reach, descending down river to near Dawson City. Depth to bedrock GPR profiles: The only significant deviation in the profile is about 6 m at the mouth of the Stewart River between P3 and P4. The upper White River gravel thickness is no different from the rest of the Yukon River.

LONGITUDINAL TRENDS, DAWSON CITY TO EAGLE, ALASKA

A second objective of this study was to examine recent channel-bed changes along the Tintina Fault (as it intersects the Yukon River) to determine recent vertical movement, and its zone of influence. Interest in the Tintina Fault stems largely from a number of suggested connections between the graben and models for the origin of the Klondike goldfields. Tempelman-Kluit (1980, 1982) suggests that development of the Tintina graben resulted in a drop in local base level, which was transferred upstream to the Klondike River valley, and caused the incision and preservation of White Channel gravel in the late Pliocene. This, arguably, could have been conceivable in either the southerly pre-glacial drainage configuration of Tempelman-Kluit (1980), or in the present Yukon River position. In order to look at the feasibility of these arguments, and determine if there may be a present-day analogue for the goldfields, a series of depth to bedrock measurements were surveyed over the long profile of the Yukon River between the Klondike River junction and Eagle, Alaska.

If vertical deformation is occurring along the Tintina Fault zone, then a greater depth to bedrock would be expected over the zone of deformation, thinning upstream to the undisturbed reach. Unexpectedly, GPR profiles imaged above and below the fault zone show no increase in the depth to bedrock (Fig. 4). A modal value of approximately 11 m occurs between km 20 and km 55, which is no different from the upstream profiles at km 75 and km 90. These data strongly suggest that vertical movement of the Tintina Fault has not recently (late Quaternary) occurred, however, some horizontal movement could still be accommodated within the dataset.

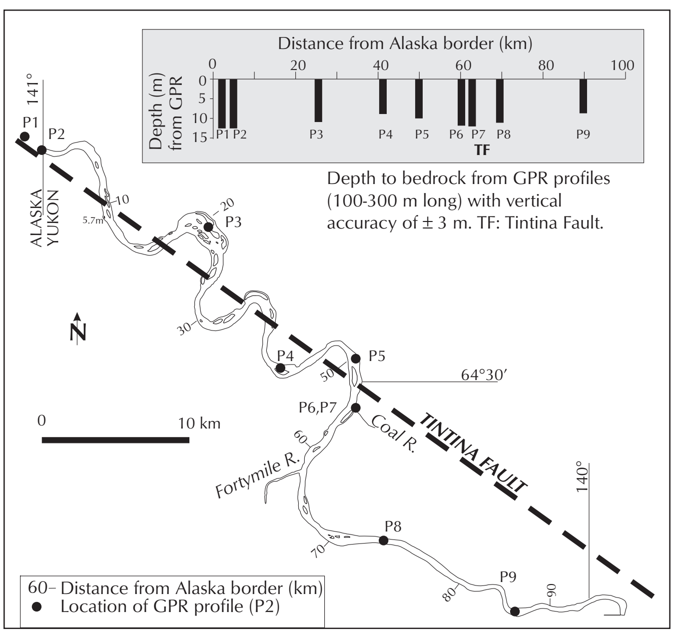

Figure 4. *Location of Tintina Fault at intersection with the Yukon River and GPR profiles collected in the area. Within the vertical accuracy of the GPR method (+/- 3 m), there is no difference in valley-fill thickness between upstream, downstream, and within the Fault area, indicating no significant recent vertical movement.*

DISCUSSION

In this study, a conservative vertical error of ± 3 m has been assigned to the representativeness and confidence of vertical GPR measurements. This was established on the basis of: (1) wavelength of induced wave (frequency of 25 MHz), giving a minimum vertical resolution of approximately 1 m (assuming all coarse, saturated gravels have the same radar wave propagation velocity of 0.08 m/ns); and (2) the vertical relief of bedrock (2 m) along any single valley cross-section. The vertical relief of bedrock was determined from both borehole data at Dawson City (Yukon Territorial Government Geotechnical report, unpublished, McKinney 1974), and the measured bedrock contact from approximately 5000 m of GPR data collected in this study.

The remarkable similarity in depth-to-bedrock over the 270 km of river investigated indicates that external forces on the river (primarily tectonism, investigated in this paper) are not readily apparent. The possibility that the thin valley-fill of the Yukon River is the result of active uplift of the Yukon-Tanana upland can be partially rejected by the low uplift rates calculated in the Klondike area. These low rates, coupled with the similarity of valley-fill-depth GPR results along the 270 km reach, suggest an equivalent process may be occurring along the entire study reach. However, this conclusion must be forgone until better uplift rates can be determined at additional sites along the Yukon River.

The lack of encountering a south-flowing pre-glacial valley-fill in the upper Yukon River is somewhat surprising. Projection of a slope of 1m/km to the south for the pre-glacial Yukon River would suggest an intersection point with the modern valley-fill in the vicinity of the Stewart/White rivers. However, it is not precisely known whether the paleo-Yukon River flowed south in its present valley south of Stewart River, or flowed toward the Tintina Trench via the present-day Stewart River valley (Fig. 1). If the latter is the case, additional GPR data along the Stewart River should be collected to test pre-glacial drainage reconstruction models.

The lack of variation in valley-fill thickness across the Tintina Fault suggests little recent vertical movement in the area. This observation is consistent with a lack of tilting of Plio-Pleistocene strata exposed in the Tintina Trench to the east (A. Duk-Rodkin, pers. comm., 1999). This does not necessarily indicate a lack of seismic activity in the area. Fault scarps up to 3 m are known to intersect Reid-age (ca. 200 ka) outwash near the Dempster Highway (Mortensen and von Gaza, 1993). In addition, the prevalence of landslides within the trench may suggest some recent fault activity (Mortensen and von Gaza, 1993).

CONCLUSIONS

- GPR profiles collected over 270 km of the upper Yukon River show little variation in the depth to bedrock between the White River, Yukon and Eagle, Alaska.
- The consistency of depth-to-bedrock measurements coupled with measured uplift rates in the Klondike area suggest a model of low uplift (~50-100 mm/ka) may be appropriate at a regional scale.
- No evidence of southerly flowing pre-glacial Yukon River was found in the southern portion of the study reach.
- There is no evidence of vertical displacement of the Yukon River across the Tintina Fault.

ACKNOWLEDGEMENTS

Greg Chernoff, John Laughton, Gary Parkstrom and Nadine Raynolds are thanked for enthusiastic support in moving antennae during 1998 and 1999. Funding for this project was provided by NSERC (operating grant to Derald Smith), Geological Society of America student research grants (1998, 1999), the Northern Science Training Program (Department of Indian Affairs and Northern Development), and a Yukon Geology program contract. Alejandra Duk-Rodkin is thanked for discussion and speculations of the pre-glacial Yukon River.

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PROPERTY DESCRIPTIONS

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The magmatic and structural setting of the Brewery Creek gold mine, central Yukon

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Lindsay, M.J., Baker, T., Oliver, N.H.S., Diment, R. and Hart, C.J.R., 2000. The magmatic and structural setting of the Brewery Creek gold mine, central Yukon. *In:* Yukon Exploration and Geology 1999, D.S. Emond and L.H. Weston (eds.), Exploration and Geological Services Division, Yukon, Indian and Northern Affairs Canada, p. 219-227.

ABSTRACT

The Brewery Creek gold mine (13.3 Mt @ 1.44 g/t Au) is a bulk tonnage, heap leach operation located 57 km east of Dawson City, Yukon. The deposit lies on the northeastern side of the Tintina Fault and within Selwyn Basin.

Gold mineralization is hosted by intrusions of the mid-Cretaceous Tombstone Plutonic Suite (TPS), and Silurian to Carboniferous clastic metasedimentary rocks of the Steel Formation and Earn Group. The sedimentary rocks are faulted and variably folded, however they display poor cleavage development. The TPS intrusions are also faulted and contain rafts of argillaceous sedimentary rock. No regional ductile fabrics were observed to crosscut the intrusions. Five phases of intrusion have been recognized; these are 'raft' monzonite, feldspar porphyry (FP1), biotite monzonite, a second phase of feldspar porphyry (FP2), and a pyroxenite.

The most important feature at Brewery Creek is a linear zone of monzonite intrusions, faulting and mineralization termed the Reserve trend. This zone trends west-northwest and has a moderate dip to the south. A number of stages and orientations of faulting have been identified along the Reserve trend; lithological relationships suggest a substantial amount of vertical movement occurred post-TPS emplacement and pre- to syn-mineralization.

RÉSUMÉ

La mine d'or Brewery Creek (13,3 Mt titrant 1,44 g/t Au) est une exploitation de lixiviation en tas à fort tonnage qui est située à 57 km à l'est de la ville de Dawson (territoire du Yukon). Le gisement repose sur le côté nord-est de la faille de Tintina, dans le basin de Selwyn.

La minéralisation aurifère est présente dans les intrusions de la Suite plutonique de Tombstone (SPT) du Crétacé moyen ainsi que dans les roches métasédimentaires clastiques du Silurien au Carbonifère de la Formation de Steel et du Groupe d'Earn. Les roches sédimentaires sont déformées par des failles et des plis d'intensité variable, toutefois elles présentent une schistosité mal développée. Les intrusions de la SPT sont aussi affectées par des failles et contiennent des inclusions de roche sédimentaire argileuse. On n'a pas observé de fabrique ductile régionale recoupant les intrusions. On peut identifier cinq phases intrusives : monzonite «à inclusions», porphyre feldspathique (PFI), monzonite à biotite, une seconde phase de porphyre feldspathique (PFII) et une pyroxénite.

L'élément le plus important à Brewery Creek est une zone linéaire, connue sous le nom d'axe Reserve, qui semble contrôler l'emplacement d'intrusifs de monzonite, le dévelopment de failles et la minéralisation. Cette zone a une direction ouest-nord-ouest et un pendage modéré vers le sud. Les relations lithologiques de part et d'autre de cet axe indiquent qu'un déplacement vertical important a eu lieu après la mise en place de la SPT et avant ou en même temps que la minéralisation.

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INTRODUCTION

The Brewery Creek gold mine (13.3 Mt @ 1.44 g/t Au; Diment and Craig, 1999) is a bulk tonnage, heap leach operation located 57 km east of Dawson City, Yukon Territory, Canada (Fig. 1). The ownership and exploration history of the property has been documented by Diment and Craig (1999). The deposit lies on the northeastern side of the Tintina Fault, and within Selwyn Basin. To date, all mining has taken place along a linear structure known as the Reserve trend. This trend is a 500-700 m wide belt of monzonite intrusions and faults, along which 95% of the gold reserves at Brewery Creek are located. The Reserve trend extends for at least 12 km from west to east, contains a number of complex fault orientations and has an overall moderate southerly dip. Minor gold mineralization is found in skarn, sheeted veins and disseminated bodies outside the Reserve trend.

There are a number of open pits located along the Reserve trend. From west to east these include Blue, Canadian, Upper and Lower Fosters, Kokanee (K1 – K4), Golden (North and South), and Lucky. Access during this study was limited to Blue, Upper Fosters, K3, K4, Golden (North and South), and Lucky (Fig. 2).

The aims of this paper are to:

- document the intrusion emplacement history along the Reserve trend;
- describe the structural orientations which control the location of alteration and mineralization assemblages; and
- propose a preliminary geological history for the deposit.

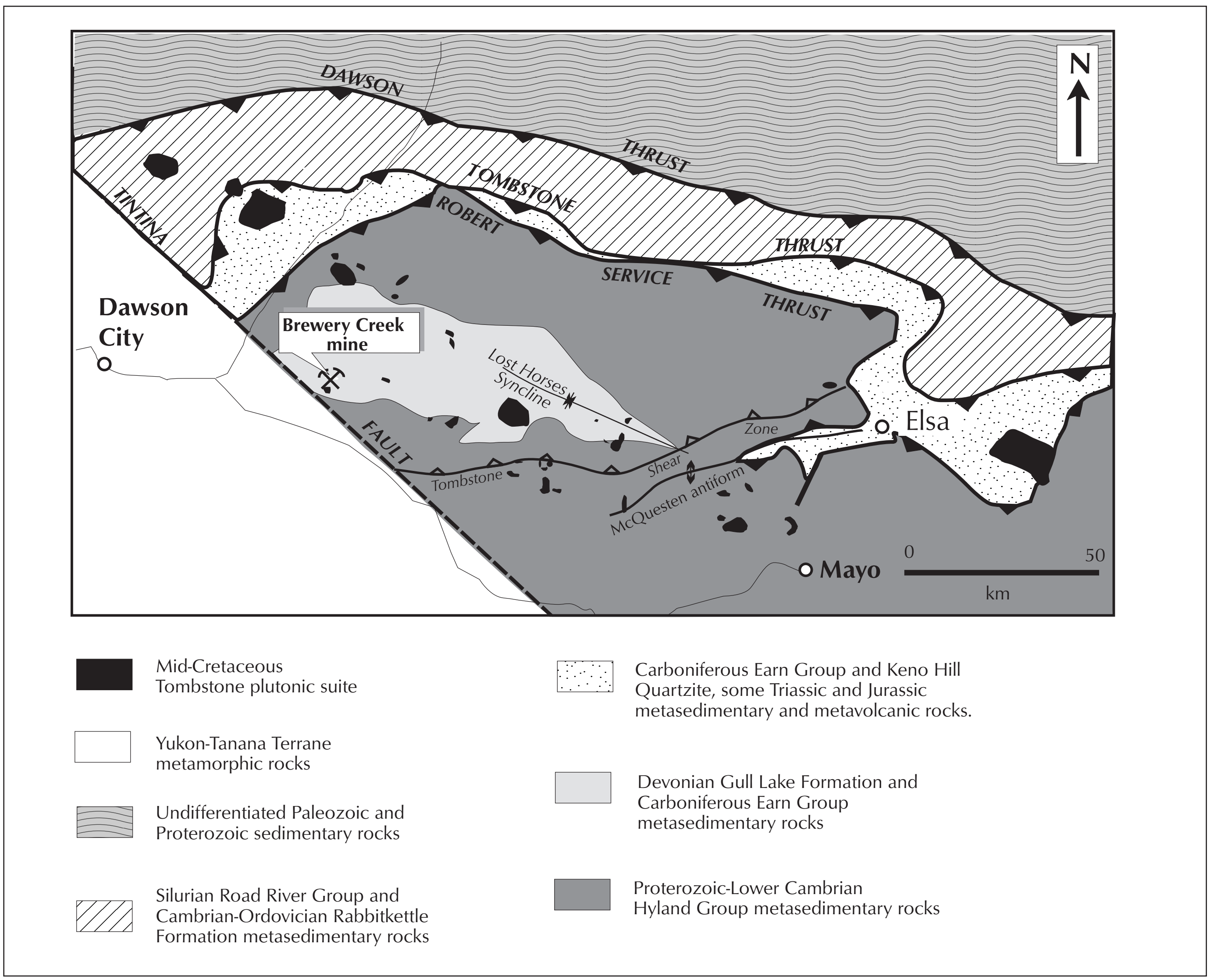


Figure 1. *A geological interpretation of the Selwyn Basin in the Dawson-Mayo area (modified from Murphy, 1997).*

REGIONAL GEOLOGY

The Brewery Creek deposit lies within Neoproterozoic to Carboniferous sedimentary rocks of the Selwyn Basin (Fig. 1). To the north and west this package is bound by the Dawson Thrust. To the south, the Tintina Fault juxtaposes sedimentary rocks of the Selwyn Basin against deformed and metamorphosed rocks of the Yukon-Tanana Terrane. Post-Cretaceous dextral movement along the Tintina Fault is interpreted to be as much as 450 km (Gabrielse and Yorath, 1991).

The structural history of the Selwyn Basin prior to the mid-Cretaceous in the McQuesten River region has been documented by Murphy (1997). A number of basin-scale features have been recognized (see Figure 1) including: (1) the Dawson Thrust, a major structure of uncertain age; (2) the Lost Horses syncline, which has been broadly bracketed between Devonian and mid-Cretaceous; (3) the Jura-Cretaceous Robert Service Thrust, which is crosscut by (4) the Tombstone high strain zone and the Tombstone Thrust, which are Jura-Cretaceous in age; and (5) the Jura-Cretaceous McQuesten antiform, which folds all of the structures listed above.

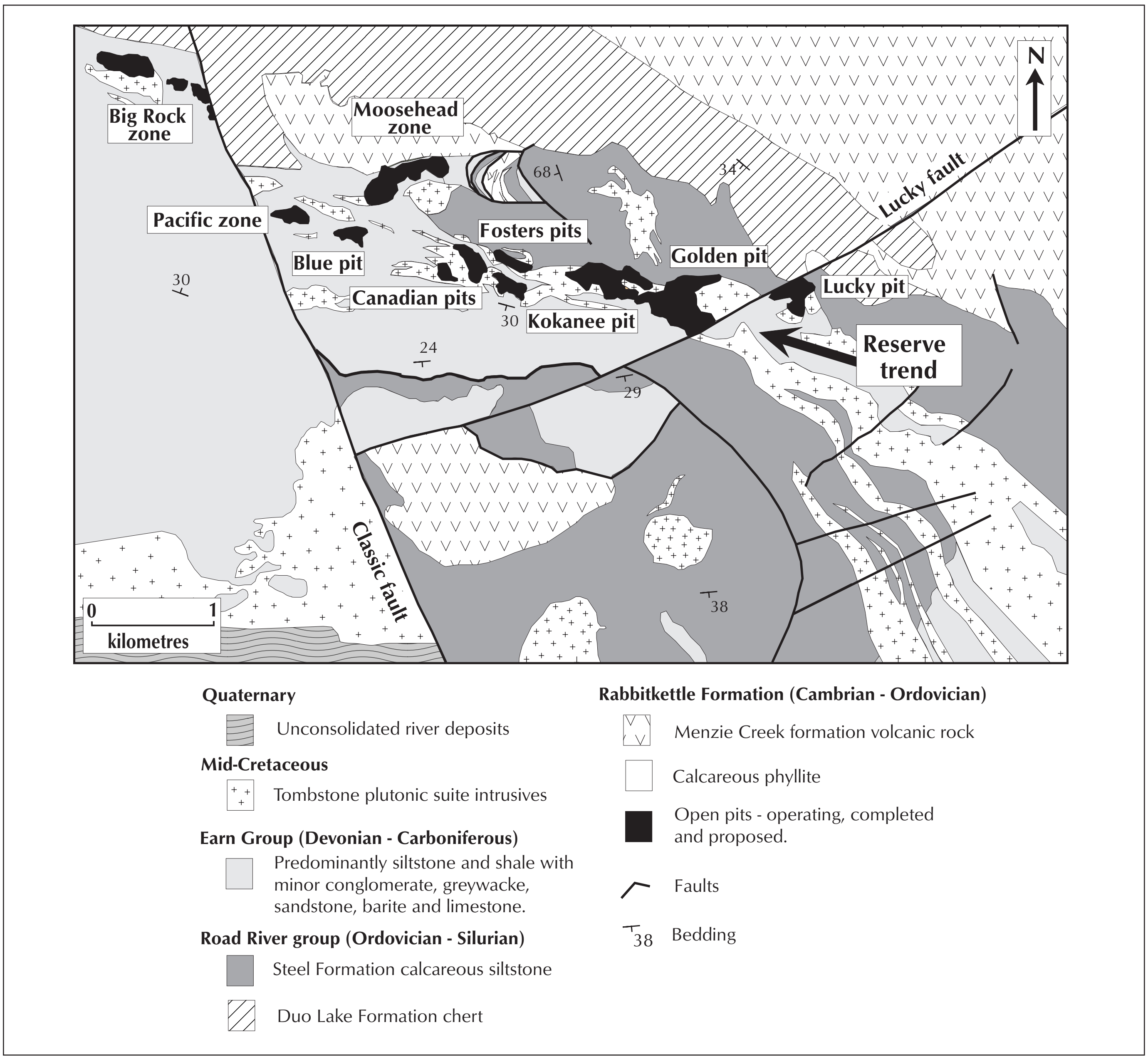


Figure 2. *A geological interpretation of the Brewery Creek property (adapted from an unpublished 1998 Viceroy Resources Ltd. company report). Note the orientation of the Reserve trend and the location of open pits along this trend.*

Mid-Cretaceous (90-95 Ma) magmatism produced a diverse suite of intrusions known as the Tombstone Plutonic Suite (TPS). TPS intrusions range from less abundant mafic phases (clinopyroxenite, gabbro, diorite) through to more common felsic end-members (granodiorite, granite; Mortensen et al., 1996).

The TPS is associated with a broad range of gold mineralization styles. These include quartz-sulphide veins, sheeted veins, stockwork, replacements and disseminated mineralization in felsic intrusive rocks, and in both carbonate and non-carbonate metasedimentary rock (Poulsen et al., 1997).

PROPERTY GEOLOGY

Previous workers (Diment and Craig, 1999; Diment, 1996; Bremner, 1993-1994) have recognized two major stratigraphic packages of sedimentary rocks at Brewery Creek. These have been correlated with the Silurian Steel Formation and the Carboniferous Earn Group of the Selwyn Basin (Fig. 2). Other comparatively minor stratigraphic units are the Carboniferous to Ordovician Rabbitkettle Formation, including the Menzie Creek formation, and the Ordovician to Silurian Duo Lake Formation.

A variety of distinct phases of intrusive rocks are present at Brewery Creek. These include quartz monzonite, monzonite, syenite and pyroxenite. A quartz monzonite sill has yielded a zircon age of 91.4 ± 0.2 Ma (Diment, 1996), indicating that the intrusions are part of the TPS. The most important intrusions are semi-conformable monzonite sills, which host approximately 80% of known mineralization. The monzonite sills have intruded along the broadly east-oriented Reserve trend.

The rocks at Brewery Creek have undergone a number of stages of deformation. Metre-scale folds are common, however cleavage development is poor. The axis of the regional-scale Lost Horses syncline trends toward Brewery Creek. To date, this structure has not been recognized on the property.

Brittle structures post-date all regional ductile deformation. Intrusive rocks were not observed to be affected by regional ductile fabrics, but they are crosscut by a number of stages of faulting. Notably, Brewery Creek is located close to the Tintina Fault. The orientation of the Reserve trend with respect to the Tintina Fault, combined with dextral offset along the fault, suggests that movement along the Tintina Fault would create a compressive regime at Brewery Creek. Some of the structures identified at Brewery Creek may be directly related to the Tintina Fault.

Gold mineralization is manifested in a wide variety of styles. These include, in order of abundance: (1) structurally controlled mineralization within intrusive rocks; (2) structurally controlled mineralization within non-carbonate sedimentary rocks; (3) decarbonization, brecciation and silicification of carbonate-rich sedimentary rocks; (4) sheeted veins within intrusions; and (5) tremolite skarn.

INTRUSIVE HOST ROCKS

The majority of known mineralization at Brewery Creek is hosted by monzonite sills, which have been emplaced along the Reserve trend and exposed in the Canadian, Fosters, Kokanee, Golden and Lucky pits. These sills occur as elongate intrusions and are only affected by the latest stages of faulting within this trend (see next section). The linear nature of the intrusions (Fig. 2) suggests that sill emplacement may have been partly controlled by structures comprising the Reserve trend. A variety of intrusive rocks have been recognized along this trend. These intrusions are described below and their relationships are summarized in Figure 3.

(1) Raft monzonite (RM). The RM is characterized by the presence of argillaceous metasedimentary (argillite) rafts as xenoliths within the intrusion (Fig. 4). The RM is variably fine- to medium-grained and locally equi-granular, porphyritic or mega-crystic. At outcrop-scale this intrusion is highly variable in composition and contains 5-30% biotite (with phenocrysts 1-3 mm long), 55-40% alkali feldspar, 40-30% plagioclase, minor quartz, and rare amphibole.

The contact between the RM and the host argillite is highly irregular. At the margins of the intrusion, the RM occurs as a number of bedding concordant sills, 2-5 m thick. Toward the centre of the Golden pit the intrusions thicken, are bedding discordant, and host rafts of argillite as xenoliths. The RM was observed to outcrop along the entire length of the Reserve trend. The absence of argillite rafts would hinder the distinction of the RM from the FP1 and BM described below.

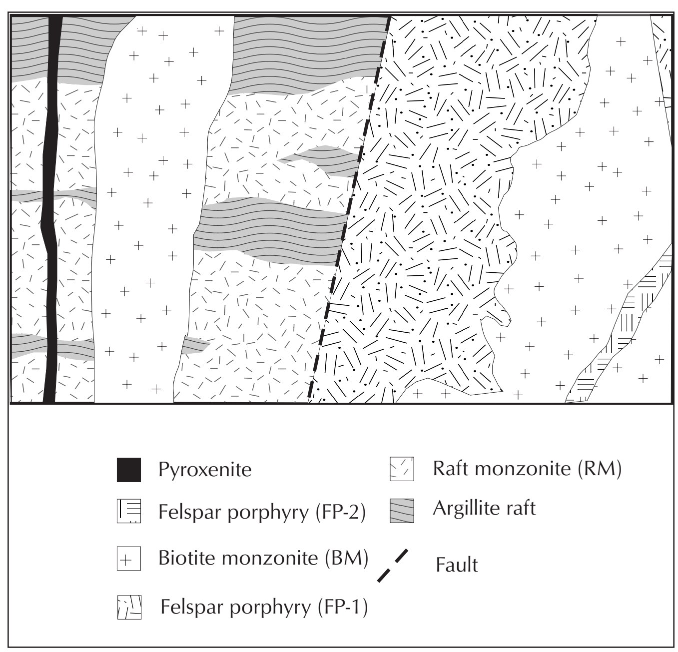


Figure 3. *A schematic cross-section illustrating the overprinting relationships of intrusive rocks identified along the Reserve trend.*

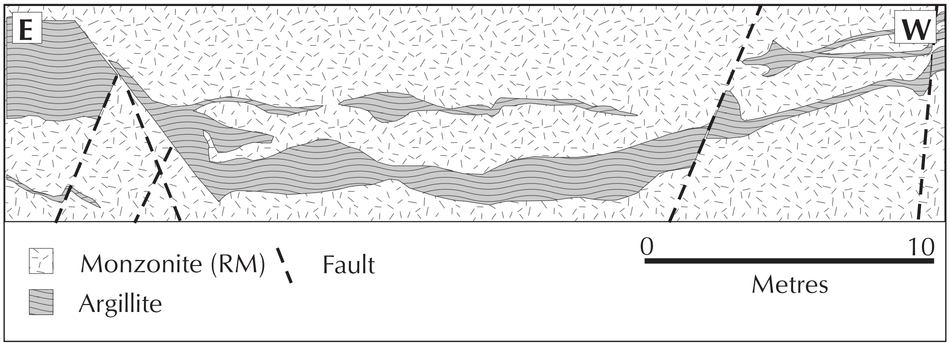


Figure 4. *A sketch of raft monzonite outcropping in the southern wall of south Golden pit (looking south). Note the highly irregular nature of the contacts between monzonite and argillite.*

(2) Feldspar porphyry (FP1). The FP1 intrusion is characterized by the absence of argillite rafts, similar amounts of alkali feldspar and plagioclase, and minor biotite. This fine-grained intrusion is generally porphyritic and is composed of 45% plagioclase, 45% alkali feldspar, 5-7% biotite, 2% quartz and rare hornblende. Feldspar phenocrysts vary between 1 and 5 mm in length. The relationship of FP1 to the RM is uncertain as the contacts between these two intrusions are faulted. This phase was observed to outcrop in the Golden and Kokanee (K3) pits.

(3) Biotite monzonite (BM). The BM is characterized by a high percentage of biotite relative to the other phases of intrusion and the absence of argillite rafts. The BM is a fine-grained and commonly porphyritic unit that contains 10-30% biotite (with phenocrysts 1-3 mm long), 40-50% plagioclase and 30-40% alkali feldspar (phenocrysts are generally 2-5 mm long, but may be up to 15 mm long). Minor quartz, rare hornblende and localized spherical, black xenoliths, containing up to 40% biotite were also noted. The BM intrudes FP1 in the Golden pit. The BM was also observed as a dyke that crosscuts the RM. This intrusion outcrops in Golden, Kokanee (K3, K4), and Blue pits.

(4) Feldspar porphyry dykes (FP2). The FP2 phase of intrusion is characterized by the presence of biotite and absence of quartz and hornblende. This unit is fine grained and porphyritic. The FP2 intrusion borders on a syenite/monzonite composition with 10-20% biotite (with phenocrysts 1-2 mm long), 55-60% alkali feldspar and 25-30% plagioclase (feldspar phenocrysts 1-4 mm long). FP2 is manifested as two dykes that crosscut the BM in the south Golden pit.

(5) Pyroxenite. One occurrence of pyroxenite dyke (30-50 cm wide) was observed in the Golden pit and crosscuts the RM. This intrusion is characterized by a composition of greater than 95% pyroxene. Minor biotite, plagioclase and rare quartz were also noted. The pyroxenite is generally fine grained with pyroxene crystals 1-3 mm long. Although younger than the RM, the relationship of this dyke to all other stages is uncertain. It is also uncertain if this intrusion can be correlated to the TPS or whether it represents an unrelated magmatic event.

DEFORMATION

The Brewery Creek property is dominated by the broadly east-oriented Reserve trend, which contains 95% of known mineralization. Diment (1996, 1999) suggested that this structure might represent a series of imbricate east to east-southeast-trending thrust faults. Analysis of brittle and ductile deformation along the Reserve trend has been undertaken. Shear zone asymmetries and lithological relationships in the Blue pit (Fig. 5) and in the Fosters pit (Fig. 6) suggest a

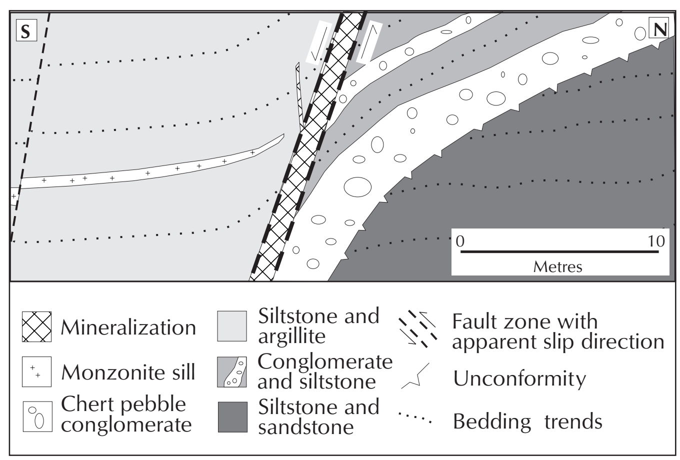


Figure 5. *A sketch of the western wall of Blue pit looking west. Three distinct packages of sedimentary rock were identified. The northern wall of Blue pit is comprised of siltstone interbedded with sandstone, which is unconformably overlain by chert pebble conglomerate interbedded with siltstone. These two units are faulted against siltstone interbedded with argillite and intruded by a number of monzonite sills; these units comprise the southern wall of the pit. Note that the sedimentary rocks, unconformity and intrusion are wrapped into the fault indicating an apparent normal movement. The siltstone, interbedded with argillite and monzonite sills, was not recognized in the northern wall of the pit indicating a minimum offset of 70 m (the height of the pit walls). Note also that a mineralized vein crosscuts this folding (vein not to scale).*

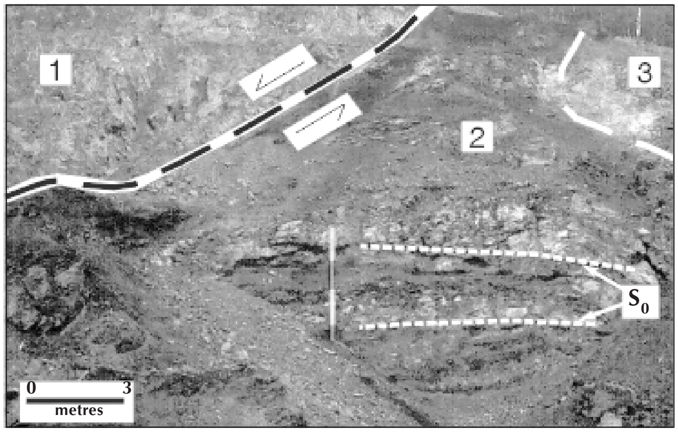


Figure 6. *A photo of a wall in Fosters pit (looking north). A monzonite (1) is faulted against Earn Group sedimentary rocks (2). Shear band asymmetries along the fault suggest normal movement. Drilling indicates that mineralization is restricted to the hanging wall intrusion (R. Diment, pers. comm., 1999). The intrusion (3) in the footwall of the fault is barren.*

substantial component of normal movement (minimum of 70 m). Horizontal slickensides on fault planes along the Reserve trend indicate a component of lateral movement, however the amount of offset is unknown.

To date, there has been no detailed description of the structural history of the Brewery Creek property. Initial fieldwork results indicate a number of phases of deformation, which are described below.

(1) Ductile deformation. Sedimentary rocks at the Brewery Creek property are variably folded, however, as a result of low metamorphic grade and low strain the rocks show poor cleavage development. Folds display wavelengths from centimetres to hundreds of metres and are commonly overturned. Complex geometries and tight folding are common, with the fold axial traces disrupted by late faulting and local refolding (Fig. 7). Intrusive rocks were not observed to be affected by any regional ductile fabrics.

(2) Early development of the Reserve trend. At Brewery Creek, the Reserve trend is typically developed along the contact between the Steel Formation and Earn Group (Fig. 2). The initial development of structures along the Reserve trend that strike west-northwest and dip moderately to the south is inferred as a mechanism for localizing TPS intrusions in a linear belt. The movement sense during the initial development of the Reserve trend is uncertain. The Reserve trend was not observed to be folded.

(3) Thrust faults. North- and west-vergent thrust faults explain observed relationships of Steel Formation overlying Earn Group, and Rabbitkettle Formation outcropping adjacent to Earn Group. The relationship of this thrusting to the early development of the Reserve trend is uncertain. Thrust faults crosscut regional ductile deformation fabrics and TPS intrusions truncate these thrust faults.

(4) Steep structures. Moderately dipping structures formed during the early development of the Reserve trend, and TPS intrusions trending parallel to these structures have been crosscut by steeply orientated, dominantly normal faults and shear zones (Fig. 8). The dominant orientations strike 110°, 150° and 260° with subordinate sets striking at 040-050° and 190°. There are a number of phases and orientations of faulting associated with this stage.

(5) Normal faults. The steep structures described above are truncated by normal faults (Fig. 6) that strike 095-105° and dip moderately to the south. Drilling indicates that the dip of these faults become shallow at depth (R. Diment, pers. comm., 1999).

(6) Lucky fault. The Lucky fault (Fig. 2) truncates alteration and mineralization assemblages that follow the orientation of the steep structures and the normal faults. The Lucky fault trends northeast and displays an apparent sinistral movement of one kilometre, however the dip is uncertain.

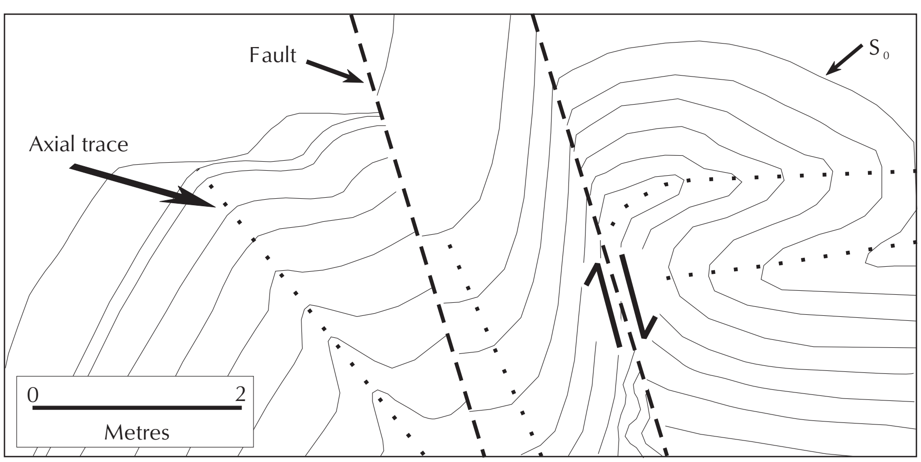


Figure 7. *A sketch of complex fold orientations in Earn Group sedimentary rocks in the northern wall of the Blue pit (looking north).*

(7) Classic fault. The Lucky fault and the Reserve trend are crosscut by the Classic fault (Fig. 2). The Classic fault strikes southeast and displays an apparent dextral movement of one and a half kilometres. Sub-vertical sheeted quartz-pyrite-gold veins trending parallel to this fault suggest a steep dip. Early movement on this structure may pre-date the thrust faulting and/or the steep structures.

STYLES OF GOLD MINERALIZATION ALONG THE RESERVE TREND

Gold mineralization along the Reserve trend is structurally controlled within intrusive and non-carbonate sedimentary rocks.

(1) STRUCTURALLY CONTROLLED MINERALIZATION WITHIN INTRUSIVE ROCKS

This style of mineralization occurs as: (1) pyrite-quartz-gold veins and associated disseminated pyrite and gold; (2) mineralized shear zones and faults; (3) breccia zones with a matrix of massive stibnite and minor quartz (± gold); and (4) sheeted stibnite-quartz (± gold) veins.

The stibnite-quartz (± gold) sheeted veins and the breccia zones may be contemporaneous, however their relationship with the pyrite-quartz-gold veins is uncertain.

At mine-scale, mineralization is hosted by monzonite sills that were emplaced along the Reserve trend. The mineralized zones stretch for more than 12 km along this trend. At outcrop-scale, mineralization is controlled by discrete fault zones that display

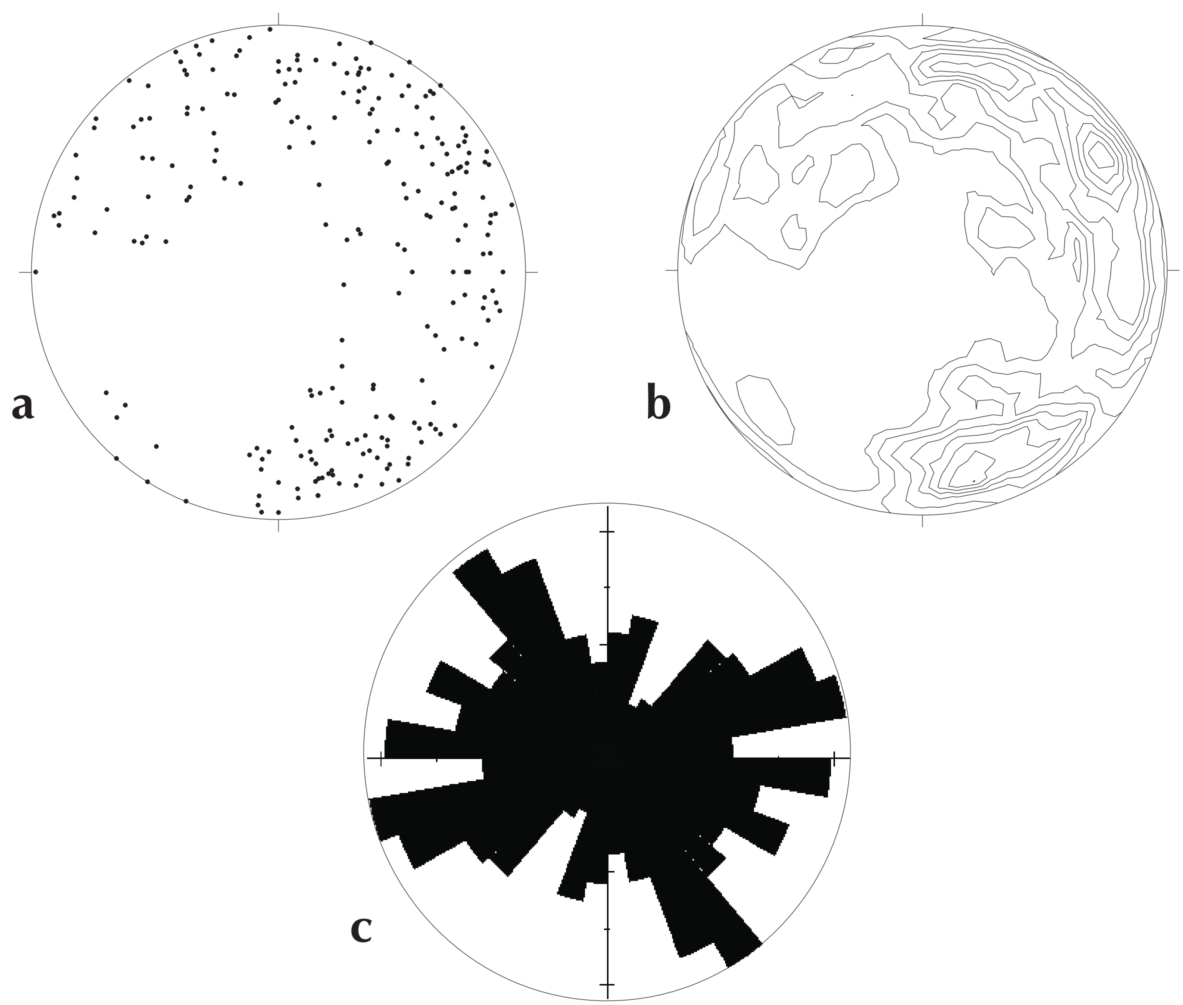


Figure 8. *Equal-area, lower hemisphere stereographic projections showing (a) poles of all fault planes measured along the Reserve trend, (b) a contour plot which illustrates three dominant poles to faults (oriented at 110°, 150° and 260°), and (c) a rose diagram of the strike of the measured fault planes.*

specific orientations (Fig. 8). The sheeted stibnite-quartz (± gold) veins and the individual pyrite-quartz-gold veins parallel these orientations.

In the Fosters pit, mineralization is restricted to the hanging wall of a normal fault. This fault juxtaposes a monzonite sill (hanging wall) against argillite (footwall; Fig. 6). A small monzonite intrusion, which is hosted by the footwall argillite, is barren (R. Diment, pers. comm., 1999). This relationship suggests that either the fault is directly related to mineralization (as a conduit), or that the fault postdates mineralization and potentially highlights a strong brittle structural control on mineralization.

(2) STRUCTURALLY CONTROLLED MINERALIZATION WITHIN NON-CARBONATE SEDIMENTARY ROCKS.

Mineralization within the Blue pit is manifested as disseminated gold in argillaceous sedimentary rocks. It is controlled by brittle structures and associated with strong argillic alteration, and breccias infilled with massive stibnite and sporadic gold. In the Blue pit, the main structural feature is the Reserve trend, which occurs as a discrete fault striking 060°, that dips moderately to the south. Bedding immediately adjacent to this structure has been folded into the fault and indicates normal movement. A vein displaying argillic alteration similar to the main ore zone was observed to crosscut this folding (Fig. 5).

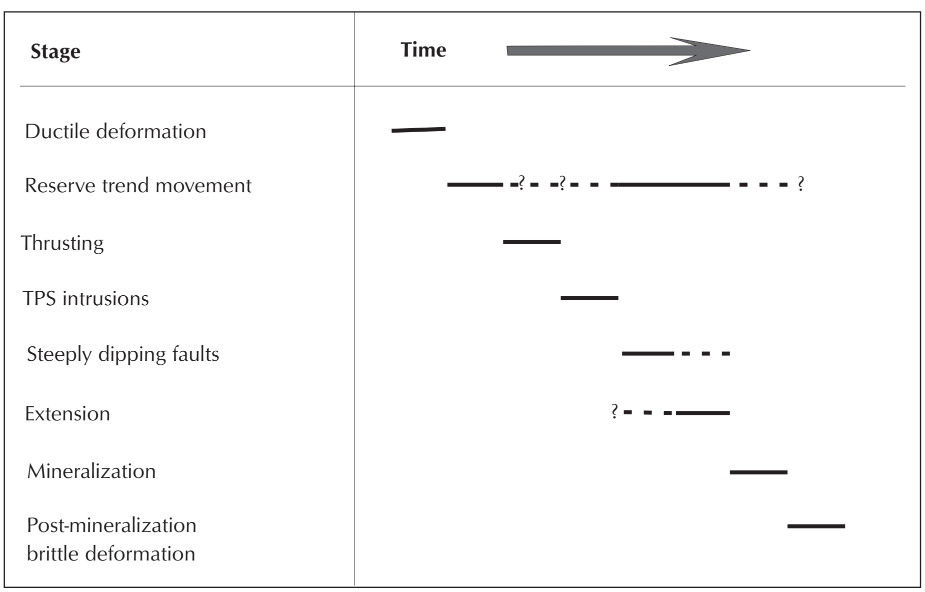
DISCUSSION

Initial fieldwork at Brewery Creek has revealed a number of important relationships from which a preliminary geological history has been established. A geological history for the Brewery Creek property is proposed below and summarized in Table 1.

Following Jura-Cretaceous regional ductile deformation, the first events recorded at Brewery Creek are the early development of structures that comprise the Reserve trend and major north- and west-vergent thrust faults. The relationship between the Reserve trend and thrusting is uncertain. It is possible that the initial development of the Reserve trend may have been triggered by the same compressive regime that generated the thrust faults. Subsequent movement along the Reserve trend may have continued through to the final stages of deformation, intrusion emplacement and gold mineralization (Table 1). Both the Reserve trend and the thrust faults truncate regional ductile fabrics.

The development of the Reserve trend provided a structural pathway for the emplacement of TPS intrusions. A variety of intrusive phases were identified along the Reserve trend and include (i) raft monzonite (RM), (ii) felspar porphyry (FP1), (iii) biotite monzonite (BM), (iv) feldspar porphyry (FP2), and (v)

Table 1. *A paragenetic chart displaying the interpreted geological history of the Reserve trend following Jura-Cretaceous deformation.*



pyroxenite. However, limited outcrop of the FP2 and pyroxenite makes their position in the geological history uncertain.

The RM, FP1 and BM are crosscut by a number of steep faults and shear zones. These steep structures appear to be bound at depth by normal (possibly extensional) 'flat bottomed' faults. It is unclear if the steep faults are truncated by normal faults or if the steep faults developed as a result of collapse during extension.

Gold mineralization is hosted by the steep structures and normal faults. A mineralized vein crosscuts bedding that has been rotated into the main structure in the Blue pit (Fig. 5). These relationships suggest that significant movement along the Reserve trend post-dates TPS emplacement and is pre- to syn-mineralization.

Post-mineralization brittle deformation resulted in the development of the sinistral Lucky fault (Fig. 2). Mineralization in Golden pit and Lucky pit is separated by this fault. The Lucky fault and the Reserve trend are crosscut by the Classic fault.

CONCLUSIONS

The following conclusions can be summarized from the geological history.

- The TPS intrusive history along the Reserve trend at Brewery Creek is complex. Five phases of intrusion have been recognized; these are raft monzonite, feldspar porphyry (FP1), biotite monzonite, a second phase of feldspar porphyry (FP2), and a pyroxenite.
- Mineralization at Brewery Creek is strongly controlled by brittle structures. The dominant structure is the Reserve trend, which has a long history of movement. This structure provided a pathway for the emplacement of TPS intrusions and for focussing gold-bearing fluids.
- Relationships in the Blue pit indicate that substantial movement along the Reserve trend has occurred post TPS emplacement, and pre- to syn-mineralization.

ACKNOWLEDGEMENTS

This paper presents some of the work undertaken as part of a Ph.D. thesis funded by the Yukon Geology Program, Viceroy Resources Ltd., the Economic Geology Research Unit at James Cook University, Townsville, Australia and the Mineral Deposits Research Unit at the University of British Columbia. Thanks are also expressed to all of the people at Brewery Creek who helped me in so many ways, especially Vivian Park, Beth Scott and Andrea Samuels.

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The Fer property: A plutonic-related gold property in southeastern Yukon

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Jones, M. and Caulfield, D., 2000. The Fer property: A plutonic-related gold property in southeastern Yukon. *In:* Yukon Exploration and Geology 1999, D.S. Emond and L.H. Weston (eds.), Exploration and Geological Services Division, Yukon, Indian and Northern Affairs Canada, p. 229-236.

ABSTRACT

The Fer gold property lies only 5 kilometres southwest of the Nahanni Range Road (Highway 10) in southeastern Yukon. It is underlain by a broadly folded sequence of coarse siliciclastic, calcareous and phyllitic, continental margin sedimentary rocks of the Neoproterozoic to Lower Cambrian Hyland Group. The extensive belt of Hyland Group rocks hosts gold mineralization in numerous occurrences from southeastern Yukon to the Dawson City area and is part of the Tintina gold belt.

The Fer property was originally staked in 1996 to cover the largest cluster of gold anomalies (>90th percentile for gold) in a regional fine-stream-sediment sampling program. Soil geochemistry on the property has outlined an area of about 2000 by 500 metres in the Southern Grid area with anomalous gold and arsenic values (>25 ppb Au, >125 ppm As). These values range up to 1870 ppb Au and 5430 ppm As. As well, a 500 by 200 metre Au-As anomaly is present in the Northeast Grid.

Mineralization is largely controlled by structure and host rock lithology, and is spatially associated with the most intense zones of silicification and quartz vein stockwork. Gold correlates best with As, Ag, Pb, and Sb. Values up to 2.3 g/t Au have been found in select rock samples in the mineralized areas. The Fer property mineralization likely represents a distal end-member of the plutonic-related gold deposits in the Tintina gold belt.

RÉSUMÉ

La propriété Fer, une propriété aurifère, est située à seulement 5 km au sud-ouest de la route Nahanni Range (route n^o 10), dans le sud-est du Yukon. Elle est sous-tendue par des roches sédimentaires de marge continentale du Groupe de Hyland, d'âge Protérozoïque supérieur à Cambrien inférieur, qui incluent des roches siliciclastiques à grain grossier, calcaires et phyllitiques, et qui sont déformées par des plis ouverts. Les roches du Groupe Hyland recouvrent une grande étendue et de nombreux indices aurifères depuis le sud-est du Yukon jusqu'à la région de la ville de Dawson, qui font partie de la ceinture aurifère de Tintina.

La propriété Fer a été jalonnée pour la première fois en 1996 de manière à couvrir le plus grand groupe d'anomalies aurifères (les anomalies >90^e percentile pour l'or) découvertes dans le cadre d'un programme d'échantillonnage des sédiments fins de ruisseau. Un levé géochimique d'échantillonnage du sol a permis de délimiter une zone d'environ 2 000 sur 500 m de la grille sud qui contient des teneurs anomales en or et en arsenic (>25 ppb d'Au, >125 ppm d'As). Les concentrations en métaux des échantillons atteignent 1 870 ppb d'Au et 5 430 ppm d'As. De plus on a mis à jour une anomalie en Au-As de 500 sur 200 m sur la grille nord-est.

La minéralisation est surtout contrôlée par la structure et la lithologie de la roche hôte et elle est spatialement associée aux zones de silicification et de stockwerk de veines de quartz les plus intenses. L'or présente de fortes corrélations avec les éléments suivants : As, Ag, Pb et Sb. On a obtenu des teneurs atteignant jusqu'à 2,3 g/t Au, dans des échantillons choisis provenant des zones minéralisées. La minéralisation de la propriété Fer représente un assemblage distal des gisements aurifères de la ceinture aurifère de Tintina.

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INTRODUCTION

The Fer gold property is situated in southeastern Yukon, 200 km north of Watson Lake, in the southeast end of the Tintina gold belt (Fig. 1). The property is located 5 km southwest of the Nahanni Range Road (Highway 10), which runs north from the Robert Campbell Highway in the Yukon, to the town of Tungsten, Northwest Territories, the location of the dormant Cantung mine.

The Tintina gold belt follows a trend of genetically related, mid-Cretaceous, felsic intrusions, which extend from east-central Alaska, across central Yukon. The gold deposits of the Tintina gold belt exhibit a wide variety in styles of mineralization, which largely reflects the depth of formation and location of the mineralization relative to the intrusions (Thompson et al., 1999). Intrusion-hosted deposits usually consist of sheeted veins and breccias, whereas distal deposits are normally skarn, disseminated replacement and vein styles. The sulphide content of these deposits is low, normally less than 3% overall, consisting primarily of pyrite-arsenopyrite. Tungsten and molybdenum mineralization, and generally bismuth content, increases with depth and proximity to the intrusions. More distal deposits are commonly dominated by arsenic (-antimony) and may have a base metal signature. Mineralization is associated with sericite, biotite, silica and carbonate alteration. Structure plays an important role, both providing conduits for fluids, and in ground preparation. Although country rocks exert no control on these deposits in a regional sense, lithological control plays a role in localizing mineralization through contrasts in competency and chemistry.

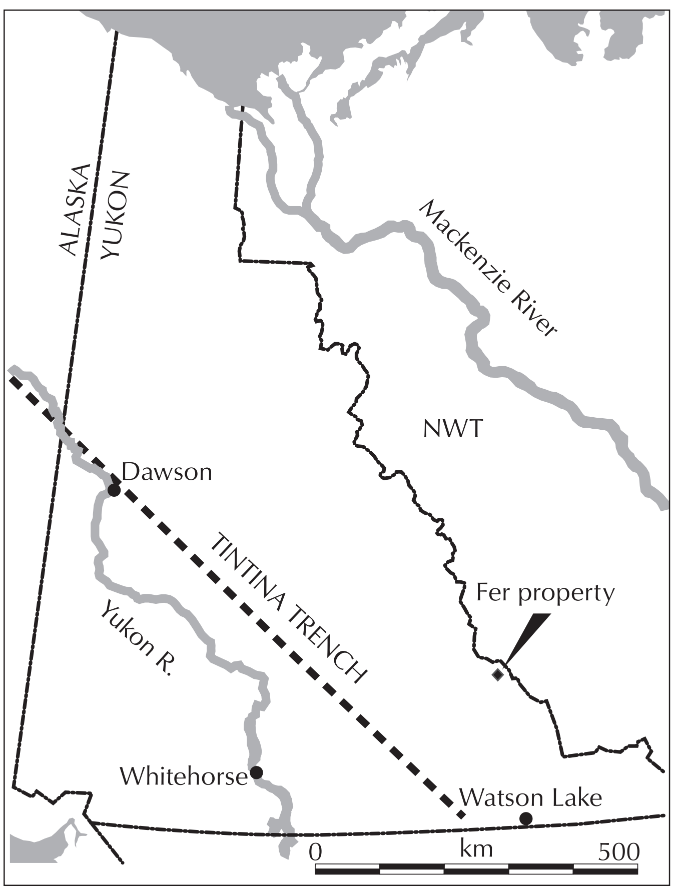

Figure 1. *Location of the Fer property, southeastern Yukon.*

PROPERTY EXPLORATION HISTORY

The Fer property was originally staked by Westmin Resources Limited in 1996, and was targeted in order to cover the strongest cluster of anomalous gold and arsenic results (>90th percentile) from a regional fine-sediment-sampling program conducted by Westmin in 1994. This survey was designed to test for distal (Telfer-style), sediment-hosted gold deposits in the Hyland Group sedimentary rocks, and covered approximately 7000 km^2, stretching from the B.C.-Yukon border to the headwaters of the Hyland River. There is no record of exploration work on the property prior to this program.

Westmin (now Boliden Westmin (Canada) Ltd.) did contour soil sampling, geological mapping (1:10 000; 1:5000) and rock sampling in 1996 (Jones, 1997) and 1997 (Gale and Terry, 1998). The results of this work indicated extensive areas of moderately to strongly anomalous results for gold and arsenic in soils on the south slope and in the east-central area, primarily associated with thick quartz-rich clastic sedimentary units. Work by Rimfire Minerals Corporation in 1998 (Jones, 1999) followed up the anomalous gold and arsenic values in soils on the South and Northeast grid areas by taking samples over significant widths as closely spaced as possible, to examine the potential for large tonnage, disseminated gold deposits. As well, minor detailed mapping of the anomalous zones was completed in conjunction with the sampling. Prospecting was carried out over the soil anomalies and beyond, to search for additional mineralization.

The area has been mapped by the Geological Survey of Canada (Roots et al., 1966), and covered by a stream-sediment sampling program sponsored by the federal government (Hornbrook and Friske, 1989). The government stream-sediment sampling identified the Fer property area as having highly anomalous arsenic and local anomalous gold values. As well, the claim group was covered by an airborne magnetic survey, also sponsored by the federal government (GSC, Aeromagnetic Series, 1961).

REGIONAL GEOLOGY

Figure 2 shows a compilation of geological, geophysical and metallogenic features of the upper Hyland River valley area, surrounding the Fer property. The area is underlain by siliciclastic and bioclastic, platformal or continental-margin sedimentary rocks of the Neoproterozoic to Lower Cambrian

Hyland Group (Fig. 2). Crosscutting the Hyland Group metasedimentary rocks are granitic, mid-Cretaceous intrusions of the Tay River and Tungsten suites. Two types of intrusions are distinguished based on their size and contact characteristics. The larger batholiths (Tay River suite), to the south and southwest of the Fer property, have ill-defined boundaries consisting of mixed intrusive, migmatitic and gneissic rocks. The smaller intrusions (Tungsten and Tay River (?) suites) have sharp contacts and pronounced metamorphic aureoles characterized by gossans (after pyrite, or biotite?). An elongate example of this type of intrusion occurs just south of the Hyland River, about 5 km south of the Fer property.

Generally, bedding and axial planes trend northwest, turning westerly, west of the Fer property, with moderate to steep dips. Shallowly plunging fold axes also follow this overall trend. North-trending, linear valleys are common in this area, indicating the presence of significant faults (also interpreted from the regional magnetic patterns). The Hyland River and Little Hyland Rivers, just to the northeast, occupy large, linear, northwest-trending valleys, which may represent major strike-slip or thrust faults.

REGIONAL GEOPHYSICS

The regional airborne magnetic patterns (Fig. 2, only available for NTS 105H) show different responses for the two types of intrusions in the upper Hyland River area. There is a relatively strong positive response recorded over the large batholiths well to the south and west of the Fer property. However, several intrusions, closer to the Fer property, have a flat to weakly negative response. This includes the elongate intrusion 3-4 km south, as well as a group of small intrusions 10-15 km east-southeast of the Fer property, which lie within the Tungsten Suite intrusions. These Tungsten Suite intrusions are outlined by a 100 gamma magnetic low in this area. A similar, slightly deeper, magnetic low lies over the Fer property, within a southeast-trending low which extends northwest (to the edge of magnetic coverage) from the confluence of the Hyland and Little Hyland rivers. This magnetic feature is not restricted to any particular sedimentary unit. Distinct magnetic high "shoulders" are present on the northeast and southwest sides of the magnetic low, with the greatest contrast situated adjacent to the Fer property. The trend of the magnetic low could represent the axis of a series of buried intrusions or structurally controlled hydrothermal activity.

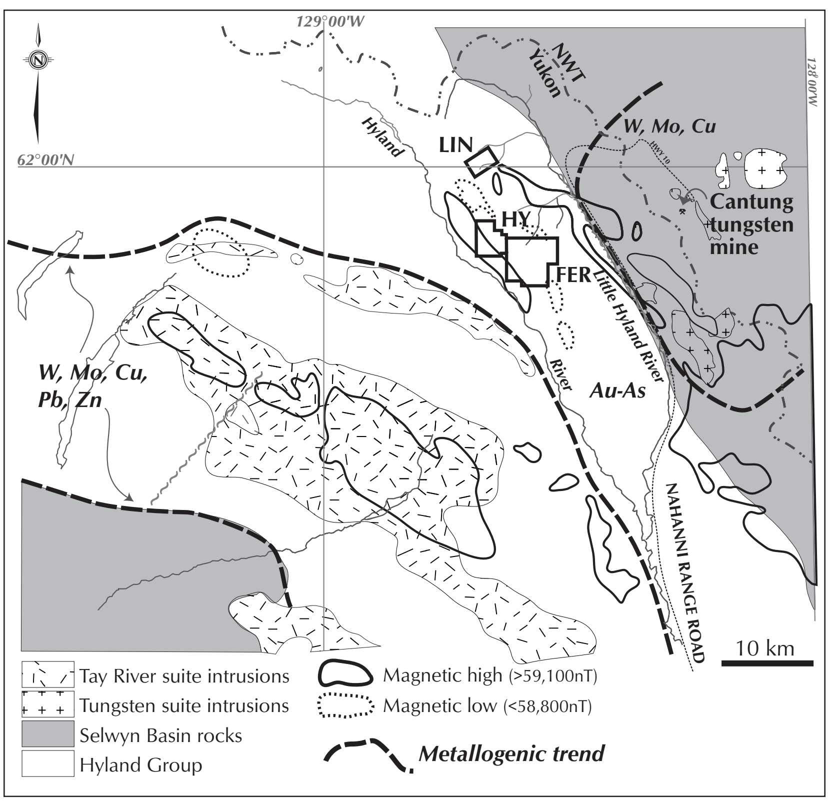

Figure 2. *Compilation map of regional geological, geophysical and metallogenic features of the Upper Hyland River area.*

REGIONAL METALLOGENY

Three distinct provinces are apparent in the regional metal distribution in the upper Hyland River area (Fig. 2). The mineral occurrence maps for this area (105H, I; Yukon Minfile, 1997) indicate a concentration of tungsten-molybdenum mineralization, as skarn, porphyry, and veins, coincident with the distribution of intrusions (both Tay River and Tungsten suites) to the northeast and to the southwest of the Fer property. As well, there is a distinct southeast gold-arsenic trend bisecting these two areas, defined by stream geochemistry and known showings, following the magnetic low which lies over the Fer property. This gold-arsenic trend is the focus of recent exploration activity in this region.

Recent exploration work in the area has turned up numerous showings. Work on Phelps Dodge's Hy Property, immediately west of the Fer claims, has uncovered several high-grade gold-bearing grab samples (Burke, 1999). Mineralization is similar in character to that found on the Fer property with disseminated to clotty arsenopyrite, pyrite and galena in quartz veins and breccias, and is related to northwest- to north-northwest-trending structures crosscutting lithologic units. Two mineralized structures have been discovered to date with gold values up to 144.2 g/t and 9.9 g/t, respectively, found in select quartzite-quartz vein material. Other companies active in the area include Viceroy Resources Ltd. (Burke, 1998) and Hudson Bay Exploration and Development Ltd. In 1999, Hudson Bay completed a diamond-drilling program on the Hit Claims, southeast of the Fer property.

Rocks of the Hyland Group host the Hyland Gold occurrence (Bremner and Ouellette, 1990), about 150 km to the south-southeast. This sediment-hosted gold deposit has been reported to have inferred oxide reserves totalling 6.75 Mt at a grade of just under 2.0 g/t Au based on sampling in surface trenches. Alteration and mineralization are controlled by north-trending structures, cutting through relatively flat-lying, Hyland Group phyllite, quartzite and grit units. There are no intrusions mapped in the area.

The Cantung deposit, located at Tungsten in the Northwest Territories is a high-grade tungsten skarn deposit (9 Mt at 1.42% WO_3). The deposit is related to a Tungsten suite intrusion, which intrudes carbonate-rich rocks of the Selwyn Basin.

PROPERTY GEOLOGY

The Fer property is underlain by a section of Hyland Group units consisting of quartzite, arkosic grit and quartz pebble conglomerates, interbedded with phyllite and much lesser limestone (Fig. 3). The quartz-rich units are primarily calcareous in the northeast corner of the property, but are devoid of calcite southwest of this area. In general, the quartz-rich units are thicker in the southwest area, ranging up to a couple hundred metres in thickness with minor interbedded phyllite. Whereas the stratigraphy in the northeast corner of the property forms a relatively homoclinal sequence, the structure of the rest of the property is more complex. The southwest area is dominated by an apparent broad synform, which traverses the area in a southeast direction, plunging shallowly to the southeast. Minor folds and crosscutting faults also complicate the geology in this area. North-northeast-, northwest- and east-trending faults are quite common and these structures are mostly associated with intense alteration and mineralization.

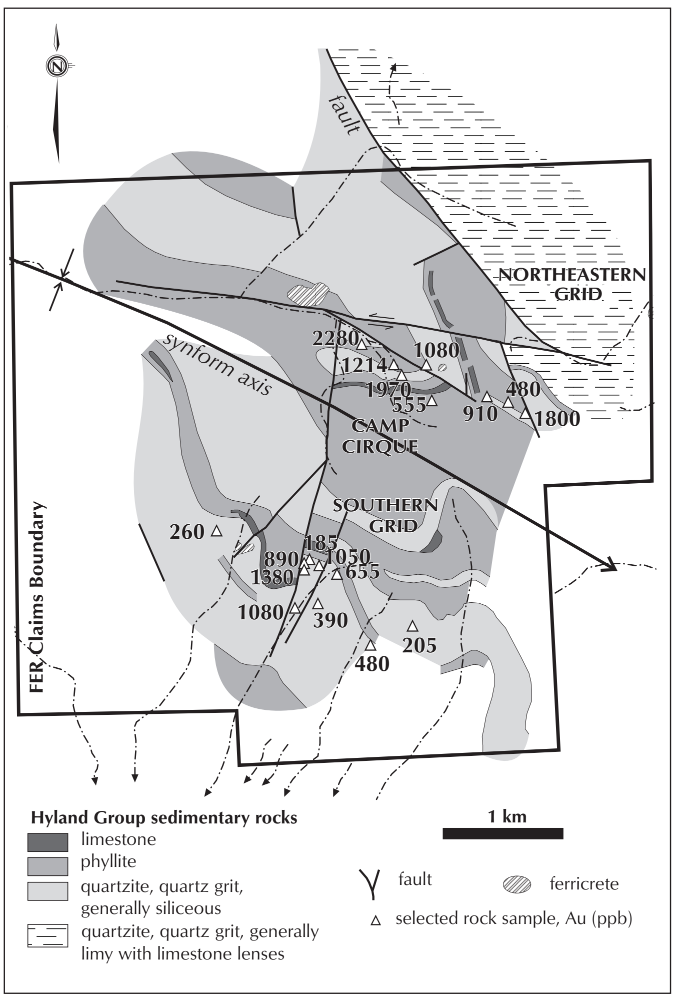

Figure 3. *Simplified geology and selected rock geochemistry for the Fer property.*

ALTERATION AND MINERALIZATION

Quartz veining and stockwork are the most common characteristics of the mineralized areas, in particular, the quartz-rich units (Jones, 1997). The veins are generally of two types: 'older,' deformed veins which are ubiquitous and generally not mineralized, and 'later,' stockwork to wide-spaced vein systems, which are commonly spatially associated with disseminated auriferous mineralization and zones of pervasive silicification. These stockwork and vein occurrences commonly form silica-rich zones with strike lengths up to 300 m, thicknesses of several metres, and a dominant strike of about 110°, with near vertical dips. As well, pervasive silicification and widespread stockwork is commonly concentrated in quartz-rich units adjacent to the phyllite contact, which may have acted as an impervious barrier to hydrothermal fluids. Several of these silicified zones can be found on the property, particularly in the Southern Grid area, where silica alteration and quartz veining occur in patchy zones over at least 2 km of strike. Similar intense veining occurs in the Camp Cirque area and on the Northeast grid. An example of structural control on mineralization is observed in the Northeast grid area, where disseminated and vein-hosted mineralization is found associated with a fold nose adjacent to a north-northeast-trending fault.

Sulphide mineralization is widespread on the Fer property, but normally at low concentrations. Pyrite, and much lesser arsenopyrite are disseminated and occur as blebs in altered host rocks. Locally, they are concentrated to 10-15% of the rock as poddy or lensy occurrences, but generally form less than 1-2% of the rock. Both sulphides also occur in quartz veins, as large blebs, fracture coatings and disseminated as fine grains. Galena was noted in quartz veins and less commonly disseminated in the host rocks, particularly in the Camp Cirque area. Generally, the sulphides are more commonly peripheral to the zones of quartz stockwork and silicification. Boxwork after sulphides is common, indicating that the overall sulphide content of the rocks prior to weathering was somewhat higher than observed on surface. Although weathering of these sulphides has created extensive gossans and ferricrete throughout the property, some zones of typical pyrite-arsenopyrite mineralization do not have any significant gossan associated with them, such as the mineralized zones on the Northeast grid. As a result, mineralization in the Northeast grid area was only recognized after anomalous soil sample results were identified.

The rock sampling on the Fer property (314 samples) generally shows anomalous gold values associated with sulphide mineralization. Gold values to date are generally less than a few hundred parts per billion, although a high percentage of these samples are representative grab samples over large widths. Higher grade samples, which ranged up to 2.28 g/t Au and greater than 1% arsenic, tend to be select samples of more visible or sulphide-rich mineralization. Elements showing correlation with gold include arsenic (r^2=0.51), silver (r^2=0.38) and antimony (r^2=0.53; Jones, 1999)

SOIL GEOCHEMISTRY

A total of 1748 soil samples have been taken to date on the Fer property. Statistical analysis of the results from all samples shows that gold has a significant correlation with arsenic (r^2=0.49), silver (r^2=0.51) and lead (r^2=0.42). Significantly, bismuth is rarely found in concentrations above 2 ppm in soils. The distribution of gold and arsenic are plotted on Figures 4 and 5. Statistics are summarized in Table 1.

In the Southern Grid area, soil sampling has delineated an extensive anomaly, defined by the 85th percentile for gold, and stretching about 2 km along the exposure of a thick, shallowly dipping quartz-rich, clastic unit (Fig. 4). The anomaly pinches and swells along this unit, generally thickening in proximity to major crossing faults (north-northwest to north-northeast). Anomalous results are generally associated with quartz stockwork and silicification within the quartz-rich unit, in particular near the upper contact of the unit with a phyllite-limestone unit. Gold values within this anomaly range up to 1870 ppb, including three consecutive samples, spread out over 60 m, which average 1590 ppb Au. Arsenic values are similarly elevated ranging up to 5430 ppm. The Southern Grid covers several areas of heavy talus, which may have muted results, and this possibility should be considered

Table 1. *Soil geochemical thresholds for all soil samples, Fer property.*

Percentile	Au (ppb)	Ag (g/t)	As (ppm)	Pb (ppm)
50th	-	-	64	28
70th	10	-	126	38
85th	25	0.2	230	50
95th	85	0.4	504	74
98th	166	0.6	787	104

Note: All values below detection shown as negative detection limit.

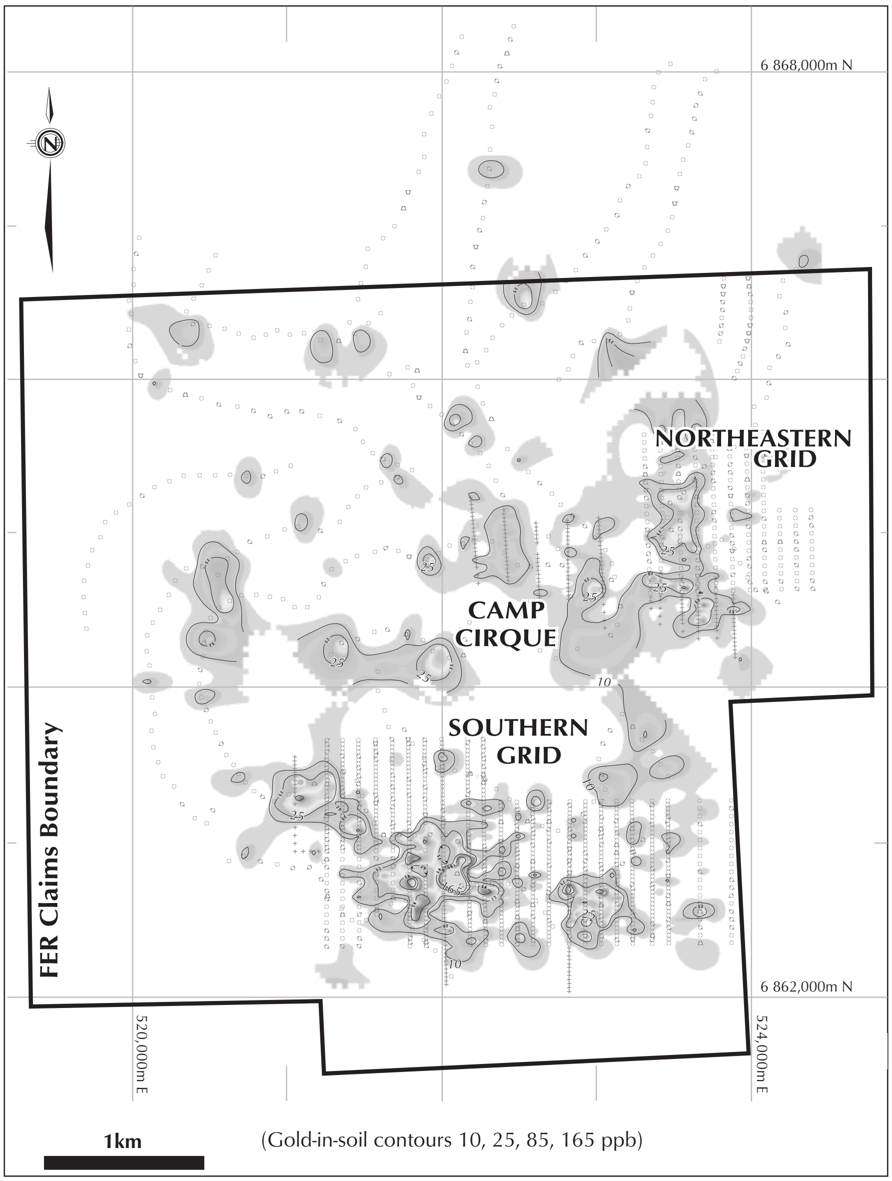

Figure 4. *Contoured gold-in-soil geochemistry of the Fer property. Shading indicates more detailed gradations in gold values.*

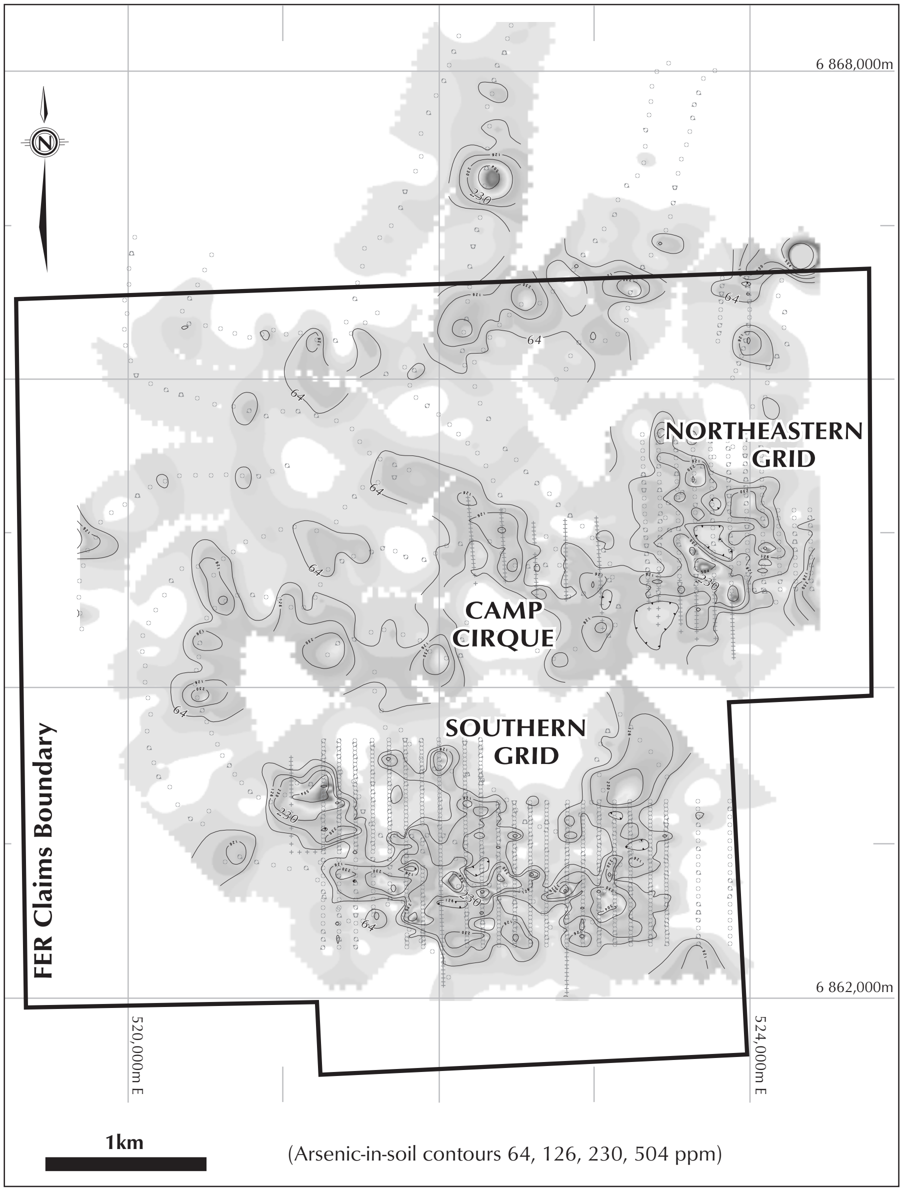

Figure 5. *Contoured arsenic-in-soil geochemistry for the Fer property. Shading indicates more detailed gradations in arsenic values.*

when evaluating the continuity of the Southern Grid anomaly. As well, the talus may be concealing the source of the anomaly, which has not been detected by the rock sampling done to date.

Sampling has delineated an approximately 500 m by 200 m, moderate gold-in-soil anomaly in the southwest part of the Northeast grid. This corresponds to mineralization in several quartz-rich sedimentary units which cut through the grid area, located primarily south of a major east-trending fault (Fig. 3). Sampling on grid lines in the Camp Cirque area, to the west of the Northeast grid and south of the major fault, detected spotty anomalous results, despite the talus and valley fill which covers a large portion of this part of the grid. These results could indicate a continuation of mineralization into this area.

EXPLORATION MODEL

The Fer property hosts a distinct style of gold mineralization within the spectrum of intrusion-related, gold-lithophile deposits found throughout the Tintina gold belt. The belt includes intrusion-hosted deposits, such as the Fort Knox deposit (200 million grams; 7 million oz. Au), high temperature (deep) vein-hosted deposits, such as Pogo (160 million grams; 5.2 million oz. Au), and disseminated and fracture-controlled deposits peripheral to intrusions, such as True North (40 million grams; 1.3 million oz. Au) among others. The variations in style of mineralization seen in the Tintina gold belt generally reflect the relative depths of formation and proximity to intrusions. The Fer property is quite distal to the nearest visible intrusion, an elongate, magnetically subdued, mid-Cretaceous granite pluton 4 km southwest of the property. Indicators of the distal nature of the mineralization at the Fer property include the lack of intrusive rocks or significant hornfels, and a metal signature dominated by As-Pb-Sb with low Bi. Distal mineralization (i.e., 2-6 km from intrusion) has not yet been well described in the Tintina gold belt. One possible analogue for this style of mineralization could be the distal, plutonic-related gold mineralization at the Telfer deposit in Western Australia.

The Telfer deposit (340 million grams; 11 million oz. Au) is a sediment-hosted, gold-lithophile element deposit (Rowins et al., 1998). It formed from circulating mineralizing fluids, driven by a distal intrusive heat source (1-6 km), which were focussed along structural conduits. Mineralization at Telfer consists of extensive replacement by sulphides of a 1- to 3-m-thick, chemically and structurally receptive stratigraphic unit, the Middle Vale Reef. The reef is continuous over 3 km of strike along the axial plane of the Telfer Dome anticline and up to 1 km down-dip along the limbs of the anticline. There are several such mineralized zones, stacked within, and focussed on the axial plane of the Telfer Dome, which acted as a fluid conduit (Fig. 6).

Mineralization at the Fer property exhibits both structural and lithological controls, similar to the Telfer deposit and other non-intrusion-hosted Tintina gold belt deposits. The majority of mineralized rocks are at least spatially associated with faults. In addition, silicification, quartz veining and stockwork commonly show a linear, planar morphology, crosscutting bedding. The predominant orientation for these alteration zones is similar to the inferred orientation of the axial plane of a broad synform present on the property. Quartz-rich lithologies are the dominant, though not exclusive hosts for significant alteration and mineralization. Strong fracturing in these silicic rocks, as a result of faulting and folding, creates permeability for extensive hydrothermal fluid-rock interaction. As well, these rocks may have been chemically reactive hosts. The lack of significant interstitial calcite in the rocks hosting mineralization may be a result of decalcification, with subsequent healing and replacement by silica and sulphides. This could explain the predominant occurrence of sulphides (pyrite and arsenopyrite) as pervasive disseminations, blebs and pods associated with well-healed, quartz-rich siliciclastic rocks.

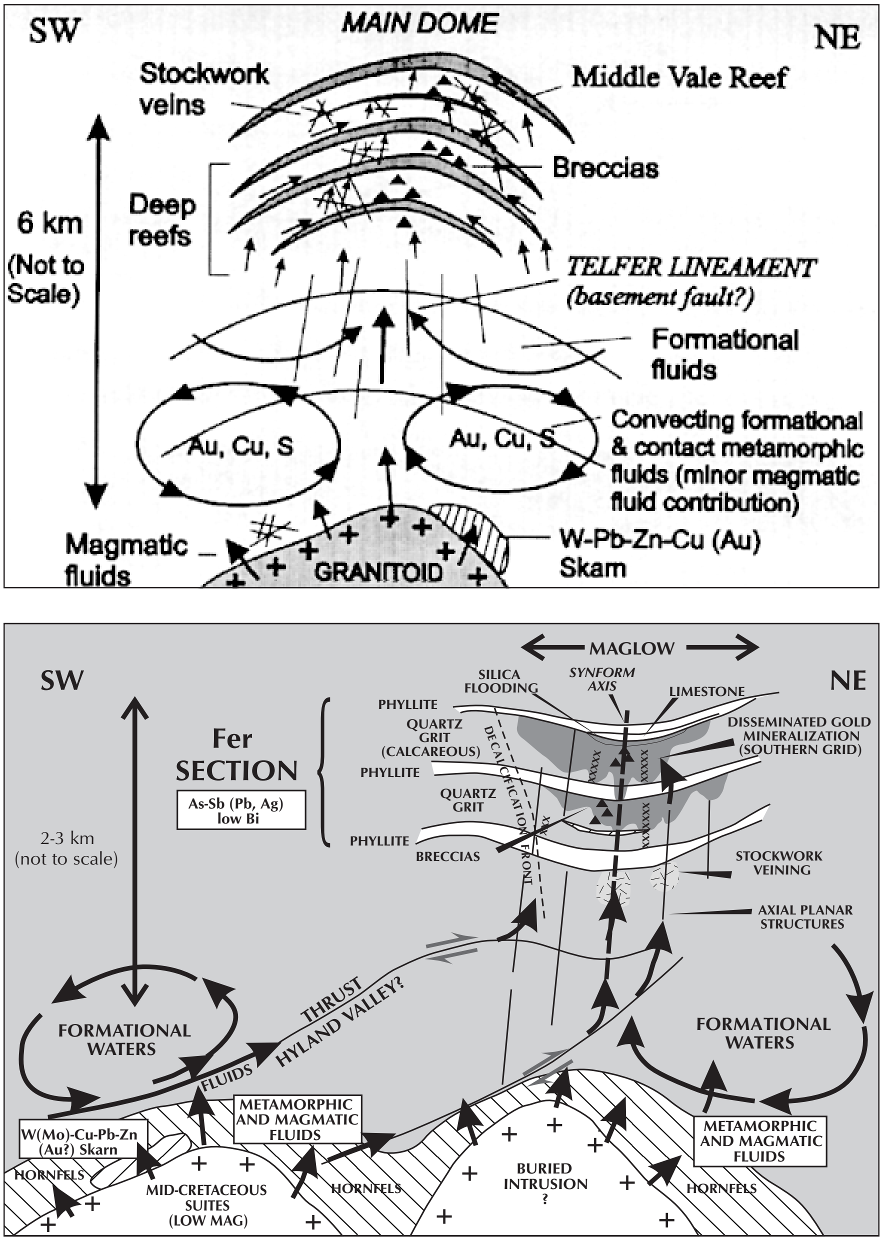

Figure 6. *Top: Schematic cross-section of the Telfer mineralization model (Rowins, et al., 1997). Bottom: Speculative model for formation of mineralization at the Fer property. Fluids emanating from mid-Cretaceous plutons (metal source?) follow regional scale structures, mixing with formational waters (sulphur source?), and eventually entering local structures (axial planar?). At the local scale, reaction with interstitial carbonate and boiling lead to silicification and mineralization.*

Figure 6 shows the genetic model for the Telfer deposit developed by Rowins, et al. (1997), and a derivative model for the formation of mineralization at the Fer property. For the Fer model, it is envisaged that fluids related to felsic intrusions of intermediate oxidation state (W (Mo)-Cu-Au signature) are channelled along structural conduits such as reactivated major lineaments or regional scale thrust faults (Hyland River valley?). As they rise, these fluids find their way into secondary structures, such as the axial planar cleavage of the synform at the Fer property. At some distance from the intrusion, the fluids deposit dissolved metals as a result of interplay between various factors, primarily reactions with interstitial carbonate in the fractured, quartz-rich clastic rocks (resulting in decalcification), and fluid cooling and boiling (resulting in silicification and quartz vein formation). The locally pervasive nature of alteration and mineralization in wall rocks suggests that the volume of hydrothermal fluid may have been higher than typical deposits of the Tintina gold belt, perhaps indicating mixing with formational waters as these fluids ascended.

The broad soil geochemical anomalies associated with the mineralization and the regional magnetic low on the Fer property record hydrothermal alteration of a large volume of rock. This is corroborated by rock sampling, which has detected widespread gold mineralization, though values to date have been generally low. The potential for narrow, higher grade, Telfer-style, stratabound mineralization is exhibited by the combined structural and lithological controls on mineralization present on the Fer property.

ACKNOWLEDGEMENTS

The authors wish to acknowledge the cooperation of Boliden Westmin (Canada) Ltd. in the preparation of this paper.

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Geology, geochemistry, and lead isotopic analysis of mineralization of the Strike property, Campbell Range, southeastern Yukon

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Mann, R.K. and Mortensen, J.K., 2000. Geology, geochemistry, and lead isotopic analysis of mineralization of the Strike property, Campbell Range, southeastern Yukon. *In:* Yukon Exploration and Geology 1999, D.S. Emond and L.H. Weston (eds.), Exploration and Geological Services Division, Yukon, Indian and Northern Affairs Canada, p. 237-245.

ABSTRACT

The Strike property is located in the Campbell Range belt in southeastern Yukon. The study area is underlain by a wide variety of mafic volcanic and volcaniclastic rocks, as well as altered mafic intrusions and cherty metasedimentary rocks. Together these rock units are interpreted to comprise several discrete, relatively flat-lying and highly faulted lithologic assemblages. Lithogeochemical analyses of metavolcanic rocks that host mineralization on the property concluded that they are moderately enriched mid-ocean ridge basalts (E-MORB) to normal basalts (N-MORB) that likely formed in an ocean basin and/or back-arc/marginal basin setting. Diamond drilling intersected minor syngenetic, massive pyrite-chalcopyrite mineralization associated with hematitic chert/exhalite, as well as quartz-pyrite-chalcopyrite veining in a rubbly fault zone. Lead isotopic compositions of the mineralization are consistent with it being syngenetic Cyprus-type volcanogenic (VMS) mineralization. The results of the study highlight the potential for more Cyprus-type VMS mineralization in the Campbell Range in addition to the previously discovered Ice deposit and Money occurrence.

RÉSUMÉ

La propriété Strike est située dans la ceinture de Campbell Range dans le sud-est du Yukon. La région à l'étude est sous-tendue par une grande variété de roches volcaniques et volcanoclastiques mafiques, de même que par des intrusions mafiques altérées et des roches métasédimentaires cherteuses. On interprète cet ensemble d'unités rocheuses comme représentant plusieurs assemblages lithologiques distincts, relativement horizontaux et fortement faillés. L'analyse lithogéochimique des roches métavolcaniques qui contiennent la minéralisation sur la propriété mène à la conclusion que ce sont des basaltes modérément enrichis (de type E-MORB) à normaux (de type N-MORB), qui ont probablement été formés dans un environnement de bassin océanique et/ou un environnement d'arrière-arc ou de bassin marginal. Des forages au diamant ont intersecté de petites quantités de minéralisation massive de pyrite-chalcopyrite syngénétique associées avec un chert/exhalite hématisé ainsi que des veines de quartz-pyrite-chalcopyrite dans une zone de faille non consolidée. Les rapports isotopiques du plomb de la minéralisation correspondent à ceux d'une minéralisation en sulfures massifs volcanogènes syngénétiques de type Chypre (Cu-Zn). Les résultats de cette étude indiquent qu'il y a potentiellement d'autres minéralisations en sulfures massifs volcanogènes de type Chypre dans la ceinture de Campbell Range, en plus du gisement Ice et de l'indice Money déjà mis à jour.

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INTRODUCTION

The Strike property is located in the Campbell Range belt (CRB) in southeastern Yukon. The study area is underlain by several metabasalt units with intercalated metachert, and is intruded by a leucogabbro body. The presence of a brecciated and sheared serpentinite unit suggests significant faulting in the area. The volcanic package has been interpreted to be part of the Slide Mountain Terrane (SMT) by Plint and Gordon (1997), but this is still under debate. Alternatively it may represent a stratigraphically higher unit of the Yukon-Tanana Terrane (YTT; Murphy, 1999).

The study area is centred on the Strike property (Fig. 1), which was the focus of base metal exploration in 1998 by Cominco Exploration Ltd. The 1998 work followed up on previously identified gossanous zones with strong associated Cu soil anomalies. The area is believed to be broadly on strike with mafic-volcanic-hosted volcanogenic massive sulphide (VMS) mineralization on Expatriate Resources' Ice property 80 km to the northwest, and possibly with the Money occurrence to the south (Fig. 1).

This contribution is based on 1:5000 scale mapping conducted in the study area in 1998 by the senior author and P.A. MacRobbie of Cominco Exploration Ltd. Geochemical, petrographic and Pb isotopic studies were also undertaken, and are discussed in this paper. A total of seven samples were analyzed for major, trace and rare earth element (REE) geochemistry. Four samples of pyrite/chalcopyrite mineralization were analyzed for trace Pb isotopic compositions. Sixteen thin sections along with five polished sections were examined petrographically.

The purpose of the study was to better understand the geology of the Strike property and, if possible, to determine the nature and origin of the mineralization on the property.

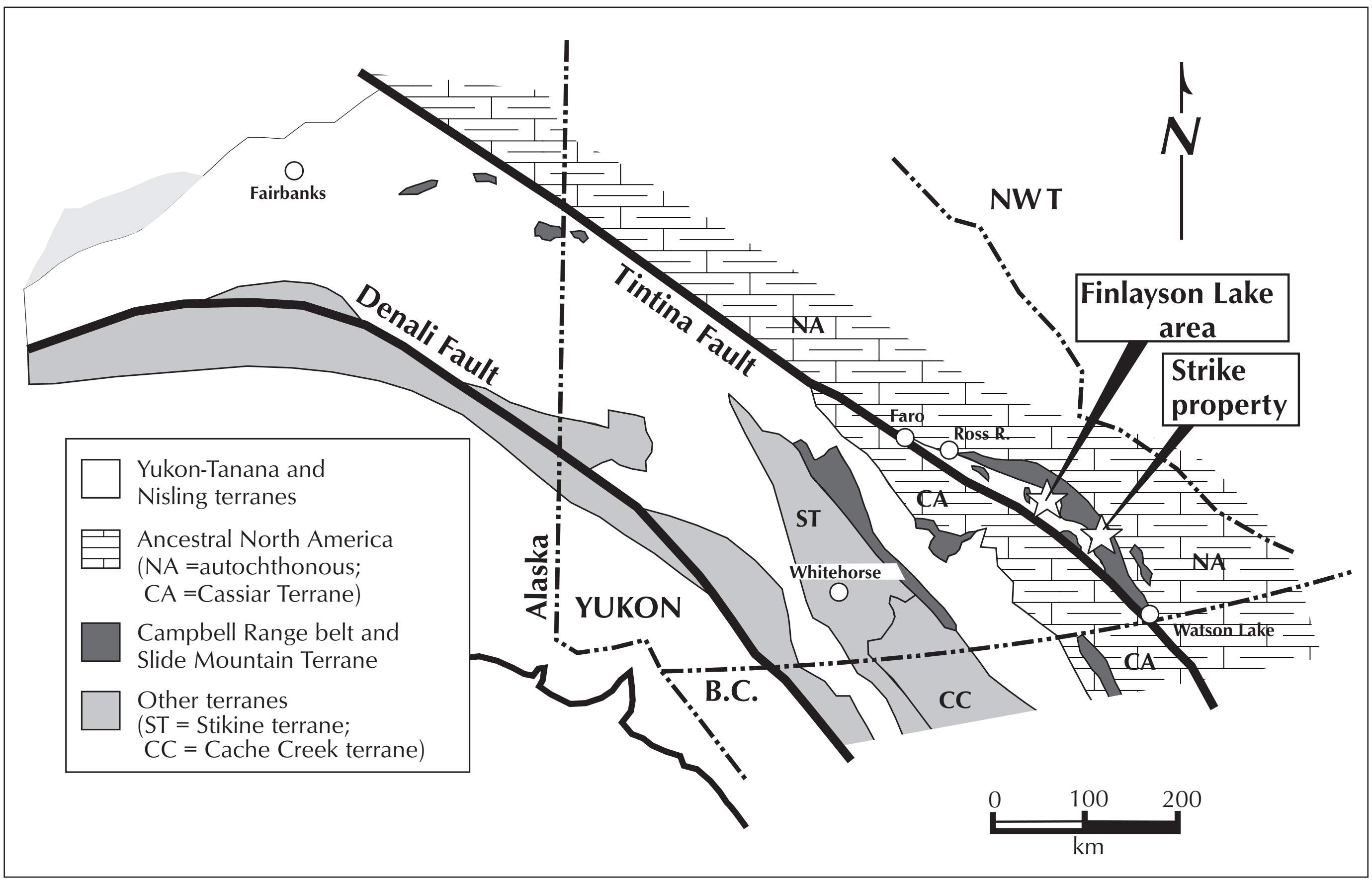

***Figure 1.** Location map for the Strike property showing Yukon regional terranes (modified from MacRobbie et al., 1998).*

LOCATION AND ACCESS

The Strike property is located in the CRB in southeastern Yukon Territory (Fig. 1). The study area lies approximately 17 km east of the north end of Wolverine Lake, and 5.5 km west of the Robert Campbell Highway. It is centred at UTM coordinates 446500 E, 6819200 N, and covers approximately 3 km^2. The area is a semi-mountainous zone of 1420-1700 m elevation with small scrub conifers and alpine vegetation. There is moderate to good bedrock exposure on steeper slopes, but much poorer exposure (<2%) on flatter areas in the lower and western part of the study area.

The 1998 program was helicopter supported and based out of the Kudz Ze Kayah exploration camp located approximately 30 km to the west, although the Robert Campbell Highway 5.5 km to the east would also be a viable base for helicopter pick-up.

PREVIOUS WORK

The Strike property was initially staked in 1995 by Cominco Exploration Ltd. to cover multi-element RGS stream silt anomalies on strike with Atna Resources' Money property. Fieldwork in 1996 located a strong Cu (>2300 ppm; locally up to 3436 ppm), Ni and Cr silt anomaly in a creek near the northern edge of the Strike property. In 1997, geological mapping upstream of the 1996-silt anomaly identified a large gossanous/ferricrete area, mafic volcanic rocks and minor malachite-stained talus. Contour soil lines identified >250 ppm Cu-in-soil anomalies (locally up to 9300 ppm) centred over the gossanous zone. The property was re-staked in 1997.

These past results, and the announcement in late 1996 of significant Cu-rich mineralization in mafic-volcanic-dominated stratigraphy on the Ice property by Expatriate Resources, prompted a program of geological mapping, geophysical surveys and diamond drilling by Cominco Exploration Ltd. in 1998. A 12.5-km grid was cut over the area of the gossanous/ferricrete zone, which was the focus of the 1998 exploration and this study on the Strike property.

REGIONAL GEOLOGY

The Strike property is underlain predominantly by rock units assigned to the SMT by Plint and Gordon (1997). These rocks make up much of the CRB and consist of the following units defined by Plint and Gordon (1997).

- massive to foliated *greenstone*, including pillow breccias and tuffs, heterolithic breccias, maroon metasiltstone and argillite, metagabbro, metadiorite, metagreywacke and various coloured metacherts;
- coarse-grained, ophitic, plagioclase-pyroxene *leucogabbro* with fine-grained and pegmatitic phases;
- green to black, magnetic, locally brecciated, massive, sugary-textured to well foliated *serpentinite*;
- varicoloured *metachert* interbedded with *metasiltstone/argillite* and minor chert breccia and chert quartz conglomerate; and
- pink, orange, tan, white or green/grey *metachert* and *phyllite* with argillaceous partings of white argillite or minor phyllite beds.

Assignment of this assemblage to SMT is now under debate. Murphy (1999) has tentatively concluded that the metabasalts of this area of the CRB conformably overlie YTT rocks that host the Wolverine deposit. More work will be needed to resolve this problem.

The CRB also forms part of the Finlayson Lake fault zone (Mortensen and Jilson, 1985; Plint and Gordon, 1997). This complex fault zone contains both thrust and steep transcurrent faults, and separates the YTT from allochthonous North America (Mortensen, 1983; Mortensen and Jilson, 1985). Thrust faulting continued after the formation of the Finlayson Lake fault zone, as indicated by the presence of overthrust sheets of SMT lithologies above the fault zone (Plint and Gordon, 1997).

The age of the volcanic rocks in the CRB is thought to range from Early Mississippian to Permian. This is based on firstly, the premise that there is no unconformity between the YTT (mainly Late Devonian-Mississippian) and the CRB, and secondly, a Pennsylvanian to Early Permian fossil (radiolarian) age for chert from the CRB that was reported by Plint and Gordon (1997).

PROPERTY GEOLOGY AND MINERALIZATION

LITHOLOGIC UNITS

Lithologic units in the study area (Fig. 2) have been subdivided based on field relations, petrography, and geochemistry into the following six main units.

Unit 1: Microphyric (plagioclase) metabasalt. This unit consists of greenish brown weathering, massive to pillow-brecciated metabasalt containing abundant plagioclase microphenocrysts up to 0.8 mm in length. Minor pillows, calcite, pumpellyite, and epidote amygdules, and epidote alteration occur locally.

Unit 2: Hematitic microphyric (plagioclase) metabasalt. This unit is well exposed and is the dominant lithology of the northeastern parts of the study area. It consists of greenish brown to maroon, massive to brecciated metabasalt. The basalt has moderate to strong hematitic alteration of the groundmass, and abundant plagioclase microphenocrysts up to 0.8 mm. Minor subhedral plagioclase phenocrysts up to 8 mm, pumpellyite, chlorite, calcite, and plagioclase amygdules, and variolites up to 3 mm all occur locally.

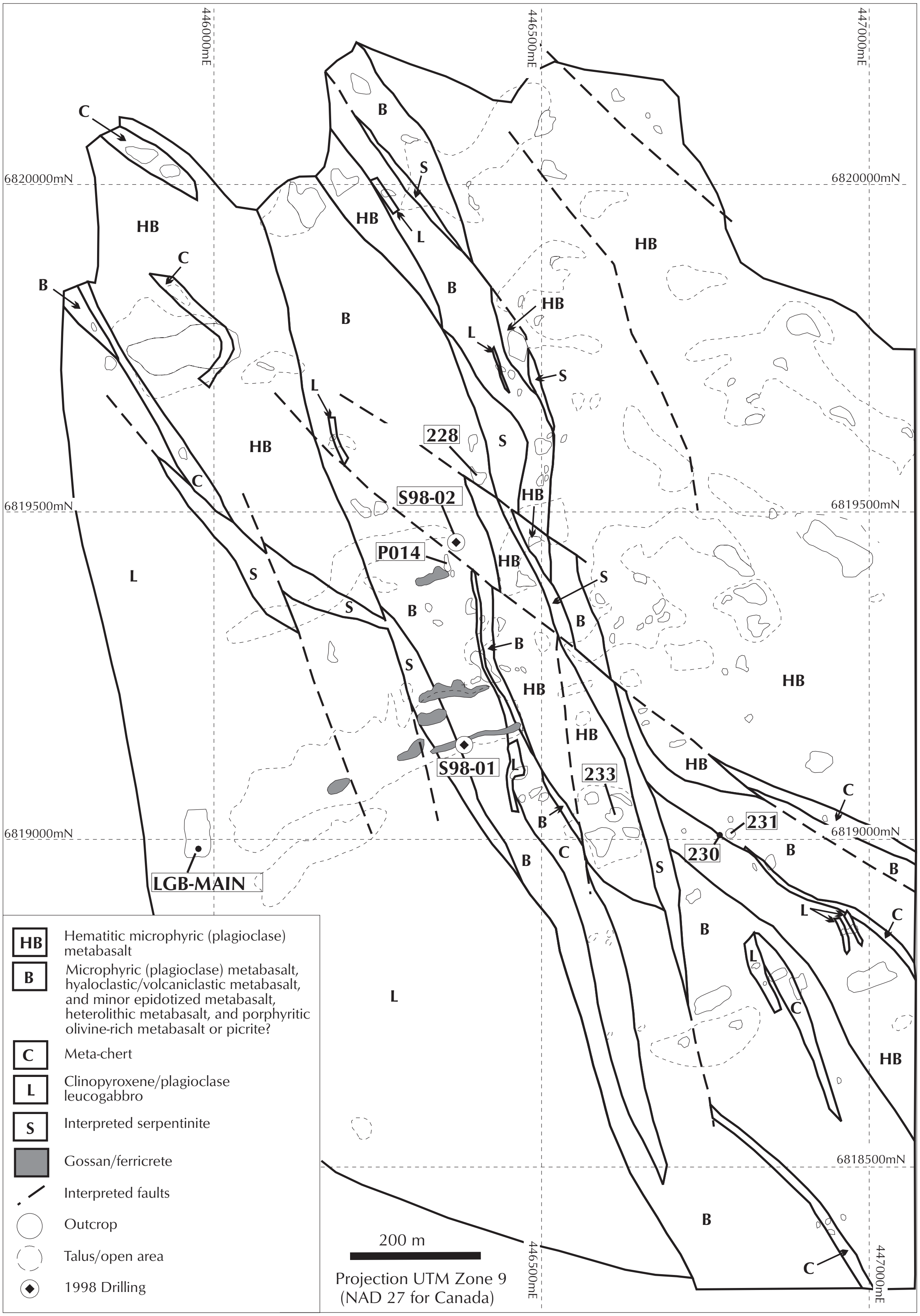

Figure 2. *Strike property study area geology and sample locations.*

Units 1 and 2 are similar in appearance and likely have a similar origin, and are shown as HB on Fig. 2. In addition to characteristics already mentioned, feldspars in both units are moderately to strongly saussuritized, and both units locally contain magnetite grains, quartz-epidote veining and relict olivine phenocrysts. The major differences are hematitic alteration, and more common brecciation of the hematitic microphyric metabasalt.

Unit 3: Hyaloclastic/volcaniclastic metabasalt (B on Fig. 2). This unit consists of tan- to light green-weathering, very fine- to coarse-grained, brecciated metabasalt with minor poorly developed banding. Breccia fragments contain rare, strongly saussuritized, relict plagioclase microphenocrysts. This rock appears to have undergone devitrification of a primary glass-rich matrix. This unit was included in Unit 1 at the time of mapping due to variability and graded boundaries.

Unit 4: Clinopyroxene/plagioclase leucogabbro (L). The leucogabbro unit occurs as a large, fine- to medium-grained intrusion in the western part of the study area; whereas it is only seen as pegmatitic and possibly peperitic phases in the better exposed northern portion of the study area. This unit consists of tan- to grey-weathering, white to light green, medium-grained, equigranular to pegmatitic metagabbro. The rock consists mainly of clinopyroxene and highly altered (albitized) plagioclase laths, as well as irregular actinolite pseudomorphs after primary orthopyroxene or clinopyroxene. Subhedral orthopyroxene crystals are also preserved locally.

Unit 5: Serpentinized ultramafic rocks (S). This unit consists of tan-weathering, dark green, strongly magnetic, and massive serpentinite with rounded and fractured magnetite grains to 2.5 mm. The rock is locally highly fractured and contains abundant talc and clay as fault gouge. Relict orthopyroxene, chrome spinel and chromite (?) are present in minor amounts.

Unit 6: Metachert (C). This unit consists of massive, grey to pale green, pink and maroon metachert. An argillaceous component is present in some areas. Poorly developed fine stratification, rare radiolarians to ~1 mm, and fine-grained breccia textures also occur locally. This unit is intercalated with the metavolcanic units.

Three other minor rock units were recognized in the study area (especially within the microphyric metabasalt unit). These include:

- dark green, olivine-phyric metabasalt containing abundant poikilitic olivine and altered plagioclase phenocrysts;
- heterolithic metabasaltic breccias containing fragments of units 1, 2, 3 and 4 above; and
- brown- to green-weathering, strongly epidotized metabasalt.

STRUCTURE

Although exposure is good in the upper and eastern portions of the study area, individual metabasalt and metachert units are difficult to trace along strike. The apparent discontinuous nature of flows and sediment units, along with the overall form of the outcrops, suggest faulting between some of the mapped units (Fig. 2). Ultramafic bodies that are interpreted to cut across geological boundaries also support this. Generally, bedding measurements can only be made from rare, poorly developed banding in the metachert units. Where present, bedding appears to be northwest-trending with shallow (20-45°) southwest dips. Deformation in the area is weak with only locally developed minor foliation. The structure of the study area is poorly constrained due to lack of good bedding indicators, and the highly faulted nature of the rocks.

SURFACE MINERALIZATION AND SOIL GEOCHEMISTRY

Talus in the gossanous/ferricrete area contains minor malachite on fractures in both the metabasalts and leucogabbro. However, no significant sulphides or rocks with significant metal contents were found on surface.

Soil sampling in 50-m intervals was carried out on 12.5 km of grid. Five soil pits, approximately one metre deep, were also dug and sampled in selected areas of the grid to try to outline and source the soil anomalies.

The results defined two highly anomalous areas. The first area coincides with the rusty-weathering, gossanous/ferricrete zones in the centre of the study area (Fig. 2). Samples returned >300 ppm Cu with higher values of 11,610 ppm and 8788 ppm. These anomalies are interpreted to be due to Cu and Fe-rich waters rising up fault zones and periodically flooding the surface. Springs near the up-slope cutoff of the gossanous zones, as well as layering of rusty-weathering soil, support this interpretation. The second anomalous area lies in a non-gossanous area in the northern part of the study area. Samples returned highly anomalous Cu, up to 11,920 ppm. This area is generally gently sloping with grassy and brushy vegetation. Analysis of soil horizons resulted in the highest anomalies being reported from dark brown to black organic-rich soil, which may indicate entrapment and concentration of metals by organic material.

The Cu soil anomalies in both anomalous areas coincide with strong Cr (>100 ppm; maximum 1155 ppm), Ni (>125 ppm; maximum 755 ppm) and weaker Co (>20 ppm; maximum 401 ppm) anomalies. Soil geochemical results from the northern portions of the study area, which are mainly underlain by non-gossanous hematitic metabasalts, were at most weakly anomalous, with a maximum of 611 ppm Cu present locally.

Rock samples of ferricrete returned 14-49% Fe, 1866-3806 ppm Cu, 4-1339 ppm Ni, 61-1533 ppm Cr, and 9-37 ppm Co.

DRILL HOLE MINERALIZATION

Minor amounts of pyrite/chalcopyrite mineralization were intersected in DDH-ST98-01 (Fig. 2), including several small rounded pebbles in fault zone wash and one ~5 cm band of massive pyrite/chalcopyrite in an envelope of hematitic chert/exhalite. Three distinct types of mineralization are present:

1) Very fine-grained pyrite (60%) with interstitial remobilized chalcopyrite (12%), quartz (28%), trace sphalerite as inclusions or adjacent to chalcopyrite, and trace hematite (?). Quartz occurs as very fine-grained matrix to the euhedral sulphide grains and is closely associated with chalcopyrite. This mineralization is associated with adjacent strongly hematitic siliceous rock (chert or exhalite). Subtle layering is locally evident macroscopically. Analyses of this material returned 1.9% Cu and 5.7 g/t Ag.
2) Quartz-pyrite-chalcopyrite and quartz-calcite veins. They are comprised of anhedral to euhedral, fine- to coarse-grained, recrystallized and fractured pyrite (20-40%); medium- to coarse-grained, remobilized chalcopyrite (8-20%); and fine- to medium-grained quartz matrix (40-50%). Analyses of the pebble wash from this zone returned 3.1% Cu and 6.4 g/t Ag.
3) Minor disseminated subhedral pyrite grains up to 3 mm found locally in the metachert, hematitic microphyric metabasalt, microphyric metabasalt, and serpentinite units.

Types 1 and 2 (above) are invariably hosted by strongly hematized cherts and/or pale siliceous exhalites. No volcanic rocks were found in contact with these types of mineralization. This may indicate a period of decreased volcanic activity with expulsion of silica- and metal-rich fluids onto the sea floor. Type 1 mineralization is interpreted to be syngenetic because of the fine-grained, massive nature of the sulphides, lack of recrystallized pyrite, and apparent macroscopic layering. Association with hematitic chert/exhalite also supports this conclusion. Type 2 mineralization occurs as veins. Breccia textures in the sulphides and an association in one sample with brecciated hematitic chert/exhalite suggests possible remobilization of syngenetic mineralization in a fault zone.

GEOCHEMISTRY OF METAVOLCANIC AND META-INTRUSIVE ROCKS

A total of seven samples (five metavolcanic and 2 meta-intrusive rocks) were analyzed for major, trace and rare-earth elements (REE) at Chemex Labs Ltd. in North Vancouver, B.C. Major elements were determined by X-ray fluorescence (XRF), whereas trace elements and REE were determined by research-grade, inductively coupled plasma mass spectrometry (ICP-MS). Table 1 summarizes geochemical data for the seven samples. The data set is relatively limited and thus may not be completely representative.

***Table 1**. Major, trace and REE abundances for metavolcanic and meta-intrusive rocks of the Strike property study area.*

Sample	PO14	RKMR-228	RKMR-230	RKMR-231	RKMR-233	RKMR-LGB-MAIN	ST9802-33.4-33.5
Major elements (%)							
SiO_2	47.42	47.96	37.83	47.90	47.78	47.27	46.60
TiO_2	1.42	1.80	1.36	1.55	1.35	0.21	0.23
Al_2O_3	14.79	13.44	14.36	14.85	14.07	16.09	17.52
Fe_2O_3	10.11	12.08	8.79	8.24	9.97	4.85	4.31
MnO	0.15	0.19	0.20	0.15	0.16	0.11	0.09
MgO	7.30	6.29	12.85	8.28	5.69	10.36	9.12
CaO	9.62	11.57	16.55	8.85	11.48	13.01	12.93
Na_2O	3.19	2.30	0.08	3.85	3.73	2.34	1.97
K_2O	0.27	0.25	0.03	0.52	0.16	0.23	0.95
P_2O_5	0.16	0.16	0.19	0.24	0.16	0.01	0.04
Cr_2O_3	0.05	<0.01	0.01	0.03	0.07	0.18	0.14
LOI	4.07	2.78	7.06	4.36	4.02	4.11	4.64
Sum	**98.55**	**98.82**	**99.31**	**98.82**	**98.64**	**98.77**	**98.54**
Trace elements (ppm)							
Ag	<1	<1	<1	1.0	<1	<1	<1
Ba	61.5	101.5	59.5	98.0	43.0	40.0	173.0
Co	40.0	45.5	35.5	36.0	37.0	33.0	29.5
Cs	0.1	<.1	0.3	0.3	<.1	<.1	0.5
Cu	45.0	80.0	65.0	40.0	55.0	85.0	430.0
Ga	15.0	18.0	13.0	15.0	14.0	9.0	11.0
Hf	2.0	3.0	2.0	3.0	2.0	<1	<1
Nb	6.0	6.0	14.0	13.0	5.0	1.0	1.0
Ni	120.0	35.0	115.0	155.0	70.0	230.0	215.0
Pb	<5	<5	<5	<5	<5	<5	<5
Rb	5.0	4.4	<.2	8.2	2.2	1.8	17.2
Sn	<1	1.0	<1	1.0	<1	<1	<1
Sr	21.7	171.0	53.5	35.0	61.1	167.0	66.0
Ta	2.0	2.0	2.0	2.0	1.5	0.5	0.5
Th	<1	<1	<1	<1	<1	<1	<1
Tl	<.5	<.5	<.5	<.5	<.5	<.5	<.5
U	<.5	<.5	<.5	<.5	<.5	<.5	<.5
V	240.0	285.0	200.0	180.0	250.0	Intf	Intf
W	19.0	18.0	10.0	16.0	11.0	7.0	9.0
Zn	75.0	90.0	65.0	55.0	85.0	25.0	40.0
Zr	75.5	96.5	88.0	109.0	67.0	<.5	<.5
REE (ppm)							
Ce	9.5	13.0	18.5	20.5	9.0	0.5	1.5
Dy	5.8	6.8	5.1	4.6	5.5	1.0	1.0
Er	3.8	4.4	3.4	3.0	3.1	0.5	0.7
Eu	1.2	1.5	1.6	1.3	1.2	0.5	0.3
Gd	4.5	5.7	5.0	4.4	4.3	0.9	0.6
Ho	1.2	1.4	1.0	1.0	1.0	0.1	0.1
La	3.0	5.0	8.5	8.5	3.5	0.5	0.5
Lu	0.6	0.6	0.5	0.4	0.5	<.1	<.1
Nd	9.5	13.0	13.0	13.5	8.5	1.5	2.0
Pr	1.7	2.4	2.8	2.9	1.7	0.2	0.3
Sm	3.4	3.8	3.9	4.2	3.1	0.6	0.6
Tb	0.8	1.0	0.8	0.7	0.8	0.1	0.1
Tm	0.5	0.6	0.5	0.4	0.5	<.1	<.1
Yb	3.5	3.9	3.0	2.4	3.3	0.5	0.6
Y	33.0	37.5	29.0	27.0	30.0	5.5	6.0

Major element discriminant plots (not shown) indicate that the metavolcanic rocks and leucogabbro are generally sub-alkaline basalt in composition. Trace element plots show that the volcanic rocks are of ocean floor affinity, rather than arc-related (Fig. 3). More specifically, trace elements indicate that both enriched (E-MORB) and normal mid-ocean ridge basalt (N-MORB) compositions are present (Fig. 4). The E-MORB group has higher Mg numbers (66.6-74.3%) than those in the N-MORB group (50.8-58.9%), indicating a lesser degree of fractionation in the E-MORB group and also showing the influence of fractional crystallization of olivine in sample RKMR-230.

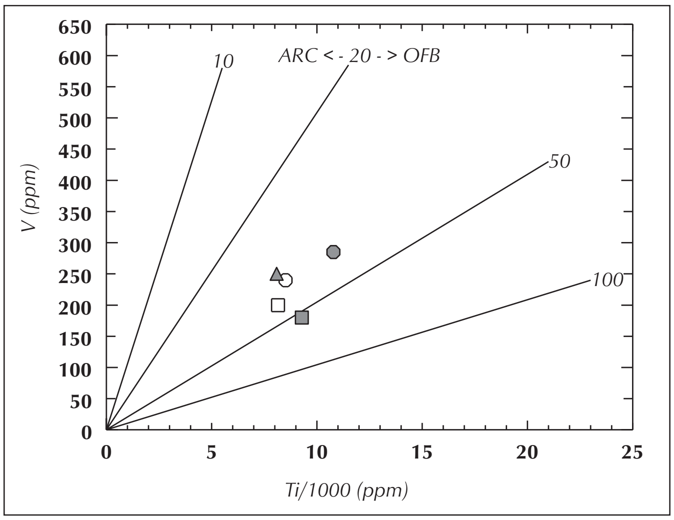

Figure 3. *Trace element plot showing ocean floor basalt (OFB) affinity of metavolcanic rocks from the Strike property (from Shervais, 1982). For symbols, see legend in Figure 4.*

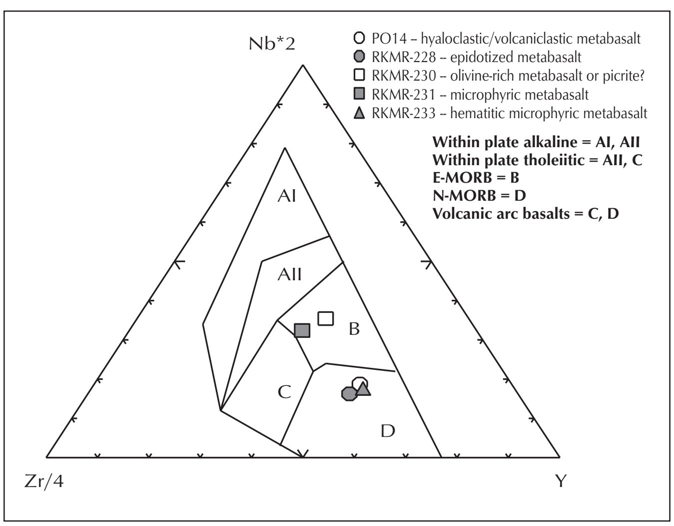

Figure 4. *Trace element plot showing differentiation between E-MORB and N-MORB settings of metavolcanic rocks from the Strike property (from Meschede, 1986).*

Primitive-mantle normalized multi-element plots (Fig. 5) show enrichment in Th, Nb, La, and Ce in samples RKMR-230 and 231 compared to a relatively flat to depleted light rare earth element (LREE pattern) for RKMR-228 and 233, and P014. This supports the separation of samples into E-MORB and N-MORB types. Generally all the metabasalts have relatively flat REE patterns with minor differences in the LREE abundances.

In view of the relatively coarse grain size and heterogeneous nature of the leucogabbro unit in outcrop and hand sample, the relatively small samples that were analyzed are likely not representative. Multi-element patterns for the leucogabbro unit are quite erratic (Fig. 5) and appear to indicate a separate origin from that of the metavolcanic rocks. A positive Eu value may result from plagioclase accumulation, which is consistent with the plagioclase-rich nature noted in outcrop and hand sample.

Metavolcanic rocks from the Strike area are geochemically similar to suites CRB_1 and CRB_2 as defined elsewhere in the CRB by Piercey et al. (1999). CRB_1 is defined by moderately LREE-enriched E-MORB-type compositions, characterized by relatively flat to slightly enriched LREE patterns, and relatively flat primitive-mantle-normalized multi-element plots. These compositions are consistent with generation in an ocean basin and/or back-arc/marginal basin setting (Piercey et al., 1999). The E-MORB samples in the Strike area differ from those described by Piercey et al. in that Strike rocks have somewhat higher Mg numbers and Zr/Y ratios. This may indicate a greater plume influence in the Strike metavolcanic rocks. The CRB_2 suite as defined by Piercey et al. consists of strongly LREE-depleted N-MORB-type rocks that are also consistent with generation in an ocean basin and/or back-arc/marginal basin setting (Piercey et al., 1999). The N-MORB samples from the Strike area are very similar to CRB_2 suite except for higher Nb contents in the Strike area.

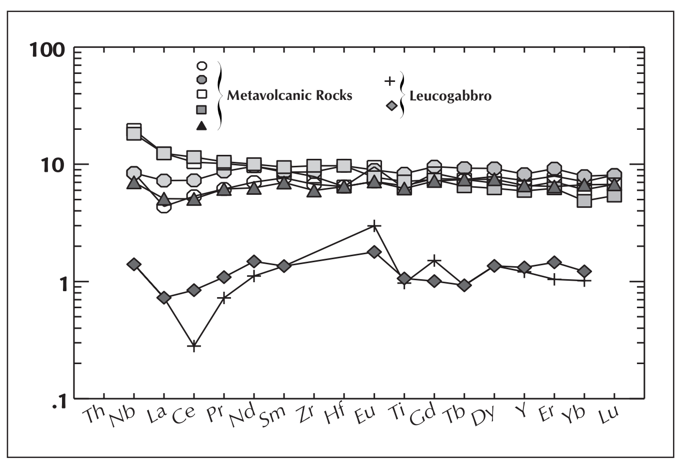

Figure 5. *Primitive-mantle-normalized multi-element plot for metavolcanic and leucogabbro rocks from the Strike property. Primitive-mantle values are from Sun and McDonough (1989).*

LEAD ISOTOPE STUDIES

Trace Pb isotopic compositions were determined for mixed pyrite/chalcopyrite samples from massive (Type 1) and vein (Type 2) mineralization in drill hole ST98-01 (31.1-38.1 m). The goal of this part of the study was to determine the source of metals and to help characterize the paleotectonic setting in which the host rocks formed. The main goal of this part of the study was to determine whether the sulphides represent syngenetic Cyprus-type volcanogenic massive sulphide (VMS) mineralization or epigenetic vein-type mineralization with no association with syngenetic targets. Lead isotopic data are given in Table 2 and shown graphically in Figure 6.

The data show a tight cluster, suggesting a similar Pb source for types 1 and 2 mineralization. The samples are all slightly more radiogenic than the "Model Mantle Growth Curve" (Fig. 6), but fall far below the "Shale Curve" on which most VMS mineralization in the YTT plots (Mortensen, unpublished data). The analyses are also significantly less radiogenic than Pb's from the Chu Chua mafic-volcanic hosted deposit in the SMT in east-central British Columbia (Aggarwal and Nesbit, 1984). This suggests a syngenetic origin for the mineralization with most Pb being derived from a MORB-type, mantle source, and a minor contribution from a more radiogenic source. This causes the analyses to plot on a mixing line between the "Mantle" and "Shale" curves. This enrichment may be explained by the fact that the host metabasalts themselves have slightly geochemically enriched signatures. Another possible explanation is that they may reflect isotopic mixing by fluid circulation through the metabasalts and more radiogenic sedimentary units that are interlayered with the volcanic rocks. Some of the cherts in the study area contain an argillaceous component, and it is possible that this material is continentally derived, which may account for the radiogenic enrichment.

Table 2. *Trace Pb isotopic analysis data.*

Sample	Type	$^{206}Pb/^{204}Pb$	$^{207}Pb/^{204}Pb$	$^{208}Pb/^{204}Pb$	$^{207}Pb/^{206}Pb$	$^{208}Pb/^{206}Pb$
RKM-33	2	18.2744	15.5380	37.6593	0.85027	2.0608
RKM-35.4	2	18.3306	15.5260	37.7250	0.84700	2.0580
RKM-35.6a	2	18.3380	15.5469	37.7859	0.84780	2.0605
RKM-38.1	1	18.2273	15.5419	37.8457	0.85267	2.0763

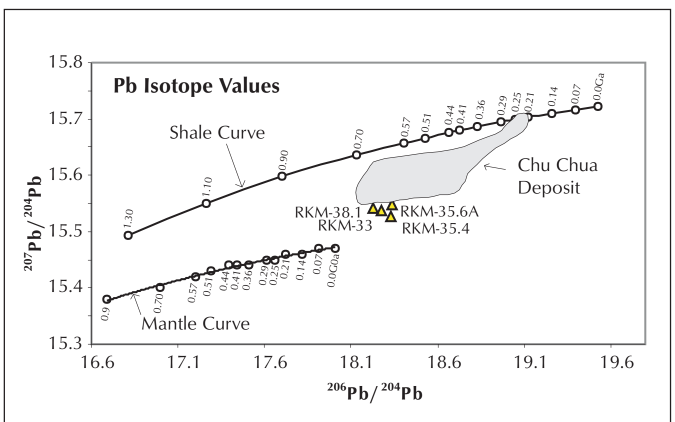

Figure 6. *Lead isotope compositions of Strike mineralization compared with data from the Chu Chua deposit, the "Model Mantle Growth Curve" and the "Model Shale Curve" (curve data from Godwin et al., 1988).*

INTERPRETATION AND DISCUSSION

As has also been concluded by Plint and Gordon (1997) and Piercey et al. (1999), the metavolcanic rocks in the study area are interpreted to have formed in a subaqeous MORB setting such as an ocean basin and/or back-arc/marginal basin. Textures observed vary from highly brecciated to pillowed to massive, which are typical of flow breccia formation. Intercalated chert beds up to 5 m thick also support the subaqeous setting. The geochemistry of the metavolcanic rock units indicates both E-MORB and N-MORB settings for the volcanic units. Given the relative proximity of the volcanic units in the study area, it is likely that the classification of two samples into an E-MORB setting and three samples into an N-MORB setting reflects varying amounts of plume contribution. This may be explained by various amounts of interaction between magmas during their rise to the sea floor. Hematization of the microphyric unit indicates possible formation in a shallow and therefore relatively oxygenated basin. This may support a marginal/back-arc basin setting rather than a deep ocean basin setting.

Epidotized metabasaltic rocks are likely a highly altered form of the microphyric metabasaltic units based on stratigraphic position and the abundance of these rock types. This unit is likely formed in a localized area of high hydrothermal flow indicated by the total epidotization of the rock. This may be significant in that mafic VMS deposits generally are associated with, or form near, areas of high hydrothermal flow. Therefore, large amounts of this unit may be a positive indicator of prospective units.

The gabbroic composition, proximity, and possible peperitic textures of the leucogabbro unit indicate an association with the volcanic units. However, the large differences in trace and REE geochemistry suggest that the leucogabbro and the metavolcanic rocks may be unrelated. A marked TiO_2 depletion, as well as high field strength element (HFSE) depletion, supports a more evolved nature and non-comagmatic relationship with the metavolcanic rocks.

The serpentinized ultramafic unit may have two origins. It may represent fault slices of basement ultramafic rock brought up by faulting, or alternatively it could represent intrusions into pre-existing faults. The unit is recessive and therefore very poorly exposed. It is also highly magnetic and may be a source of local magnetic anomalies.

The metachert unit occurs as intercalated beds within the metabasalt units. The presence of rare radiolarians and minor banding indicates that it is indeed of sedimentary origin, and does not represent hydrothermal jasper. Thicknesses up to 8 m indicate prolonged periods of volcanic inactivity and a period of time suitable to VMS sulphide deposition.

EXPLORATION IMPLICATIONS

The two basaltic suites (CRB_1 and CRB_2) in the CRB defined by Piercey et al. (1999) and the metavolcanic rocks area of the Strike property are all interpreted to have formed at spreading centres. This comes with generic MORB magmatism and abundant fractures and faults that could have formed conduits for hydrothermal fluid flow. The inferred tectonic setting, as well as the presence of the Ice deposit and Money occurrence, indicates a strong potential for mafic-volcanic associated VMS mineralization within the CRB.

The geology of the Ice deposit shares many characteristics with the Strike property, including:

- host rocks of the CRB dominated by metabasalts with interlayered, locally argillaceous metacherts;
- intimately associated chert and/or exhalite as an envelope around mineralization; and
- a large gossanous area with high copper soil anomalies on surface.

These similarities, together with minor, apparently syngenetic Cu mineralization present in DDH-ST98-01, suggest excellent potential for additional discoveries of Cyprus-type VMS mineralization in this area.

ACKNOWLEDGMENTS

This research was done by the first author as part of a directed study at the University of British Columbia. We thank Cominco Exploration Ltd. and especially Paul MacRobbie for supporting the field and lab component of the study. We also thank J. Gabites of the UBC Geochronology Laboratory for assistance in producing the trace Pb analytical data reported here. Thanks also goes to Scott Billows for his help with formatting and reproducing the maps, and Steve Piercey for his invaluable insight into volcanic geochemistry.

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Geologic setting, genesis, and potential of the Rusty Springs Ag-Pb-Zn-Cu property, northern Yukon (NTS 116K/8 and K/9)

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Greig, C.J., 2000. Geologic setting, genesis, and potential of the Rusty Springs Ag-Pb-Zn-Cu property, northern Yukon (NTS 116K/8 and K/9). *In:* Yukon Exploration and Geology 1999, D.S. Emond and L.H. Weston (eds.), Exploration and Geological Services Division, Yukon, Indian and Northern Affairs Canada, p. 247-266.

ABSTRACT

Despite many years of exploration and relatively limited success, the Rusty Springs prospect retains considerable potential for a large-tonnage deposit. The property lies within the east-vergent Taiga-Nahoni fold belt, occurring in the core of a structural culmination exposing host dolostones of the Lower and Middle Devonian Ogilvie Formation. Mineralization occurs in stratabound and discordant zones along the contact with the overlying Devono-Mississippian unnamed shale. Various deposit models, ranging from Mississippi Valley-type to epithermal vein-type have been employed. Poor exposure and relatively deep weathering, resulting from the lack of Pleistocene glaciation, account for the lack of consensus with regard to genesis. Evidence points to the potential for a high-temperature, carbonate-hosted massive sulphide deposit (manto-chimney complex). The great extent of mineralized and altered rocks, together with their stratabound nature, significant thickness, local high grades, and potential for supergene enrichment, suggest that Rusty Springs remains an attractive drill-oriented exploration target.

RÉSUMÉ

Malgré les minces succès obtenus après plusieurs années d'efforts d'exploration, l'indice de Rusty Springs présente un très bon potentiel pour un gisement de tonnage important. La propriété est située à l'intérieur de la ceinture de plissement Taiga-Nahoni de vergence est et se retrouve dans le coeur d'une culmination structurale qui expose les dolomies de la Formation d'Ogilvie du Dévonien inférieur à moyen. La minéralisation se présente en zones stratiformes et discordantes le long du contact de la Formation d'Ogilvie avec le shale Dévono-Mississipien sus-jacent (non nommé). On a tenté d'appliquer plusieurs types de modèles génétiques variant du type Mississipi Valley jusqu'au modèle des veines épithermales. La rareté des affleurements et une altération météorique relativement profonde due à l'absence de glaciation Pleistocène expliquent l'absence de consensus en ce qui concerne la genèse de la minéralisation. Les observations indiquent un potentiel pour un gisement du type sulfures massifs de haute température dans les roches carbonatées (complexe de cheminées du type Manto). La grande étendue de la minéralisation et des roches altérées combiné avec leur nature stratiforme, leur grande épaisseur, la présence par endroits de hautes teneurs ainsi que la possibilité d'un enrichissement supergène suggèrent que Rusty Springs demeure une cible attrayante pour les forages d'exploration.

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INTRODUCTION

The Rusty Springs prospect is an Ag-Pb-Zn-Cu occurrence of enigmatic origin. In spite of limited success during considerable exploration over the past 25 years, the mineralizing system at Rusty Springs still holds significant potential. Recent general interest in Rusty Springs and nearby properties has been heightened due to its location near the boundary of the Fishing Branch protected area, a proposed wilderness area in the process of being excluded from mineral claim staking. This paper reviews previous geological work on the property and discusses the genesis of mineralization. It also addresses the potential for further exploration, both on the property and in surrounding areas, a potential which is still considered high. The basis for discussion includes work undertaken in 1999, which is also summarized herein. The work included three diamond drill holes for a total of 317 m, as well as some reconnaissance work and re-mapping (at 1:50 000 scale) of the area immediately surrounding the property.

LOCATION, ACCESS, AND PHYSIOGRAPHY

Rusty Springs is located in the northern Ogilvie Mountains of northwestern Yukon, near the headwaters of the Yukon and Porcupine rivers (Fig. 1). It is located approximately 8 km south of the Arctic Circle, 29 km east of the Alaska border, and 115 km south of the village of Old Crow. Relief in the Rusty Springs area is on the order of 1000 m, with the highest point in the surrounding mountains at about 1500 m. Summits and ridges are generally rounded and subdued, and the valleys are broad (Fig. 2) and V-shaped, as the area lies in that part of the Yukon which was not glaciated during Pleistocene time.

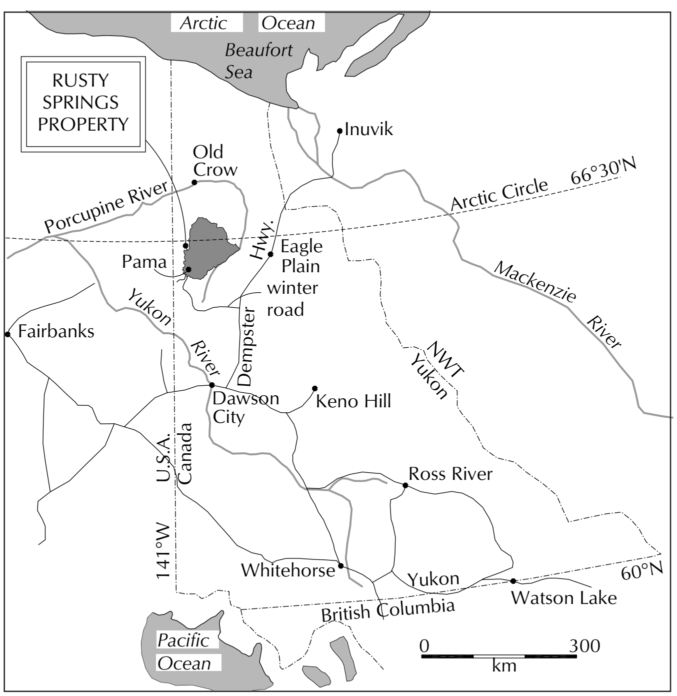

Figure 1. Location map of Rusty Springs property; shaded area shows location of proposed Fishing Branch Protected Area.

Access to the property is via aircraft or by winter road. An all-weather, 600-m airstrip was completed in 1996. The nearest staging areas are approximately 150 to 200 km away along the Dempster Highway, near Eagle Plains. The winter haulage road, nearly 200 km in length, leads from Mile 123 (Ogilvie Crossing) on the Dempster Highway (Fig. 1).

EXPLORATION HISTORY

The Rusty Springs property was first staked in 1975, after investigation of deep, red-orange springs and seeps in the valley of Carrol Creek led to the discovery of nearby silver, lead, zinc, and copper mineralization; the rusty seeps were first noted during petroleum exploration in the area. Since the discovery, the property has been the focus for nearly $5 million of exploration, including 10 separate drill campaigns in 2 major phases (1975-83 and 1994-96) totalling over 11,000 m of drilling in 123 holes (see Appendix).

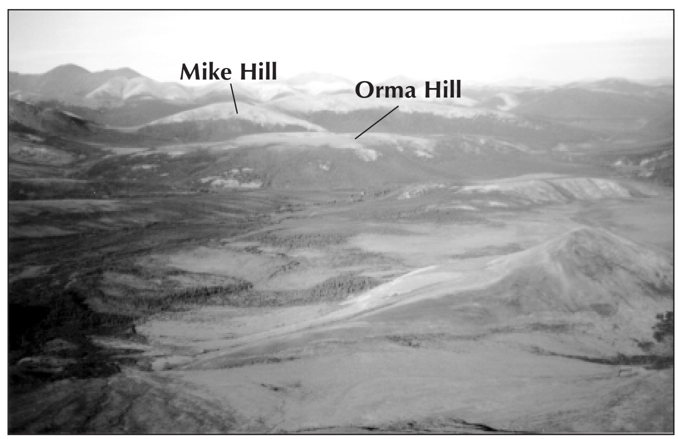

Figure 2. *View eastward across the core of the Porcupine-Rusty Springs anticlinorium, showing rounded hills, broad valleys, and poor exposure typical of the area. Mineralization occurs mainly on the two low hills in the middle ground: Orma Hill (to right, smaller and lower) and Mike Hill (larger, somewhat higher). Hill in right foreground is underlain primarily by limestone of Carboniferous and Permian (?) age (Ettrain and Jungle Creek formations), while the low-lying area between is underlain by relatively recessive Devono-Mississippian, fine-grained clastic rocks. Ridges immediately behind Mike Hill are also underlain by Ettrain and Jungle Creek formations; those on the skyline consist of Early to Late Proterozoic siliciclastic rocks (darker colour) and Late Cambrian to Early Devonian dolomite (lighter colour).*

Exploration has mainly targeted high-grade silver, lead, copper, and zinc mineralization within brecciated, and quartz- and carbonate-cemented and veined dolomite. It has been based on several genetic models, developed in part, through research by geology students employed on the property, and working on B.Sc. theses (e.g., Schoel, 1978; Hansen, 1979; Bankowski, 1980a). At various stages of exploration, models used to help guide exploration included Mississippi Valley-type (MVT); Irish Plains-type (carbonate-hosted exhalative, Bankowski 1980a); epithermal-type (veins and/or hydrothermal replacement along a karsted surface, with supergene enrichment); and manto-chimney-type (high-temperature, carbonate-hosted massive sulphides). Direct targeting of drill holes utilized various techniques, including prospecting, geological mapping, geochemistry and geophysics (see Appendix). Many of the drill programs were plagued by drilling problems, such as poor recoveries in the strongly oxidized and leached mineralized intervals, or loss of water pressure in blocky brecciated zones with abundant open space. Drilling was often slow and costly in resistant siliceous 'chert' horizons that cap the mineralized stratigraphy. Trenching was also challenging, mainly because of deep permafrost and deep, solifluncted overburden which predominate in unglaciated parts of the Yukon.

REGIONAL GEOLOGICAL SETTING

The area mapped lies within the northernmost part of the Cordilleran orogenic belt, known locally as the Taiga-Nahoni fold belt. In this belt, Precambrian to Cretaceous, predominantly sedimentary rocks of the eastward- and northward-tapering North American miogeocline were deformed in latest Cretaceous to Tertiary time (Fig. 3; Norris, 1996; Lane, 1998). The area was first mapped by Norris (1981), who outlined a

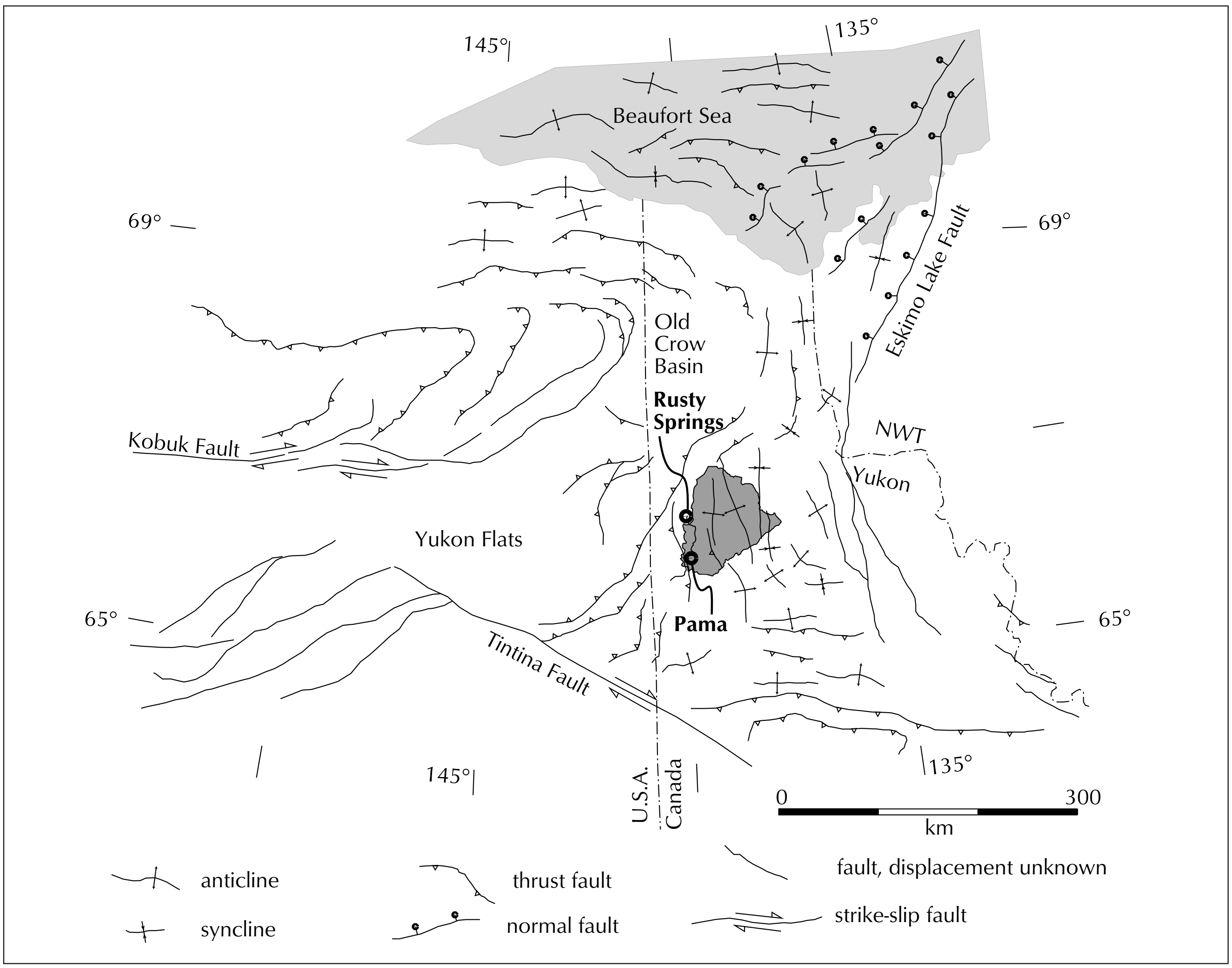

Figure 3. *Major structures of northwesternmost Canada and adjacent Alaska, showing location of Rusty Springs and Pama properties, as well as proposed Fishing Branch Protected Area (shaded) in the northern Ogilvie Mountains (after Lane, 1998).*

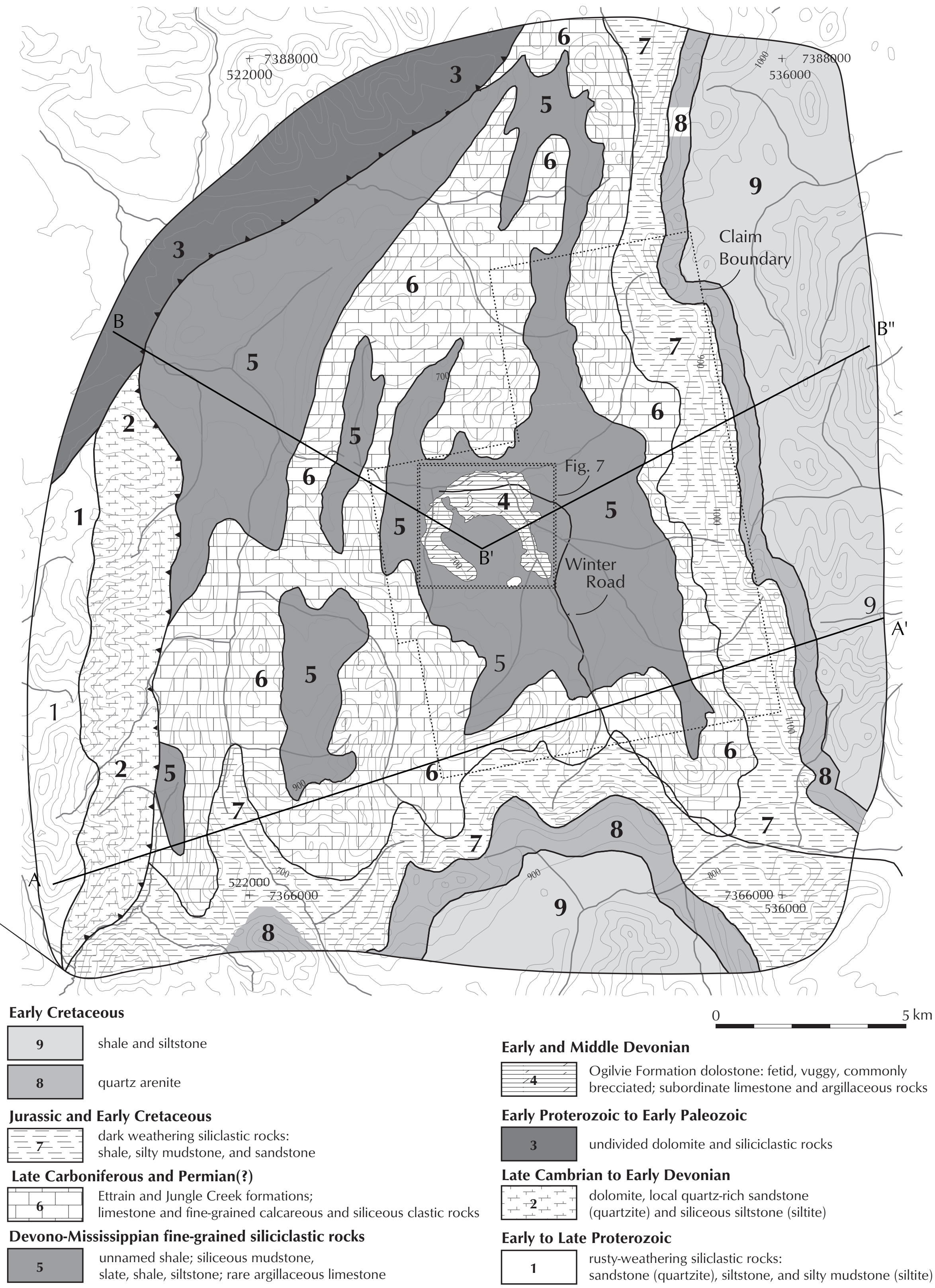

Figure 4. *Geology of the Rusty Springs property. Contour interval is 100 m. A-A′ and B-B′-B′′ mark the location of cross-sections in Figure 6.*

Figure 5. *Structural map of the Rusty Springs property; bedding orientations estimated from a distance: g=gentle, m=moderate, s=steep; contour interval 200 m and A-A′ and B-B′-B′′ mark the location of cross-sections in Figure 6.*

structural culmination, in part coincident with his Porcupine Anticline, cored by rocks of the Lower and Middle Devonian Ogilvie Formation. Norris (1981) shows stratigraphically lower rocks of Early Paleozoic, Cambrian, and Proterozoic age bounding the west side of the culmination and brought up by mainly west-vergent contractional faults.

PROPERTY GEOLOGY

Nine map units, ranging in age from Proterozoic to Cretaceous, correspond largely with those mapped by previous workers (e.g., Chernoff, 1976; Kirker, 1980a; Tempelman-Kluit, 1981; Fig. 4), but improved bedding control (Fig. 5) yields a significantly different structural interpretation (see cross-sections, Fig. 6). Ages of the map units were taken mainly from Norris (1981, 1996). Exposure is generally poor near the valley bottom and consequently the focus for property-scale geologic mapping was on the rocks exposed on surrounding ridges. The geology in the immediate vicinity of the mineralized and altered zones at Rusty Springs, which outcrop at lower elevations in the vicinity of two lower hills, named the Mike and Orma hills, was examined briefly; a compilation map and cross-section are shown in Figures 7 and 8, respectively.

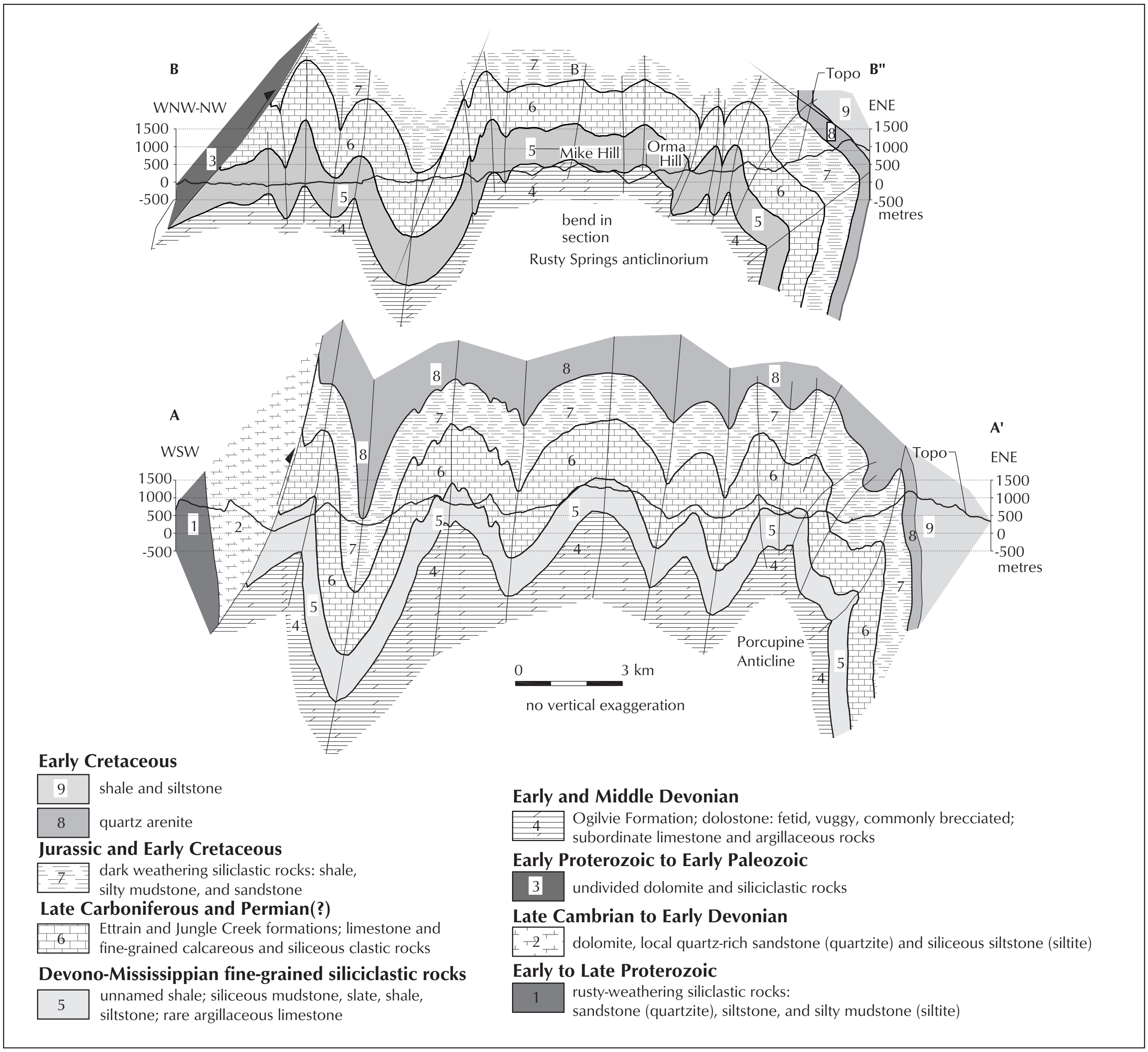

Figure 6. *Geologic cross-sections, Rusty Springs property; see Figure 4 and 5 for location of sections.*

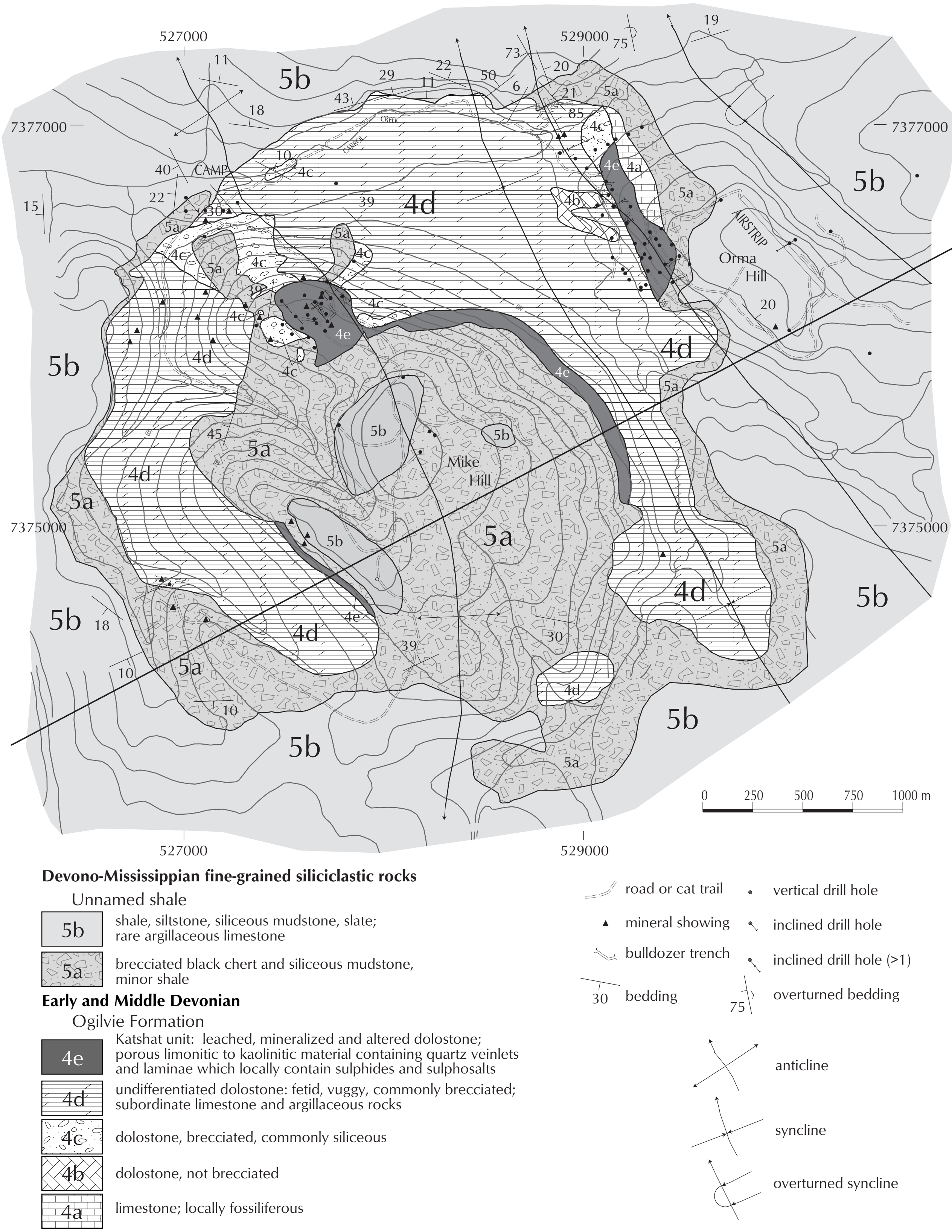

Figure 7. *Geology of the core of the Rusty Springs anticline, Mike and Orma hills (location of map shown in Figure 4; geology mainly after Hansen,1979; Hansen and Bankowski, 1979; and Aussant, 1983); contour interval 20 m. C-C' is location of cross-section in Figure 8.*

LOWER TO UPPER PROTEROZOIC ROCKS

Rusty-weathering, fine-grained sandstone (quartzite), interbedded with maroon and local green siltstone and silty mudstone (siltite) occurs in a northerly trending belt in the southwesternmost corner of the area mapped (Fig. 4). The siliciclastic rocks, which were only briefly examined, appear to be conformable with steeply east-dipping Lower Paleozoic dolostone and quartz-rich sandstone to the east.

LOWER PALEOZOIC ROCKS

Like the older rocks which they appear to overlie conformably, rocks of probable Late Cambrian through Early Devonian age occur in a northerly trending belt along the west margin of the map area (Fig. 4). The Lower Paleozoic rocks consist of white-weathering dolostone, rusty-weathering quartz-rich sandstone (quartzite), and siliceous fine-grained clastic rocks, including green and maroon siltstone and silty mudstone (siltite). Rocks of similar general appearance occur to the north, but were neither examined nor differentiated from the older siliciclastic rocks. The Lower Paleozoic rocks are inferred to be in thrust contact with younger Paleozoic and Mesozoic rocks to the west, although a down-to-the-east normal fault was mapped along trend to the south by Norris (1981). The presence of the inferred thrust is supported by the marked easterly vergence of folds in the area (see Fig. 6).

LOWER AND MIDDLE DEVONIAN OGILVIE FORMATION

Pale grey-weathering, dark grey dolostone and subordinate limestone and argillaceous rocks of the Ogilvie Formation underlie the central part of the Rusty Springs property in the core of the Porcupine-Rusty Springs anticlinorium (Figs. 7, 8). They form common talus slopes on the flanks of Orma and Mike hills, but outcrop is scarce, even on roads and cat trails. Dolostone is fetid, and commonly brecciated (Fig. 9), veined, and/or vuggy. Breccia cements consist mainly of dolomite and sparry calcite with local quartz; vugs are commonly lined with calcite and quartz, and veinlets are of similar mineralogy. Another common constituent of Ogilvie Formation breccias is pyrobitumen. Pyrobitumen is commonly intergrown with dolomite cements and is always associated with quartz and/or calcite spar (Kirker, 1982); it also locally coats vugs. Dolomite crystals in dolostone are typically fine- to medium-grained and locally coarse-grained, with coarser grained varieties typically

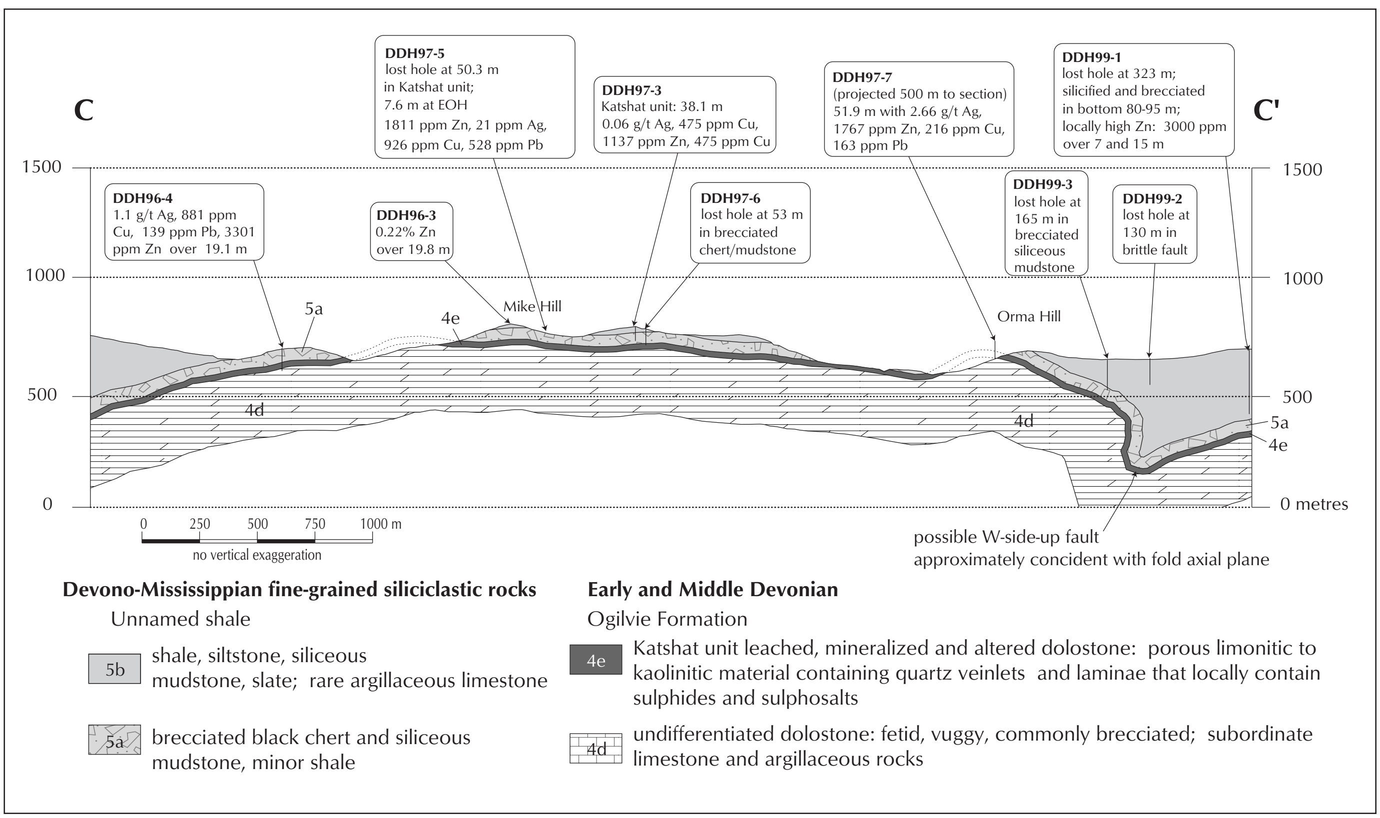

Figure 8. *Geologic cross-section through Mike and Orma hills, showing most of the drill hole intersections of the mineralized 'Katshat unit', as well as drill hole control on its probable location at depth toward the east side of the property, mainly from 1999 drilling; see Figure 7 for location of section.*

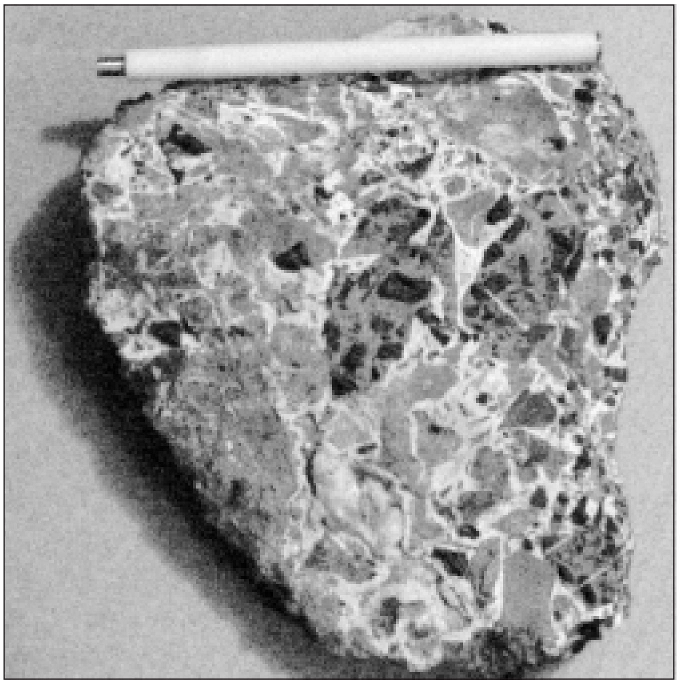

Figure 9. *Dolostone breccia from Mike Hill. Breccia is polyphase and cement is sparry calcite with local quartz (higher relief).*

weathering a paler grey colour. Locally, weakly dolomitized limestone contains recognizable brachiopods, ostracods, corals, and crinoids (Hansen, 1979; Davis and Aussant, 1982), although no diagnostic fossils have been reported. Float boulders and the few outcrops of the Ogilvie Formation suggest that it is poorly stratified. However bedding is more apparent in diamond drill core, particularly where brecciation is less intense. Bedding to core axis angles typically suggest that the strata in the vicinity of Mike and Orma hills are dipping gently. Mainly on the basis of their contained fauna, Hansen (1979) interpreted the dolostones of the Ogilvie Formation as a shallow water 'reefal' unit, while Kirker (1982) suggested a shallow-water shelf environment. The base of the Ogilvie Formation at Rusty Springs is not exposed, but a drill hole between Mike and Orma hills penetrated about 210 m (probable true thickness) of dolostone, with local interbedded shale, and rare limestone and quartzite (Chamberlain, 1986).

At the top of the Ogilvie Formation at Rusty Springs is the informally named 'Katshat unit,' a recessive, gossanous oxide- and clay-rich unit which corresponds to a significant degree with the mineralized zones on the property. In general, the unit appears to be stratabound, separating the dolostone from overlying siliciclastic rocks, but in detail, its contacts are highly irregular. The Katshat unit most likely represents altered and mineralized Ogilvie Formation limestone–it is discussed in more detail below.

DEVONO-MISSISSIPPIAN FINE-GRAINED SILICICLASTIC ROCKS

Disconformably overlying the Ogilvie Formation are siliceous mudstone, slate, shale, siltstone, and rare limestone of probable Devono-Mississippian age. Norris (1981) assigned these rocks to the Hart River Formation (Early and Late Carboniferous age). However they are more likely correlative with fine-grained clastic rocks, such as the Upper Devonian Canol Formation, the 'unnamed shale,' the Upper Devonian and Lower Carboniferous Ford Lake shale (Norris, 1981, 1996), and the Kayak Formation (Richards et al. ,1996), since the Hart River Formation consists mainly of limestone (Norris, 1981, 1996). Herein the rocks have been assigned to the 'unnamed shale.'

The lowermost rocks in the sequence, best exposed on Orma and Mike hills and referred to locally as black 'chert,' are perhaps more accurately referred to as a silicified and/or siliceous mudstone. Thin laminations and recrystallized radiolaria are locally preserved (Hansen, 1979). The siliceous rocks are up to 40 m thick (Hodder, 1997) and are commonly veined and brecciated; veins and breccia matrices consist mainly of quartz, calcite, and dolomite. The brecciated siliceous rocks appear in most places to cap the mineralized Katshat unit of the uppermost Ogilvie Formation. Black siliceous (?) fragments are locally a component of the dolostone breccias that commonly comprise upper Ogilvie Formation rocks beneath the Katshat unit.

Up-section from the siliceous rocks, and comprising the bulk of the rocks assigned to the unnamed shale, are relatively recessive pyritic, carbonaceous shale, mudstone, silty mudstone, and local thin- to medium-bedded, poorly sorted, fine-grained litharenite. They are generally thinly bedded, and typically siliceous, although local calcareous shale was also noted. Local true slate and rare dark grey, fetid and laminated algal limestone occur not far above its contact with the Ogilvie Formation. Erosion of this part of the unit, which is as much as 500 m thick, has led to the broad and open drainage basin within which the Rusty Springs property is located (Fig. 2).

The transition of the fine-grained clastic sequence to the overlying mixed carbonate and clastic unit is commonly marked by the presence of thin- to medium-bedded, siliceous, fine sandy siltstone or fine-grained sandstone. These rocks are typically pale grey and locally rusty-weathered up close, but appear very dark from a distance because of a common covering of black lichen.

UPPER CARBONIFEROUS AND PERMIAN (?) LIMESTONE AND FINE-GRAINED CALCAREOUS AND SILICICLASTIC ROCKS

Medium-bedded, pale grey-weathering, medium to dark grey, sandy and locally pebbly fetid limestone and rare dolostone characterize this unit. The limestone commonly contains irregular dark grey chert nodules and occurs in several (?) horizons of amalgamated beds that are up to several tens of metres thick. They form many of the better outcrops in the area, and because of their resistant character, they underlie many of the ridges surrounding the broad upper drainage basin of Carrol Creek (Fig. 2). The upper limit of the map unit is defined by the presence of the uppermost continuous limestone sequence. Scattered float blocks of pebbly limestone commonly mark the transition from the underlying siliciclastic sequence. The pebbles are typically round to sub-round and are dominantly chert (Fig. 10). Pebbly lithologies are more common to the southwest, whereas to the east, sandy limestone is more common, and pebbly limestone occurs only locally. In addition, a limestone horizon containing abundant *in situ* corals (Fig. 11) was noted in the east but not to the south or southwest, and composite limestone horizons appear somewhat thicker (up to 50-60 m) and may contain thicker-bedded to massive layers up to 15 m thick. In spite of the predominance in outcrop of pebbly and cherty limestone, a significant portion of the map unit consists of relatively recessive, variably calcareous fine-grained clastic rocks. They include dark weathering, thin-bedded and laminated siliceous or calcareous silty mudstone, and calcareous to siliceous shale, as well as local fine-grained siliceous sandstone and siltstone. The total thickness of the limestone and associated clastic units is about 550-700 m.

The rocks of this sequence have been included previously in the Upper Carboniferous Ettrain Formation. However, Pennsylvanian and Permian fossils have been reported from within the area mapped, and so it is probably longer ranging and likely includes rocks mapped as Jungle Creek Formation by earlier workers. If so, it is difficult to distinguish Ettrain from Jungle Creek in the field.

JURASSIC AND LOWER CRETACEOUS DARK WEATHERING SILICICLASTIC ROCKS

Lying conformably above the sequence containing the resistant grey carbonates is a dark weathering package of shale, silty mudstone, and sandstone approximately 600 m thick. Included in this map unit are rocks that Norris (1981) assigned to the Jurassic and Lower Cretaceous Kingak, Porcupine River, and Husky formations. The lower part in the Rusty Springs area consists of common pale to medium-brown-weathering silty mudstone with local buff-weathering carbonate layers, and dark brown-weathering shale. Near the east-central part of the area mapped, close to its base, the sequence includes a thick (up to 46 m; Chernoff, 1976) oolitic, hematite-magnetite siliceous iron formation. Several kilometres along strike to the north, and at the same stratigraphic level, massive black carbonaceous and siliceous mudstone and silty mudstone mark the base of the unit. Similarly resistant siliceous rocks mark the upper part of the unit, which underlies many of the highest ridges in the south and east parts of the area mapped. They are very dark weathering and consist mainly of blocky weathering, medium-grained feldspathic cherty quartz arenite, and fine-grained carbonaceous siliceous litharenite.

LOWER CRETACEOUS SHALE, SILTSTONE, AND QUARTZ ARENITE

The two units bounding the east side of the map area were taken from the mapping of Chernoff (1976), who shows numerous overturned beds within their bounds. He assigned the shale, siltstone, and quartz arenite comprising the units to the

Figure 10. *Limy pebble conglomerate or pebbly limestone common to Carboniferous or Permian (?) rocks of the Ettrain or Jungle Creek formations; pebbles are predominantly chert.*

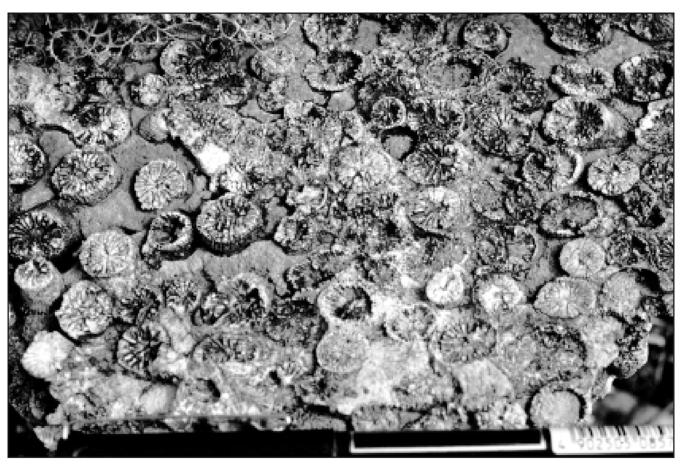

Figure 11. *Carboniferous or Permian (?) colonial corals common in limestone of the Ettrain or Jungle Creek formations in the eastern part of the map area.*

Cretaceous Marten Creek and Goodenough (*sic*) formations. Norris (1981) assigned them a Lower Cretaceous age, and included them in his 'KWC' unit and the Mount Goodenough Formation.

STRUCTURAL GEOLOGY

Folds are the dominant structural feature in the map area, and wavelengths of the typical east-vergent, open to tight and locally overturned folds are on the order of 1-5 km (Figs. 5, 6, 12). The folds occur across the crest of an approximately 20-km-wide, northerly trending and doubly plunging anticlinorium centred on the mineralized showings at Rusty Springs. The east side of this domal feature corresponds to the Porcupine Anticline of Norris (1981). Brittle faults are common on the property, and have been intersected in drill holes and interpreted from geophysical surveys and surface features (such as linear stream patterns), but none of these faults appears to offset map units at the property scale. The plunge reversal that corresponds with the mineralized area and which has been interpreted by some (e.g., Chernoff, 1976) to have been associated with a brittle fault, appears from the map patterns to be fold-related and the consequence of some deeper level structure, such as a lateral ramp.

Several property-scale cross-sections have been prepared previously, beginning with that of Chernoff (1976), and followed by Kirker (1980) and Tempelman-Kluit (1981). Chernoff (1976) shows a large-scale easterly overturned antiform, which is centred on the Rusty Springs showings and which he interprets as being cored by intrusive rocks and floored by north-trending, east-directed thrust faults. In contrast, Kirker (1980) and Tempelman-Kluit show inferred, north-trending faults, but interpret them as west-vergent contractional faults. They also show related folds with generally open geometries (Kirker 1980; Tempelman-Kluit, 1981). Cross-sections based on improved bedding control, compiled in part from previous work and benefitting from recent drill hole control, suggest that the structural setting is somewhat more akin to that shown by Chernoff (1976), in that the transport direction across the anticlinorium is toward the east. An east-directed transport direction is also more in accord with the regional sense of vergence (e.g., Fig. 3).

Figure 12. *Anticline outlined by Ettrain and/or Jungle Creek formation limestones in the southeast corner of the map area; elevation of hill is 250 m.*

Speculatively, the area may be floored by a large-scale east-vergent contractional fault, in part as envisioned by Chernoff (1976). Key to this interpretation are the steeply dipping and overturned Cretaceous rocks along the east side of the area (Figs. 4-6) mapped by Chernoff (1976). They may represent the eastern, overturned limb of the northern Porcupine Anticline, and may be floored by an inferred southern continuation of an east-vergent contractional fault shown by Norris (1981). Norris sees this fault as bounding a panel of Late Proterozoic to early Paleozoic rocks on their east side, about 15-20 km to the north-northeast. If this is the case, the doubly plunging anticlinorium underlying the Rusty Springs area may reflect the influence of a deep-seated feature, such as a lateral ramp, along the inferred contractional fault.

MINERALIZATION

Although exploration models utilized at Rusty Springs have tended to exclusively target either stratabound (e.g., Mississippi Valley-type (MVT) or Irish Plains-type) or discordant styles of mineralization (hydrothermal veins), there appears to be good evidence for both styles on the property, and they appear to be genetically related. Both styles of mineralization are found almost exclusively in the upper Ogilvie Formation and in the vicinity of the Mike and Orma hills (Fig. 7; Hansen and Bankowski, 1979). Their spatial association, similar geochemical signatures, and association with similar brecciated and dolomitized zones suggest the genetic link. Potential rests mainly with the stratabound mineralization, which may have greater thickness, much greater continuity, and can be much more readily explored.

VEIN-TYPE MINERALIZATION: THE ORMA ZONE

Mineralization at the Orma zone, on the northwest flank of Orma Hill, has been the focus for the bulk of the exploration work at Rusty Springs. Up to the 1990s, virtually all of the drilling on the property occurred there. The zone has yielded many of the highest grades in grab samples, trenches, and drill core (e.g., DDH80-1: 583 g/t Ag, 8.23% Pb, and 1.48% Cu over 6.5 m). Trenching and drilling have confirmed that it is a discontinuous vein and stockwork zone, which trends northwest and dips steeply. Vein-type mineralization also appears to be present locally at Mike Hill. However, here relatively high Zn and trace Au values commonly accompany the Ag, Pb, and Cu (Downie, 1994; e.g., DDH95-07: 518 g/t Ag, 0.77% Pb, 3.0% Cu, and 1.3% Zn over 15.3 m; see Fig. 13).

Veins consist of massive galena-tetrahedrite (tennantite?, as is suggested by elevated As:Sb ratios in some assays; Liedtke, 1980), locally up to 1.0 m thick, which assay roughly 10-50 g/t Ag. The veins are contained within a broader, commonly oxidized, mineralized and altered zone (in part, a stockwork) of up to 6 or 7 m in thickness. The altered zone typically assays 30 to 60 g/t Ag; Davis and Aussant, 1982). Alteration within Ogilvie Formation carbonates, as described by Bankowski (1980b), is characterized by silica replacement, dolomitization, local brecciation, sanding (silicic alteration?), and decomposition (supergene alteration). It is also manifest in part, as a darker grey colour of the host rocks. The margin of the altered zone has a northwest trend, subparallel to that of the mineralized zone, and it appears to terminate, or turn bedding-parallel, to the southeast at the contact with overlying siliciclastic rocks (Bankowski, 1980b). Minerals identified from the oxidized zones include smithsonite, cerussite, malachite, azurite, aurichalcite, pyrolusite, hemimorphite, plumbojarosite, gibbsite, valentinite, and natroalunite (Hansen, 1979; Kirker, 1980b); sphalerite and pyrite are also preserved locally with galena and tetrahedrite in siliceous vein and vein-breccia material.

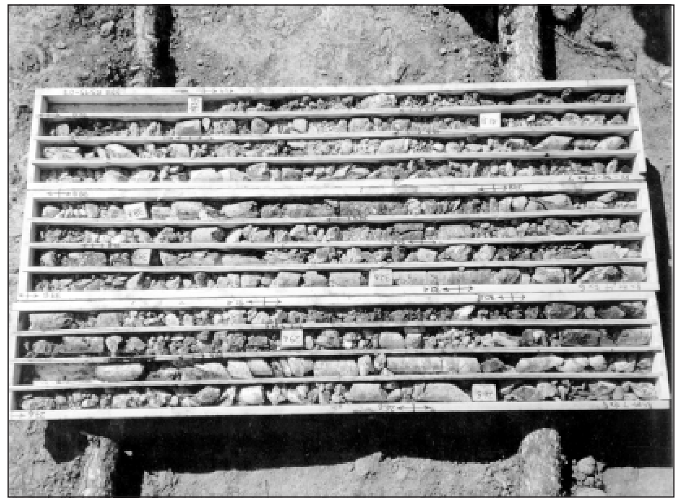

Figure 13. *Typical broken and crumbly nature of clay-rich and limonitic supergene-altered mineralization at Rusty Springs in drill core. In this case the mineralized zone represents discordant material from Mike Hill, but it is similar in general appearance and mineralogy (though of higher grade) to typical Katshat unit mineralization. DDH95-07: 15.3 m assaying 518 g/t Ag, 0.77% Pb, 3.0% Cu, and 1.3% Zn.*

STRATABOUND MINERALIZATION: THE KATSHAT UNIT

Near the end of the 1996 exploration program, stratabound mineralization along the contact between the Ogilvie Formation and overlying Devono-Mississippian siliciclastic rocks became the principal exploration target (Termuende and Downie, 1997). Almost all holes drilled in footwall Ogilvie Formation dolostone had essentially been barren. Relatively thick oxidized mineralization was previously intersected at the contact, in hanging wall siliciclastic rocks. Thus substantial potential existed for stratabound mineralization. It was also recognized that the most extensive geochemical anomalies on the property coincided with the contact, and that many drill holes targeting them had been collared in the strongly oxidized mineralized material. These holes had been plagued by poor core recoveries.

The oxidized material common to the upper contact of the Ogilvie Formation was referred to locally as the Katshat unit. It consists of strongly leached, porous limonitic to kaolinitic material with an earthy, gougy consistency, and is similar in appearance to the oxidized material surrounding discordant mineralization (e.g., Fig. 13, 14). It is typically 20 to 40 m thick, and although it appears stratabound at the property scale, in detail, it is irregular and discordant. Many of the minerals noted above as occurring in the Orma zone are also common in the Katshat unit. X-ray diffraction studies indicate that much of the

Figure 14. *Trench in Katshat unit from near top of Mike Hill, which shows typical crumbly to rubbly appearance and deep weathering profile of supergene-altered mineralized zones, with darker limonite-rich parts and paler kaolinite-rich parts. Also shown is Bob Termuende, the driving force behind exploration at Rusty Springs for nearly 25 years.*

Katshat material consists of granular Fe, Mn, Ag, Pb, Zn, Cu, Ba, Al, P as well as V oxide, carbonate, sulphate, and silicate mineral species. In addition, there are quartz veinlets and laminae locally containing sulphides and sulphosalts like those in Orma zone veins and vein stockwork (Hodder, 1997). The Katshat unit is invariably overlain by brecciated and veined siliceous or silicified mudstone and chert of probable Devono-Mississippian age which caps it and in part has protected it from erosion. It is underlain by Ogilvie Formation dolostone, also typically brecciated and veined. The Katshat unit is strongly anomalous in Ag, Cu, Pb, and Zn over broad intervals and across a wide area. For example, hole RS96-04 from the southwest part of Mike Hill had an intersection of 1.1 g/t Ag, 881 ppm Cu, 139 ppm Pb, 3301 ppm Zn over 19.1 m. In addition, hole RS96-14 from the south end of the airstrip on Orma Hill contained 1.6 g/t Ag, 1475 ppm Cu, 1321 ppm Pb, and 2701 ppm Zn over 22.2 m (see Fig. 8). Results such as these suggest the possibility of tremendous continuity and potential. The oxidized nature of the mineralization and the sub-economic grades also suggest that the preferred target be unoxidized portions of the horizon below the present and/or paleo-water table (Hodder, 1997). Unoxidized Katshat unit was the target of the latest drill program, which attempted to test the upper Ogilvie Formation to the east and south of Orma Hill (Figs. 7 and 8). Results were mixed. The mineralized horizon was not reached due to problems penetrating the very resistant siliceous and brecciated rocks which overlie the upper Ogilvie Formation and cap the Katshat horizon. However, the presence of the siliceous rocks suggests that a strong stratabound mineralizing system existed well away from the surface exposures on Mike and Orma hills. The new information confirms that the Rusty Springs system is very large, and that it has significant potential remaining to be tested.

TIMING OF MINERALIZATION

The interpretation that Rusty Springs is a Mississippi Valley-type deposit related to karsting along the upper Ogilvie Formation contact suggests that the mineralizing event was likely bracketed by the Middle Devonian rocks below and the Late Devonian to Mississippian rocks above. On the other hand, the discordant nature of mineralization and alteration at Rusty Springs indicates that it postdates deposition of the early to Middle Devonian Ogilvie Formation and at least the lowermost part of the overlying Devono-Mississippian section. In addition, there is a lack of obvious cleavage development in the Ogilvie Formation dolostones, which contrasts sharply with most rocks across the property, including other carbonates. This suggests that the mineralizing event may even have postdated much of the Latest Cretaceous to Tertiary deformation affecting the area. Alternatively, it is possible that this may reflect a contrast in competency between the more competent silica-altered and dolomitized rocks associated with mineralization, and other less competent lithologies, or, that a more subtle stylolitic cleavage exists in the dolostones. Further study is needed. The parallelism of the Orma zone with structural trends (a fold axial plane?) and localization of Katshat-style mineralization in anticlinal hinge zones at Orma and Mike hills also supports the hypothesis that mineralization post-dated deformation. A relatively young age is also supported by the rare occurrence of discordant metre-scale quartz or Fe-carbonate vein/breccia bodies at high stratigraphic levels (Carboniferous to Permian) in the area surrounding Rusty Springs. Limited Pb isotope data supports the young age, as they approximate those of Cordilleran Ag vein deposits of Late Mesozoic age (Kirker, 1982).

GENESIS

As mentioned above, several deposit models, including those for MVT and hydrothermal replacement along a karsted surface, have been employed in an effort to aid exploration at Rusty Springs. Poor exposure and consequent lack of local bedding control has hindered the collection of evidence with which to evaluate the various models, as has leaching and oxidation of the mineralized zones and dolomitization of footwall rocks. However, discussion of some of the existing evidence is worthwhile so that some models may be critically evaluated and perhaps ruled out, and others put forward in the hope that they aid exploration.

MISSISSIPPI VALLEY-TYPE

Few, if any, of the textural features distinctive of MVT deposits (e.g., Leach and Sangster, 1993) have been positively identified on the property. For example, although the breccias common on the property have been interpreted as solution collapse features (e.g., Hansen, 1979; Hodder, 1997), cements and matrices of carbonate and local quartz are either massive or encrusted symmetrically around breccia fragments (e.g., Kirker, 1982). There is no evidence for infilling by internal sediment, which would be strongly suggestive of a karst environment. Stratigraphic evidence also appears to argue against a karst environment. No regolith is preserved along the contact between the Ogilvie Formation and the overlying siliciclastic rocks that would indicate subaerial exposure, and even evidence for uplift, such as the presence of coarse-grained clastic rocks, is lacking. According to Liedtke (1980), very little relief exists on the contact, and if anything, subsidence is indicated. The stratigraphic transition is from a shallow water environment in which platformal carbonate was deposited, to a deeper water environment in which basinal shales were deposited.

Differences from classic MVT deposits also exist in the geochemistry and mineralogy at Rusty Springs, as has been noted by many previous workers. The high copper and silver contents, as well as low Zn:Pb ratios are generally atypical of MVT deposits (Leach and Sangster, 1993), as are locally very high As and Sb values and the high Al values occurring in the Katshat unit (Termuende and Downie, 1997). A geochemical fingerprint such as this is more consistent with an epithermal origin for metals within the host unit. Similar arguments can be made on mineralogic grounds, with the siliceous character of alteration, particularly in the hanging wall, and the common presence of tetrahedrite and argentiferous galena, which are more diagnostic of vein rather than stratabound Ag-Pb-Zn deposits. Fluid inclusion and sulphur isotope data from quartz, calcite, and sphalerite at Rusty Springs are also more comparable to those from epithermal deposits than from those of MVT (Kirker, 1982).

Regionally, the evidence also argues against an MVT setting. As Hodder (1997) notes, it is significant that the Ogilvie Formation at Rusty Springs is comprised largely of dolostone in an area in which limestone generally predominates. Even within the Ogilvie Formation itself, the regional dolomitization common to MVT districts appears to be absent. Norris (1996) describes only local dolomite beds in the lower part of the Ogilvie Formation in measured sections farther south in the Ogilvie Mountains.

In spite of the arguments against the presence of MVT mineralization, it remains possible that the mineralization and alteration evident on the Rusty Springs property may simply be the distal expression of a more typical MVT system. However, it may be an MVT system with its origins in a hydrothermal karst system, rather than a meteoric or meteoric-hydrothermal one (*cf.* Leach and Sangster, 1993).

HIGH-TEMPERATURE, CARBONATE-HOSTED MASSIVE SULPHIDES: MANTO-CHIMNEY COMPLEXES

The mineralizing system at Rusty Springs bears some of the features of high-temperature, carbonate-hosted massive sulphide deposits (Titley, 1993), which are also commonly referred to as manto-chimney complexes, and are rich sources of base and precious metals. This type of deposit, although occurring in quite varied structural or stratigraphic settings, is typically wholly or partially stratabound, commonly contains abundant pyrite, and contains Pb and significant Ag. Copper and Au can be present but are less common than Ag-Pb-Zn, and enrichment in one or the other of Cu-Pb-Zn can be variable. The deposits are generally thought to occur by replacement processes, initiated by hot fluids and/or gases, above or near centres of thermal activity, and thus intrusions are commonly (though not always) spatially associated. Vein, skarn, and even porphyry copper deposits may be closely associated with the manto-chimney ores, and it is generally accepted that all are genetically related to the associated intrusions (Titley 1993).

Termuende (1996) initially recognized the potential for manto-chimney deposits at Rusty Springs. The few preserved hypogene ore minerals recognized at Rusty Springs, such as galena and tetrahedrite, are common in the manto-chimney class. The silica alteration common on the property is also commonly peripheral to ore in this deposit type, or at least to districts in which such deposits occur. In addition, dolomitization is known to play a role in the formation of many high-temperature, carbonate-hosted deposits, and breccia bodies also common to these systems (Titley, 1993). The apparent controls on mineralization at Rusty Springs, such as the overlying impermeable fine-grained siliceous shale cap, and perhaps the anticlinal fold hinges at Mike and Orma hills, also bear similarities to some manto-chimney deposits (e.g., Tombstone, Arizona; Titley, 1993). This factor of predictability is an important advantage in exploration for manto-chimney ores, since they are known to be difficult in terms of exploration. One of the main arguments against the application of the manto-chimney model at Rusty Springs is the lack of direct evidence for intrusive rocks, either on the property or in the region. However, Chernoff (1976) shows an inferred intrusion at depth below the domal core of the Rusty Springs antiform. The nearest known plutons to Rusty Springs property are Devonian (?) in age and outcrop to the north in the vicinity of Old Crow (Fig. 1; Woodsworth et al., 1991).

OTHER ECONOMIC POTENTIAL IN THE VICINITY OF RUSTY SPRINGS

Little in the way of significant mineralization has been found in the immediate area around Rusty Springs, but recent work and a re-evaluation of work done previously indicates that some potential exists and warrants testing. For example, in the most recent drilling, an interval approximately 40 m thick within the Devono-Mississippian pyritic shales that overlie the Ogilvie Formation was highly anomalous in zinc. It included intersections of 7 and 15 m, which returned nearly 3000 ppm Zn. Although the hole did not reach its target, it is estimated that the Zn-rich zone lies approximately 100-150 m up-section from the Ogilvie Formation, at about 250 m depth. The zone occurs within a siliceous or weakly silicified carbonaceous pyritic mudstone. Sphalerite occurs as disseminated fine- to medium-grained, honey-brown grains, both within mudstone clasts, and within host rocks, as well as in zones of quartz or quartz-carbonate microbreccia. The pyritic and locally zinc-rich shales may be the source for the gossanous springs near the base of the north end of Mike Hill which lend their name to the Rusty Springs property. In fact, sediment issuing from the springs themselves was highly anomalous in zinc (Chernoff, 1976). This suggests further that the recessive shale package may have potential for hosting Zn deposits, either similar in character to Rusty Springs, or perhaps of the Sedex type (sedimentary exhalative). Rocks of similar age, character, and tectonic setting further southward in the Cordillera (e.g., Macmillan Pass area, Yukon; Gataga district, B.C.; Dawson et al., 1991) also indicate similar mineral potential. One might begin to evaluate this potential immediately south-southeast of the area mapped, where rusty creeks and springs, similar in appearance to those at the Rusty Springs property, were noted in the drainage that lies in the recessive core of Norris' (1981) Porcupine Anticline. The springs likely emanate from rocks correlative with the recessive and pyritic Devono-Mississippian rocks that overlie the Ogilvie Formation in the area mapped.

With regard to other possibilities, rare iron-carbonate breccia and siliceous veins and vein breccias were noted in outcrop or float while mapping the surrounding ridges, but none bore visible sulphides, appeared extensive, or was accompanied by significant alteration. About 40 km further south, however, at the Pama (Bern) occurrence, which lies just inside the western boundary of the proposed Fishing Branch Protected area, an impressive, steeply dipping, north-northwest-trending quartz-carbonate breccia zone that is hosted by carbonates can be traced for greater than 2 km. It is outlined by a broad and intense soil geochemical anomaly (O'Donnell, 1974) and near its southern end, contains tetrahedrite, copper oxides, and zinc and lead sulphates that bear some similarities to mineralization at Rusty Springs. The Pama property has never been drill-tested, yet smithsonite-rich samples yield assays of up to 47.80% Zn. Although it is hosted in carbonates and has at least some mineralogic similarities to Rusty Springs, no convincing evidence was found at the Pama property that was suggestive of a significant element of stratigraphic control to mineralization. The breccia zone is hosted by limestone that is probably correlative with the uppermost limestones in the vicinity of Rusty Springs (Upper Carboniferous and Permian (?); considerably younger than the Ogilvie Formation). The breccia appears to dip steeply to the east-northeast, and lies subparallel to the steeply dipping eastern limb of what appears to be a gently southerly plunging, asymmetric, east-vergent antiform. The breccia appears to be hosted entirely within limestone, and the limestone is only very locally dolomitized, which is in sharp contrast to Rusty Springs, where the better part of the Ogilvie Formation is dolomitized. Overlying the limestone is a sequence of relatively recessive, fine-grained black carbonaceous rocks that appears to be capped by more resistant siliceous sandy beds. The sequence is similar in appearance to the Jurassic and Lower Cretaceous rocks along the east margin of the area mapped at Rusty Springs.

SUMMARY AND CONCLUSIONS

In spite of many years of sound exploration work, the genesis of the Rusty Springs prospect remains incompletely understood, yet its considerable potential for a large-tonnage Ag-Pb-Zn-Cu deposit remains inadequately tested. The extent of the mineralized and altered rocks at Rusty Springs suggests that the hydrothermal system is large. In fact, limits to the altered and brecciated zones in the upper Ogilvie Formation have yet to be established, with the possible exception of the northeast part of the property (Bankowski, 1980b). The size of the mineralizing system, together with its apparent stratabound nature, its commonly significant but sub-economic thicknesses, its local high grades, and its potential for supergene enrichment, indicates that Rusty Springs remains an attractive exploration target. Future exploration should be drill-oriented and should target the uppermost Ogilvie Formation beneath Devono-Mississippian fine-grained clastic rocks to the south and southeast of Mike and Orma hills.

The region surrounding Rusty Springs has the potential for Sedex-type mineralization displayed by the Devono-Mississippian fine-grained clastic rocks, and that of the carbonate-hosted vein/breccia on the Pama claims. This suggests that prior to alienation of the large tracts of land in the proposed Fishing Branch Protected Area that are underlain by favourable geology, the Paleozoic rocks (at a minimum) merit baseline geological information, such as regional stream sediment data controlled by up-to-date 1:50 000 scale geologic mapping. This information is particularly relevant in areas like the northern Yukon, which are more difficult to explore because of the lack of extensive Pleistocene glaciation. Such data collection can only provide a more sound footing for the present process of Protected Area evaluation and will yield a useful database for all stakeholders.

ACKNOWLEDGMENTS

Tim Termuende and Chuck Downie of Eagle Plains Resources Ltd. are acknowledged for their support and assistance in preparing this paper. Yukon and federal government geologists Danièle Héon, Grant Abbott, and Mike Burke spent several days based in the Rusty Springs camp examining prospects in the proposed Fishing Branch Protected Area. Their work was particularly helpful in correlating the rock units mapped in this study with stratigraphic units identified by previous workers. Burke also provided copies of several theses done at Rusty Springs. Steve Irwin at the Geological Survey of Canada is thanked for prompt supply of paleontologic data for the Rusty Springs area. Thanks also go to Diane Emond for careful editing and for guiding this paper through to publication.

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APPENDIX 1

Summary of exploration work on the Rusty Springs property.

Year	Work done	Company	Interpretations	Drilling	Significant results	Expenditure	Reference
1976	staking, prospecting, mapping, limited soil sampling, hand-pitting	Rio Alto Exploration Ltd.	intrusive-related hydrothermal vein systems with supergene enrichment		Chip samples of float from several localities with 30-40% Zn, 5-15% Cu, and variable Pb and Ag; grab samples commonly averaged 10-70 opt (300-2000 g/t) Ag	$150,000	Chernoff (1976)
1977	prospecting, mapping, grid-soil sampling, diamond drilling, staking, metallurgical sampling	Rio Alto Exploration Ltd.	precious-metal-enriched Mississippi Valley-type (MVT) model adopted	3200 ft. (975 m) in 8 holes	High Ag and Pb values in one hole (123 ft. averaging 33.27 opt (947.5 g/t) Ag, 4.72% Pb, 2.36% Cu) but with poor recoveries	$187,000	White (1978); Schoel (1978)
1978	extensive line cutting and soil geochemistry, prospecting, diamond drilling, mapping, construction of winter road and airstrip	Rio Alto Exploration Ltd.	mineralized zones on Orma Hill follow low-angle fault; MVT model still accepted	6035 ft. (1840 m) in 30 holes	stratigraphic control noted on anomalous soil geochem zones following chert–dolomite contacts: Cu-Pb-Ag±Zn on Orma Hill; Zn±Cu±Pb±Ag on Mike Hill; poor recoveries in drilling	$555,000	Beck (1978)
1979	Induced Polarization and gravity surveys, line cutting, prospecting, mapping, soil sampling, hand pitting, trenching	Rio Alto Exploration Ltd.	MVT model still accepted		extent of upper Ogilvie Formation (mineralized showings or float found throughout) and contacts with overlying siliciclastic rocks established	$300,000	Hansen and Bankowski (1979); White (1979)
1980	diamond drilling, cat trenching, detailed mapping	E&B Explorations Inc. and Rio Alto Exploration Ltd. joint venture	mineralization considered to be of hydrothermal origin; Ogilvie-Hart River contact still considered a karsted horizon channelling mineralizing solutions	6,000 ft. (1829 m) in 27 holes	poor recoveries in upper parts of holes; numerous cm- to decimetre-thick tetrahedrite-tennantite veins intersected, which commonly yielded high Ag, Pb, and Cu values; mineralization on Orma Hill in part appears to be vein-related	$1,200,000	Bankowski (1980); Liedtke (1980)
1982	soil geochemistry, VLF-EM surveys, mapping, trenching, diamond drilling	Kenton Natural Resources Corporation	epithermal veins	1673 ft. (510 m) in 7 holes	common WNW-, NW-, and NNW-trending EM conductors outlined; Orma Hill vein systems defined	$116,000	Davis and Aussant (1982)
1983	fill-in soil geochemistry and VLF-EM surveys, diamond drilling	Kenton Natural Resources Corporation	epithermal veins	1600 ft. (488 m) in 2 holes	focussed on Orma Hill vein systems	$350,000	Aussant (1983)
1986	diamond drilling	Kenton Natural Resources Inc.		1326 ft. (404 m) in 2 holes	tested (unsuccessfully) IP anomalies between Orma and Mike hills	$96,000	Chamberlain (1986)
1992	restaking						

Appendix 1. *continued*

Year	Work done	Company	Interpretations	Drilling	Significant results	Expenditure	Reference
1994	regional reconnaissance; trenching, airstrip and road construction; clean-up	Eagle Plains Resources Ltd.	epithermal veins, MVT		vein mineralization on 040°-trend discovered using soil geochem and trenching on Mike Hill; new showings discovered SW of Mike Hill	$190,000	Downie (1994)
1995	trenching, diamond drilling, soil geochemistry, staking, airstrip and road construction, GPS survey, claim staking	Eagle Plains Resources Ltd.	manto-chimney-type carbonate-hosted deposits	5440 ft. (1658 m) in 21 holes	15.1 oz/ton (425 g/t) Ag, 3% Cu, and 1.3% Zn over 50 ft. (15.3 m) on Mike Hill	$539,000	Termuende (1996)
1996	diamond drilling; airstrip extension, road construction, staking	Eagle Plains Resources Ltd.	carbonate-hosted manto-type deposits; stratabound hydrothermal mineralization along Ogilvie-Hart River Formation contact	7610 ft (2320 m) in 15 holes	highly anomalous base metal values over significant widths along Ogilvie-Hart River Formation contact	$560,000	Termuende and Downie (1997)
1997	reverse-circulation drilling, surface mapping, prospecting, road and drill pad construction, improvements to airstrip	Eagle Plains Resources Ltd. and Canaustra Resources Ltd.	stratabound hydrothermal mineralization along Ogilvie-Hart River Formation contact	1351 feet (412 m) in 8 holes	two widely spaced holes drilled through Ogilvie-Hart River Formation contact, confirming presence of stratabound mineralization; affirmation of distribution of chert and shale, including in low-lying areas (may cap mineralization preserved beneath the water table)	$356,000	Termuende and Downie (1998); Hodder (1997)
1998	gravity and seismic reflection surveys, property reconnaissance prospecting and mapping	Eagle Plains Resources Ltd. and Canaustra Resources Ltd.	stratabound hydrothermal mineralization along Ogilvie-Hart River Formation contact, below present and paleo-water tables		continuation of prospective stratigraphy at shallow depths northeast of Orma Hill; coincident with gravity anomalies	$54,000	Power (1998)
1999	diamond drilling, property-scale mapping, regional reconnaissance mapping, prospecting, and sampling; clean-up	Eagle Plains Resources Ltd. and Canaustra Resources Ltd.	stratabound hydrothermal mineralization along Ogilvie-Hart River Formation contact, below present and paleo-water tables	1040 ft. (317 m) in 3 holes		$273,000	in progress
				total drill frontage: 36,264 ft. (11,050 m) in 123 holes		**total expenditures: $4,927,000**	

APPENDIX 2

Exploration methods employed on the Rusty Springs property.

Method	Aim of survey/application	Results and comments	Recommendations
prospecting	locating mineralization	successful in locating silica-hosted vein-type mineralization	useful for following-up geochem
soil geochemistry	to locate potential mineralized zones and target trenches and drill holes	in spite of thick overburden and permafrost, effective in outlining near-surface mineralization	target top of Ogilvie Formation on remaining unsampled parts of property
stream geochemistry	location of new drill targets	creek sampling led to discovery of new showings local to property; geochemically anomalous drainages present in region	regional stream sediment sampling, targeting Ogilvie Formation and overlying shale
trenching	to reach bedrock	mixed success with cat trenching: bedrock exposure not guaranteed; may require 2 seasons; environmental degradation problems	any further trenching may be more successful using an excavator
geophysics	targeting drill holes	most geophysical anomalies tested were coincident anomalies	
IP	targeting sulphides	resistivity anomalies outlined, but drill testing unsuccessful	not recommended without sound geologic framework
VLF-EM	targeting conductive sulphide horizons	many conductors outlined, but drill testing unsuccessful; may outline water-filled gougy fault zones	not recommended without sound geologic framework
magnetometer	targeting sulphides	anomalies outlined but unexplained; drill testing unsuccessful	not recommended without sound geologic framework
gravity	targeting more dense sulphides	anomalies outlined, but drill testing unsuccessful	several anomalies untested; not recommended without sound geologic framework
seismic	determining depth to favourable stratigraphic contact	unsuccessful, possibly imaged permafrost horizon	not recommended without sound geologic framework
drilling			
diamond drilling		reasonable drilling and recovery in oxidized mineralized zones using modern equipment and drilling techniques; drilling slow in resistant siliceous zones	recommended for future work; need high-powered rig, plenty of casing, mud, bits, core barrels, and patience
RC drilling		difficult drilling in oxidized mineralized zones; good drilling in resistant siliceous zones	not recommended

The Harlan property: A new sediment-hosted gold discovery in the Selwyn Basin, Yukon

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Schulze, C. and Johnson, G., 2000. The Harlan property: A new sediment-hosted gold discovery in the Selwyn Basin, Yukon. *In:* Yukon Exploration and Geology 1999, D.S. Emond and L.H. Weston (eds.), Exploration and Geological Services Division, Yukon, Indian and Northern Affairs Canada, p. 267-270.

ABSTRACT

The Harlan property is a significant new sediment-hosted gold prospect within the Selwyn Basin of east-central Yukon Territory. The property has a large, kilometre-scale surface gold-arsenic-antimony-mercury-bismuth anomaly within a thick sequence of Paleozoic Selwyn Basin shelf and off-shelf sedimentary rocks. A series of mid-Cretaceous, late-stage, Tombstone Suite, quartz-feldspar-porphyritic monzonite dykes and small plugs intrude these rocks. Two major mineralized zones have been defined: 1) the Vortex Zone, a thick package of strongly brecciated, silicified, and argillic-altered coarse clastic sedimentary rocks overlain by a thrust-faulted argillite member; and 2) the West Porphyry Zone, consisting of abundant mineralized and altered monzonitic dykes. Surface sampling over the Vortex Zone has defined a north-northwest-trending 1600 m by 700 m zone averaging over 500 ppb gold in soils, with rock sample values up to 6.5 g/t Au. Within this zone, an intensely brecciated area measuring 500 m x 300 m averages greater than 1 g/t Au in soils. A broad anomalous area was identified from surface sampling across the West Porphyry Zone, revealing gold-in-silt values up to 230 ppb and numerous rock chip samples over 1.0 g/t Au. No drilling has been done on the property to date. NovaGold Resources plans to complete detailed surface geological mapping, geochemical sampling, and geophysical surveys to refine drill targets for testing in 2000.

RÉSUMÉ

La propriété Harlan est un nouvel indice aurifère important dans des sédiments du Bassin de Selwyn, dans le centre-est du territoire du Yukon. La propriété contient une vaste anomalie de surface en or, arsenic, antimoine, mercure, et bismuth, d'échelle kilométrique, au sein d'une épaisse succession de roches sédimentaires de plateau et de talus de continental du Paléozoïque du Bassin de Selwyn. Une série de dykes et de petits dômes intrusifs tardifs de monzonite porphyrique à quartz et feldspath, d'âge Crétacé moyen de la Série plutonique de Tombstone, recoupent les roches sédimentaires. Deux zones minéralisées majeures sont reconnues : 1) la zone Vortex, une épaisse séquence de roches sédimentaires clastiques à grains grossiers qui sont fortement bréchiques, silicifiées et altérées (argillique), et qui est chevauchée par un membre d'argilite; et 2) la zone de porphyre ouest, contenant de nombreux dykes de monzonite minéralisés et altérés. L'échantillonage de surface sur la zone Vortex a permis de définir un corridor d'orientation nord-nord-ouest, long de 1 600 m et large de 700 m, où les sols ont des concentrations moyennes de plus de 500 ppb d'or, et les échantillons de roches titrent jusqu'à 6,5 g/t Au. Au sein de ce corridor, une région fortement bréchique, de 500 m par 300 m, a des concentrations moyennes de plus de 1 g/t Au dans les sols. Une vaste anomalie, identifiée par l'échantillonage de surface sur la zone de porphyre ouest, révèle des valeurs atteignant 230 ppb Au dans les silts et de nombreux fragments de roches contenant plus de 1,0 g/t Au. Il n'y a pas eu de forage exécuté sur cette propriété jusqu'à ce jour. NovaGold Resources prévoit compléter la cartographie géologique détaillée, l'échantillonage géochimique, et des relevés de géophysique afin de définir des cibles de forage qui seront examinées au cours de l'année 2000.

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LOCATION AND ACCESS

The Harlan property is 100% owned by NovaGold Resources Inc. It is located 150 km north of the town of Ross River, within the Tintina gold belt of Yukon Territory (Fig. 1). It is centred at 63°14' north latitude, 131°40' west longitude on NTS map sheets 105O/4 and 105O/5. The property consists of 339 Yukon quartz mining claims covering 7098 hectares (17,490 acres). The property, located 35 km southeast of the Plata airstrip, has winter road access from Yukon Highway 6 (the North Canol Road), 60 km to the southeast.

HISTORY AND PREVIOUS WORK

The Harlan project area was first identified by Viceroy Resources Inc. in 1997 during a regional exploration program focussed on bulk tonnage, intrusive-related and sediment-hosted (Carlin-style) gold systems. A thorough GIS database compilation was undertaken of all available regional stream sediment geochemistry, Yukon Minfile occurrences, airborne geophysics, Thematic Mapper Landsat satellite imagery, and published geology for the Selwyn Basin of eastern Yukon Territory (Schulze, 1998). A multi-factorial prioritization of anomalous geochemistry, geophysics, remote-sensing, and geologic data (Yukon Minfile, 1997, 105J, 105K, 105N, 105O), delineated numerous high-priority reconnaissance level exploration targets. The criteria for prioritization were based on the presence of specific characteristics similar to those found in the Tintina gold belt deposits such as Pogo, Fort Knox, True North, Donlin Creek, and Brewery Creek (Diment, 1997), as well as those for sediment hosted (Carlin-style) gold systems (Poulson, 1996). Using this approach, the Harlan property was acquired based on the return of widespread gold in reconnaissance rock, soil and silt samples (Schulze, 1998). Additional follow-up work was completed during 1998; during 1999 NovaGold Resources acquired 100% interest in the property.

REGIONAL GEOLOGY

The Harlan property is situated within the Selwyn Basin, a broad package of Paleozoic marine sedimentary rocks that extend southeast from the Alaskan border to the Yukon-Northwest Territories border. The project area is located north of the major

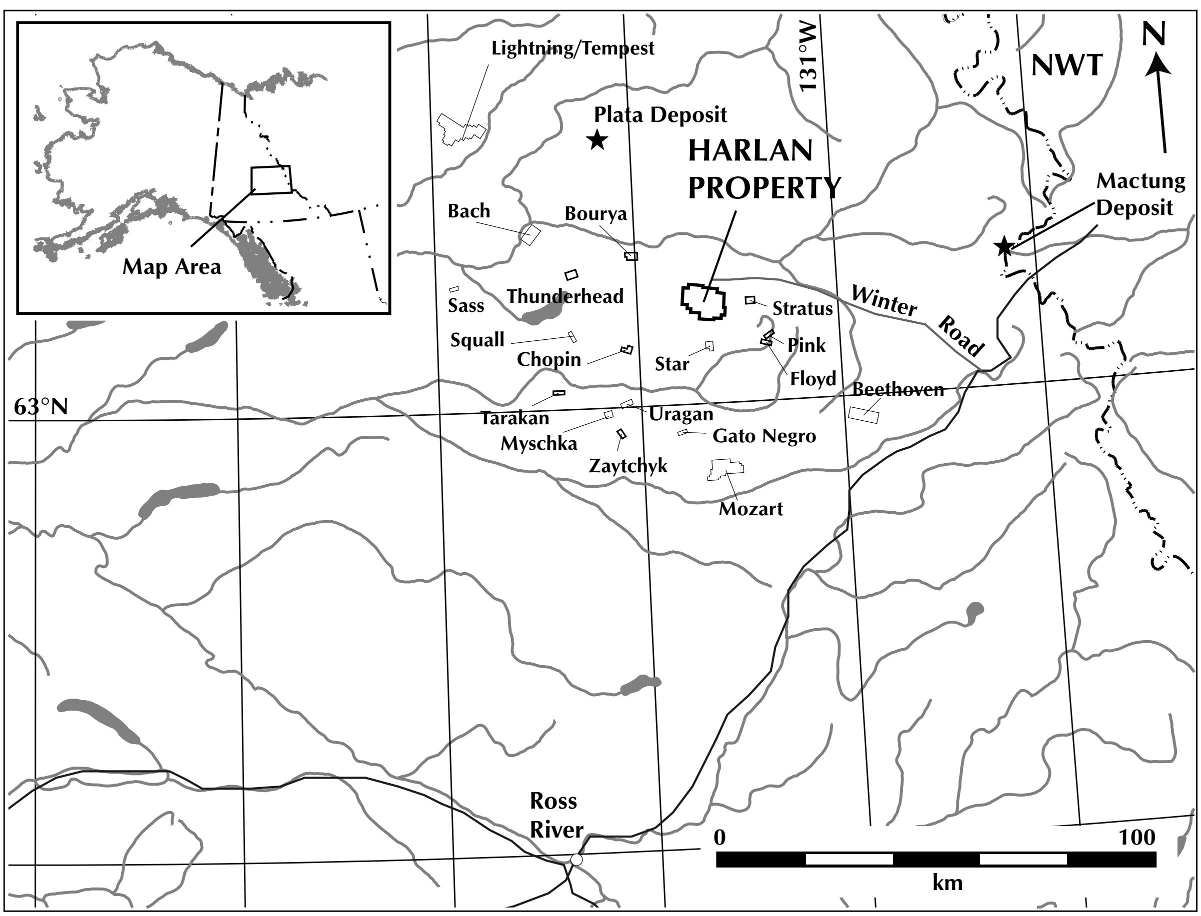

Figure 1. *Harlan property location map.*

northwest-trending Tintina Fault. The Selwyn Basin consists of shallow-shelf to off-shelf marine clastic and chemical sediments, as well as basinal clastic sediments derived from the ancient North American platform to the northeast (Gordey and Anderson, 1993). Several episodes of basin formation have occurred with deposition of chert and fine clastic sediments, followed by periods of increased erosion resulting in the deposition of sequences of higher energy, coarse-grained, shallow-water sediments (Diment, pers. comm., 1997). Age of deposition ranges from Late Precambrian to Triassic. The Selwyn Basin is comprised of numerous stratigraphic groups, including: Late Precambrian to Early Cambrian Hyland Group, consisting of coarse clastic grits and shales; Ordovician to Early Devonian Road River Group, consisting of chert, shale, and siltstone; and Devono-Mississippian Earn Group, consisting of chert-pebble conglomerate, greywacke and shale (Gordey and Anderson, 1993; Roots et al., 1995).

Sedimentary rocks of the Selwyn Basin have been intruded by the 90 to 110 Ma mid-Cretaceous Tombstone Plutonic Suite, forming a southeast-trending belt of intrusive rocks extending from Alaska to the Yukon-Northwest Territories border (Diment, 1997). These rocks vary in composition from dioritic to granitic, most commonly monzonitic to quartz-monzonitic, with common porphyritic phases. These intrusives are important due to their close association with the formation of numerous gold deposits in the region, most notably the world class Pogo and Fort Knox deposits in Alaska.

In the region of the Harlan property, several west-northwest-trending thrust faults, reactivated as dextral strike-slip faults, have formed a compressional setting of Selwyn Basin stratigraphy (Roots, 1998; Roots, pers. comm., 1998). Such faults are associated with fairly intense, locally overturned folding and comprise a broad deformation belt referred to as the "Gold River Fold Belt" (J.G. Abbott, pers. comm., 1999). Stratigraphy is dominated by a southeast-trending, imbricated assemblage of Earn Group siliclastic rocks with lesser Road River Group chert, siltstone and limestone, as well as Gull Lake Formation siliceous shale and siltstone (Cecile and Abbott, 1992). This stratigraphy occurs within a major northwest-trending regional antiformal structure. Several Tombstone suite quartz-monzonite to syenite stocks intrude this structural zone and occur within 20 km of the property.

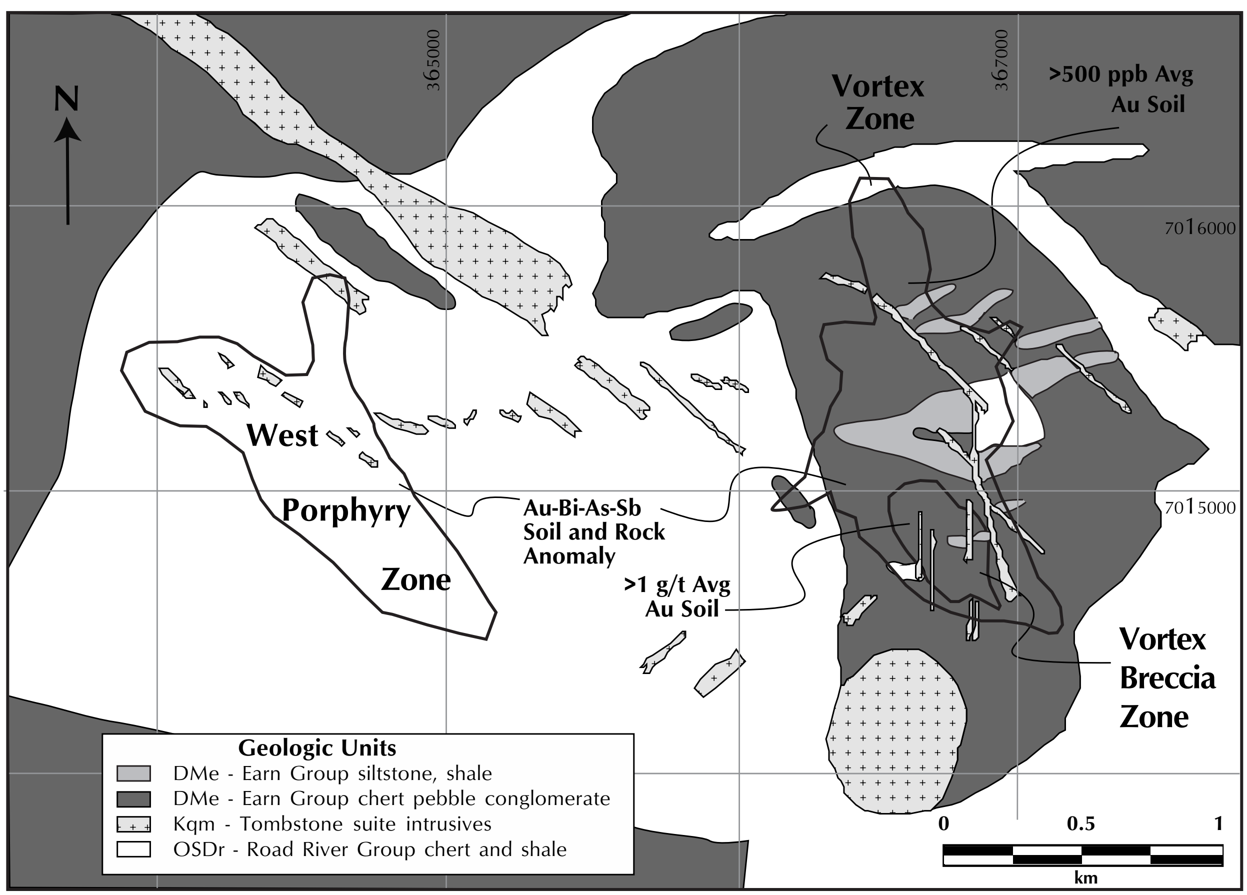

Figure 2. *Harlan property geology and geochemical anomaly map.*

PROPERTY GEOLOGY AND MINERALIZATION

The Harlan property is underlain by a thick sequence of locally calcareous chert-pebble conglomerate, sandstone and greywacke of the Earn Group; minor shale and siltstone members are present. Several southeast-trending units of Road River Group shale to siltstone, and graphitic argillite units extend across the property and appear to be thrust over locally intensely altered Earn Group rocks (Schulze, 1998). Southeast-trending, moderately south-dipping thrust faults have been mapped within Earn and Road River Group stratigraphy in the area.

An approximately 10 km^2 area of anomalous surface geochemistry has been identified on the Harlan property. Within this broadly anomalous area, two kilometric-scale target areas have been identified that contain highly anomalous gold, bismuth, arsenic, antimony and mercury in rock and soil geochemical samples (Fig. 2). Follow-up sampling on the central part of the Harlan property has identified a major northwest-trending gold-bismuth-arsenic-antimony-mercury anomaly measuring 1600 m by 700 m that averages over 500 ppb gold in soil; this area is known as the Vortex Zone. Rock samples within this zone contain values up to 6.5 g/t Au. Within this area is an intensely brecciated and clay-altered zone measuring 500 m by 300 m that contains gold-in-soil values up to 10.4 g/t Au and averages over 1 g/t Au in soil. Rocks within the breccia zone contain both altered dyke and sedimentary clasts and are highly anomalous in gold, arsenic, and mercury.

Mineralization within the Vortex Zone is associated with intense advanced argillic alteration and silicification with multi-episodic quartz stockwork and veining, and brecciation of locally calcareous chert-pebble conglomerate, greywacke, siltstone, and shale (Schulze, 1998). This sedimentary sequence has been intruded by a series of altered Tombstone suite porphyritic monzonite dykes and sills. Numerous north-, northwest-, and northeast-oriented structural zones are evident within the sedimentary sequence. These structures appear to have controlled the emplacement of small intrusive dykes and sills and were an important focus for later gold mineralization.

A second kilometric-scale target area, the West Porphyry Zone, occurs one kilometre west of the western limit of surface exposure of the Vortex Zone. The West Porphyry Zone, measuring 1500 m by 500 m, is a broad geochemically anomalous area defined by surface sampling containing values up to 2.5 g/t Au from rock chip sampling and stream silts up to 230 ppb Au. Channel sampling of abundant mineralized northwest-trending Tombstone suite porphyritic dykes returned values of slightly less than 1 g/t Au over 20.8 m (Schulze, 1998). A second dyke returned gold values exceeding 1 g/t Au over 8 m. Due to the widely spaced traverses and preliminary nature of exploration, all of the anomalous zones are open and expandable.

CONCLUSION

Favourable structural and stratigraphic settings, combined with the widespread nature of gold mineralization, indicate that the Harlan property has excellent potential to host a new style of bulk-tonnage, intrusive-related/sediment-hosted gold deposit within the Tintina gold belt. The Vortex and West Porphyry zones, both hosting kilometric-scale gold, bismuth, arsenic, antimony and mercury anomalies on the Harlan property are significant new exploration targets. NovaGold Resources plans to complete detailed surface geological mapping, geochemical sampling, and geophysical surveys in preparation for the first planned drilling program scheduled for the 2000 field season.

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