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YUKON
EXPLORATION & GEOLOGY
2007

- Mining, Exploration and Oil & Gas Overviews
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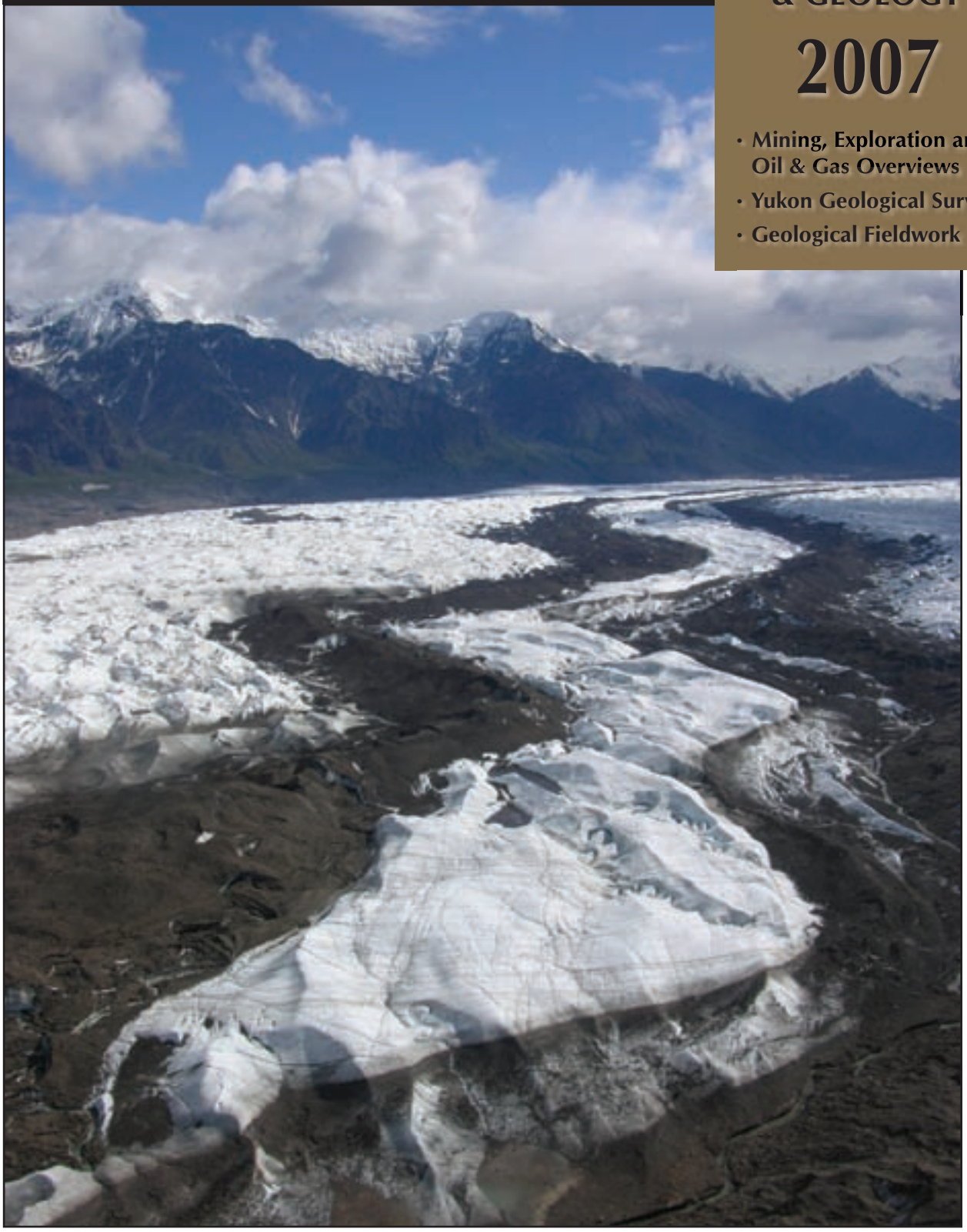

YUKON GEOLOGICAL SURVEY

Yukon
Energy, Mines and Resources

YUKON EXPLORATION & GEOLOGY 2007

Edited by
D.S. Emond, L.R. Blackburn, R.P. Hill
and L.H. Weston

Yukon Geological Survey
Energy, Mines and Resources
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PHOTOGRAPHS

FRONT COVER: Southward view up-valley, near the terminus of the Klutlan Glacier, St. Elias Mountains. The characteristic compression observed in the medial moraine is typical of surging-type glaciers. According to Clarke and Holdsworth[1], the Klutlan glacier is one of 136 surging glaciers in the St. Elias Mountains. Photo provided by Jeff Bond.

BACK COVER: Lori Walton looking at the drillcore through a handlens on the Sonora property, Yukon. Lori was the Yukon Prospector Association's 2007 Prospector of the Year. Photo provided by Lori Walton.

[1]*Clarke, G.K.C. and Holdsworth, G., 2002. Glaciers of the St. Elias Mountains. In: Glaciers of North America, U.S. Geological Survey Professional Paper 1386-J-1, p. J301-J328.*

PREFACE

Yukon Exploration and Geology (YEG) continues to be the main publication of the Yukon Geological Survey (Energy, Mines and Resources, Yukon government). This is the 30th volume of the series.

YEG 2007 contains up-to-date information on mining and mineral exploration activity, studies by industry, and results of recent geological field studies. Information in this volume comes from prospectors, exploration and government geologists, mining companies and students who are willing to contribute to public geoscience for the benefit of the scientific community, general public, and mineral and petroleum industries of the Yukon. Their assistance and patience is sincerely appreciated.

This year our editing team consisted of Leyla Weston, Lauren Blackburn, Rod Hill and I. I thank my co-editors for their thoroughness and efficiency. We also thank the Translation Bureau, Public Works and Government Services Canada for translating the French abstracts. Appreciation is also extended to Maurice Colpron of the Yukon Geological Survey (YGS) for his able assistance in the review of French translations of abstracts. We also thank all the geologists who contributed by critically reviewing YEG manuscripts: T. Allen, M. Burke, K. Kennedy, D. Murphy, M. Colpron, G. Lowey, L. Pigage, R. Sumanik, D. Turner and G. Zazula.

Wynne Krangle and Peter Long of K-L Services continue to provide excellent service in putting this production together, including editing suggestions, design of diagrams, volume layout, and working under the pressure of a tight deadline. Sherry Tyrner of the Queen's Printer once again ensured that the printing process went smoothly.

The 2007 volume has three parts. The first — Mineral and Petroleum Industries — includes overviews of hardrock and placer mining, development and exploration and a summary of oil and gas activities in the Territory, as well as a summary of the Yukon Mining Incentives Program. The second part — Government — outlines the activities and organization of the Yukon Geological Survey, and includes announcements of the eighth Mining Land Use Reclamation Awards, the Robert E. Leckie Awards, as well as work of Oil and Gas Resources. The last part — Geological Fieldwork — contains reports describing regional mapping, and more detailed geoscience studies. This year there are no Property Descriptions — submissions from the mineral industry on mineral occurrences and deposits - these papers are usually in short supply when the mining industry is busy which has been the case in the past few years.

This year's report is dedicated to Bruce Patnode and Grant Abbott. Bruce tragically passed away earlier this year; he is widely known for his great contributions to the prospecting and arts community in the Yukon. Grant is retiring from YGS this year. Over the years, he has been instrumental in enhancing and modernizing the geological data base of the Yukon — his strong leadership will be greatly missed by staff.

We welcome any input or suggestions that you may have to improve future YEG publications. Please contact me at (867) 667-3203 or by e-mail at diane.emond@gov.yk.ca.

Diane Emond

PRÉFACE

Yukon Exploration and Geology (YEG) continue d'être la publication principale de la Commission géologique du Yukon (Énergie, Mines et Ressources, gouvernement du Yukon). Ce volume est le 30e de la série.

YEG 2007 contient une mise à jour sur l'exploitation et l'exploration minières, les études réalisées par l'industrie et les résultats des travaux géologiques exécutés récemment sur le terrain. L'information est fournie par des prospecteurs, des géologues d'explorations et du gouvernement, des sociétés minières et des étudiants qui souhaitent en faire bénéficier la communauté scientifique, le grand public, ainsi que les industries minières et pétrolières du Yukon. Nous apprécions leur aide et leur dévouement.

Cette année les co-rédacteurs du YEG sont Leyla Weston, Lauren Blackburn, Rod Hill et moi. Nous remerçions le Bureau de la traduction, Travaux publics et Services gouvernementaux du Canada, pour la traduction française des résumés. Nous remerçions également Maurice Colpron de la Commission géologique du Yukon pour son aide avec la révision des traductions françaises. Il faut aussi souligner la contribution de plusieurs géologues à la lecture critique des manuscrits, au cours de cette année; il s'agit notamment de T. Allen, M. Burke, K. Kennedy, D. Murphy, M. Colpron, G. Lowey, L. Pigage, R. Sumanik, D. Turner et G. Zazula.

Wynne Krangle et Peter Long de K-L Services ont une fois de plus fourni un excellent service de production, incluant des suggestions de révision, la conception de diagrammes, la mise en page et le respect d'échéances serrées. Sherry Tyrner de l'Imprimeur de la Reine a, pour sa part, veillé au bon déroulement de l'impression.

Le volume de 2007 comprend trois parties. La première — Industries minérales et petrolières — renferme des survols sur l'exploitation, le développement et l'exploration minières des roches dures et des placers dans le territoire, de même qu'un résumé sur le Programme d'encouragement des activités minières du Yukon. Cette année il y a aussi un survol sur les activités petrolières. La deuxième partie — Gouvernement — décrit dans les grandes lignes les activités et l'organisation de la Commission géologique du Yukon, et présente la huitième édition des prix Robert E. Leckie, récompensant les meilleurs travaux de remise en état des sites miniers. La dernière partie – Travaux géologiques sur le terrain — contient des rapports décrivant la cartographie régionale et des études géoscientifiques plus détaillées. Cette année il n'y a pas d'articles présentant des descriptions de propriétés minières - présentations des sociétés minières concernant des indices et des gîtes minéraux - le recrutemment de ces articles est typiquemment difficile en temps de forte activité dans l'industrie minière, tel que l'on connait depuis quelques années.

Ce rapport est dédié à Bruce Patnode et Grant Abbott. Bruce est décédé tragiquemment plutôt cette année ; il est bien connu pour ses contributions à la prospection et à la communauté artistique du Yukon. Grant prendra sa retraite de la CGY cette année ; au cours des ans, il a contribué grandement au développement et à la modernisation des bases de données géologiques du Yukon – on manquera beaucoup sa direction examplaire.

Pour tout commentaires ou suggestions afin d'améliorer les futures publications du YEG, vous être priés de communiquer avec moi par téléphone au (867) 667-3203 ou par courriel à l'adresse suivante : diane.emond@gov.yk.ca.

Diane Emond

Bruce Patnode

IN MEMORIUM

On September 13, 2007, the Yukon lost a significant member of its prospecting and arts fraternities. Bruce Patnode lived in Whitehorse for nearly 40 years and, more recently, in Parksville, BC. He was only 60 years old when he passed away on Vancouver Island from a brain aneurysm.

Bruce prospected as a young man with his father, Larry, another prominent Yukon prospector. Upon his father's death, Bruce inherited several Yukon mineral properties and further explored many of them. He also worked in exploration and mining at Macmillan Pass, Keno Hill, Faro, Wellgreen and Cassiar, in addition to working abroad. He operated radios and heavy equipment, surveyed mineral claims, drove ore trucks, worked on diamond-drill rigs, and supervised geochemical and geophysical field programs. Eventually, he started his own mineral exploration company. Bruce also played a role in exploring the geothermal potential of the Wheaton River area.

In the mid-1980s, Bruce returned to college and finished his business administration degree; he then took a job with the Yukon government's Department of Economic Development. Bruce was an active and long-term executive member of both the Yukon Prospectors' Association and the Yukon Chamber of Mines.

Bruce was also a talented artist. He designed and promoted the large bronze prospector statue in the courtyard of the Elijah Smith Building on Main Street in Whitehorse. He created the wooden scroll housed in the main Government of Yukon Administration Building, with brass plaques for names of those who were inducted into the Hall of Fame and Honour Roll. He helped produce the commemorative mural for the RCMP Whitehorse detachment, and he designed the large mural on the exterior wall of the Transportation Museum. The backgrounds of the dioramas in the Kluane Museum of Natural History at Burwash Landing is another example of Bruce's fine work.

Bruce Patnode's name was inscribed on the Yukon Prospectors' Association's Honour Roll on November 26 at the 2007 Yukon Geoscience Forum. Former Yukoner Dutch Van Tassel, an Alberta-based geological consultant and former exploration superintendent for United Keno Hill Mines, spoke recently of Bruce:

"For every area that has its past history steeped in mining, there are individuals who stand out in so many ways for their energies and contributions. Such is the story of Bruce Patnode whose roots were planted and nurtured by his prospector dad. I remember Bruce for his friendly, positive attitude. Bruce will be remembered for his contribution to the Yukon Prospectors' Association and the Yukon Chamber of Mines and, as importantly, for his creative artistry."

Contributions from Jane Gaffin, Jim McFaul and Larry Carlyle

YUKON GEOLOGICAL SURVEY

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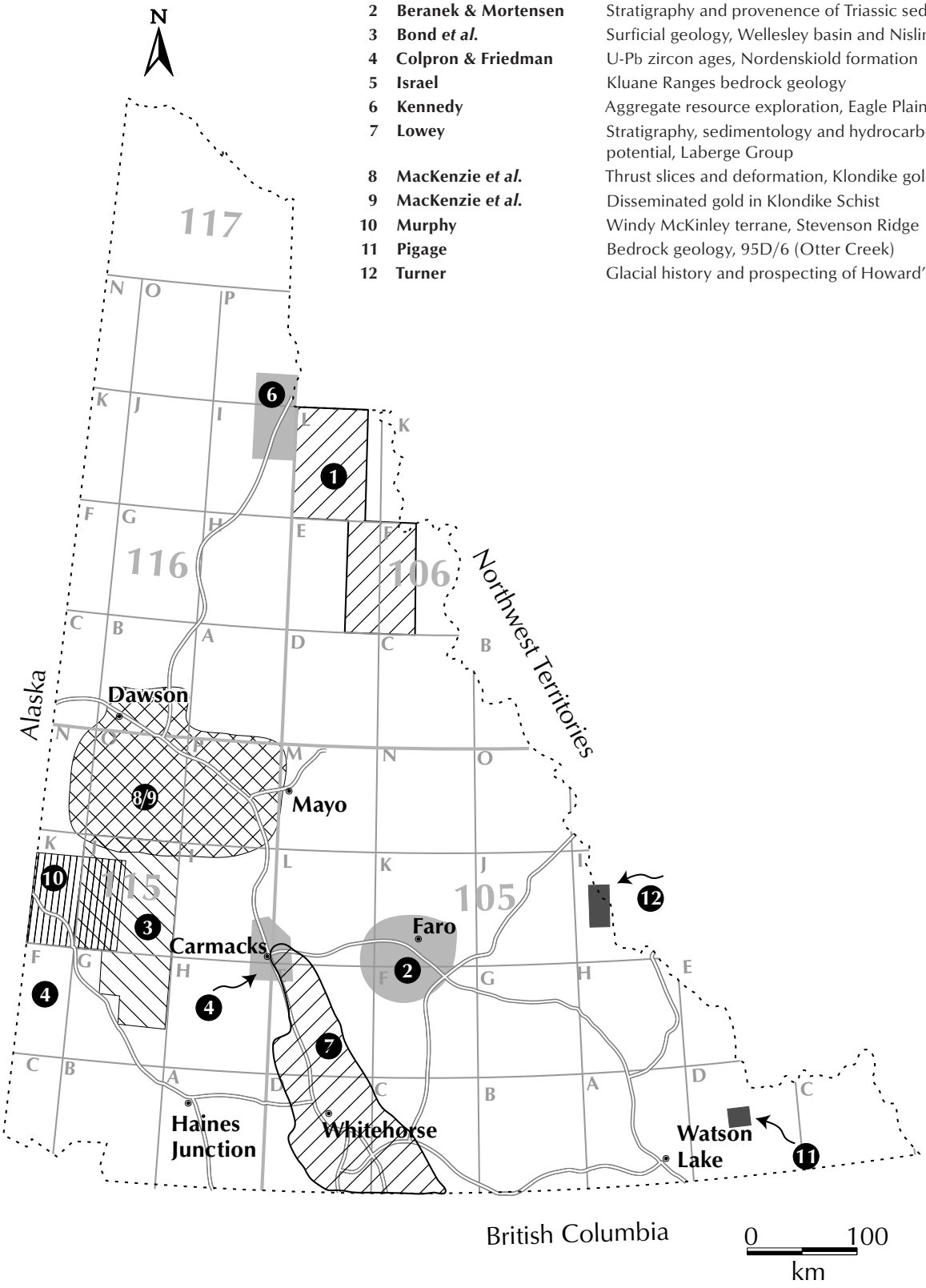

MINERAL AND PETROLEUM INDUSTRIES

Yukon Mining, Development and Exploration Overview 2007

Mike Burke, Ken Galambos, Lara Lewis and Steve Traynor
Yukon Geological Survey

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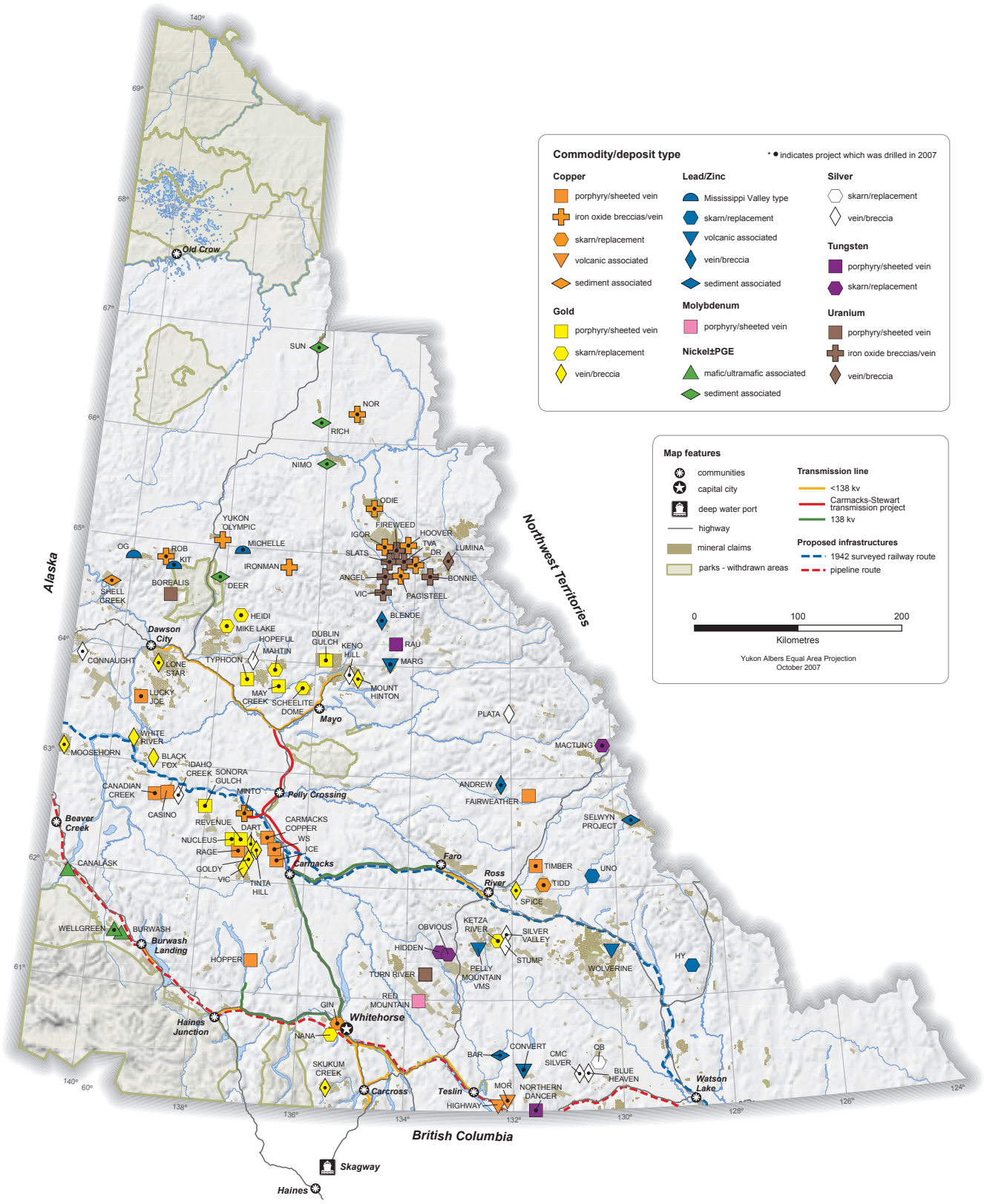


Figure 1. *Yukon advanced exploration projects, 2007. The exploration activity data represented on this map was compiled by the Mineral Services Unit of the Yukon Geological Survey. Advanced projects totaled over $100 000 in expenditures.*

Yukon Mining, Development and Exploration Overview 2007

Mike Burke[1], Ken Galambos, Lara L. Lewis and Steve Traynor
Yukon Geological Survey

Burke, M., Galambos, K., Lewis, L.L. and Traynor, S., 2008. Yukon Mining, Development and Exploration Overview 2007. *In:* Yukon Exploration and Geology 2007, D.S. Emond, L.R. Blackburn, R.P. Hill and L.H. Weston (eds.), Yukon Geological Survey, p. 2-42.

ABSTRACT

Mineral exploration in Yukon in 2007 continued its dramatic rise from the past few years, with an estimated $130 million spent on the search for base and precious metals, and uranium. Exploration for gold held the largest share of exploration expenditures (29%), followed by zinc and copper (23% each), silver (10%), uranium (8%), and tungsten, molybdenum, nickel and others (together 7%).

Mine development expenditures have also increased to an estimated total of $72 million. The bulk of development dollars were spent on the Minto copper-gold mine, which achieved commercial production on October 1, 2007 and at the Wolverine deposit, where road and site preparation for the construction camp were completed. Final development of the Wolverine polymetallic deposit will begin upon completion of additional project financing. The total Phase 1 development costs at Minto were $100.2 million over two years — this was only 2% above the feasibility study estimate of $98.1 million.

Exploration activities have experienced an increase at all levels in Yukon, from grassroots stages to advanced exploration, prefeasibility and feasibility stage projects. There were approximately 170 exploration projects in Yukon this year; 97 had expenditures of greater than $100 000, with 29 spending more the $1 million. The remaining projects were regional or grassroots generative projects. The largest program, with expenditures of approximately $25 million, was upgrading and expanding the huge zinc resources at the Selwyn (Howards Pass) project.

RÉSUMÉ

La prospection minérale au Yukon en 2007 a continué d'augmenter considérablement par rapport aux années antérieures et l'on estime à 130 millions de dollars les sommes consacrées à la recherche sur les métaux de base, les métaux précieux et l'uranium. La prospection minérale de l'or détient la plus grande part des dépenses d'exploration (29 %), suivie par le zinc et le cuivre (23 % chacun), l'argent (10 %), l'uranium (8 %) et enfin par le tungstène, le molybdène, le nickel et autres (totalisant ensemble 7 %).

Les sommes consacrées à la mise en valeur des mines ont également augmenté pour atteindre 62 millions de dollars au total (valeur estimée). La majeure partie d'entre elles ont été consacrées à la mine Minto, qui a entrepris la production commerciale le 1er octobre 2007 et au gisement Wolverine, où la route et la préparation du site pour le site de construction ont été complétés. Les activités finales de mise en valeur du gisement Wolverine débuteront dès l'obtention du financement additionnel lié au projet. Les coûts totaux de mise en valeur de la Phase 1 de la mine Minto se sont élevés à 100,2 millions de dollars, soit seulement 2 % de plus que l'estimation faite par l'étude de faisabilité, qui était de 98,1 millions de dollars.

Pour ce qui est des activités liées à l'exploration à tous les niveaux au Yukon, allant du développement au niveau local à l'exploration avancée, les projets de préfaisabilité et de faisabilité ont connu une augmentation. On dénombre environ 170 projets d'exploration au Yukon cette année; de ce nombre, 97 ont eu des dépenses supérieures à 100 000 $, et 29 ont dépensés plus d'un million de dollars. Les autres projets sont des projets génératifs locaux ou régionaux. Le programme le plus important est le projet Selwyn, dont les dépenses se sont élevées à environ 25 millions de dollars pour la valorisation et l'agrandissement du vaste gisement de zinc du projet Selwyn (Howards Pass).

[1]*mike.burke@gov.yk.ca*

INTRODUCTION

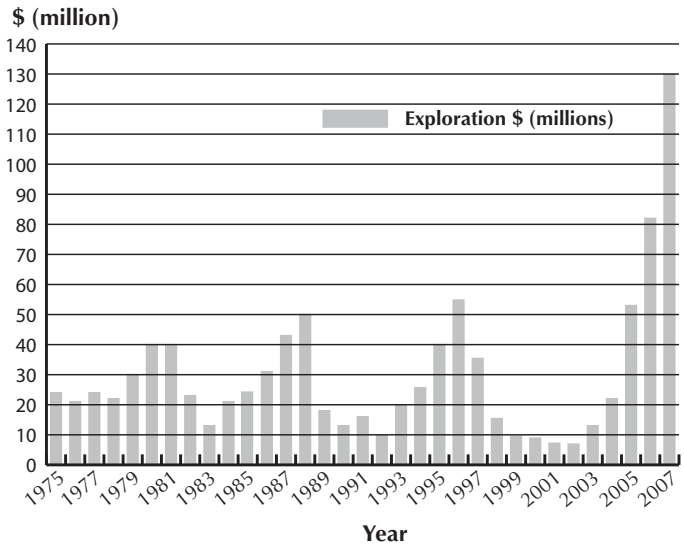
Mineral exploration expenditures in Yukon experienced a significant increase for the sixth consecutive year, rising to an estimated $130 million (Figs. 1 and 2). Mine development expenditures also increased with the completion of the Phase 1 development of the Minto copper-gold mine of Sherwood Copper Corporation, which allowed the mine project to achieve commercial production on schedule and only 2% above the feasibility study budget. The successful discovery of additional resources at the Minto mine allowed the company to begin construction of the Phase 2 mill expansion. Mine development also began at the Wolverine deposit of Yukon Zinc Corporation. The company received a number of permits allowing construction to proceed at the site in 2007, including a Quartz Mining Licence and a Type A Water Licence. A 24-km access road was constructed to the site and preliminary earthworks for the main camp facility were completed. Final construction will begin when project financing is completed and a production decision is made.

Claim staking remained at high levels, with a total of 12 123 claims staked and the number of claims in good standing rising to a total of 69 038 by year end (Figs. 3 and 4).

Although the bulk of expenditures can be attributed to large projects that involve drilling, Yukon has also benefited from an increase in the amount of grassroots generative exploration programs that continue to provide a steady stream of projects. This can be directly attributed to the high quality of prospectors and junior mining companies who have a long history of exploration in Yukon. They have enjoyed the support of the Yukon Mining Incentive Program (YMIP) which has allowed them to continue to generate new projects, especially in times of reduced activity.

The reader is reminded that the exploration overview is in no means a comprehensive overview of the activity in Yukon. Many results are still pending at the publication deadline of this volume and thus are preliminary in nature. This publication is available on the Yukon Geological Survey (YGS) website *(www.geology.gov.yk.ca)*. Links to company websites are available in this report; these contain much more comprehensive information including, in many cases, up-to-date results, plans and sections. The other valuable reference used throughout this report is the online version of Yukon MINFILE – A database of mineral occurrences *(www.geology.gov.yk.ca/databases_gis.html)*.

Figure 2. *Exploration expenditures in Yukon, 1971 to 2007.*



MINE DEVELOPMENT

The **Minto** mine (Yukon MINFILE 115I 012) is a high-grade copper-gold deposit operated by Sherwood Copper Corporation (Fig. 5). Sherwood acquired the Minto project in June, 2005, and, in just two years from its acquisition, completed a definitive feasibility study, arranged project financing and spent $100 million to bring the open-pit mine into production. Commercial production commenced on Oct. 1, 2007. A Phase 2 mill

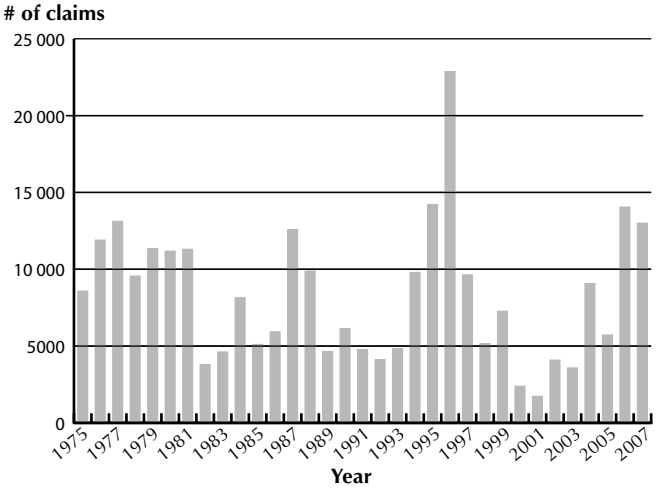


Figure 3. *Mineral claims staked, 1975–2007.*

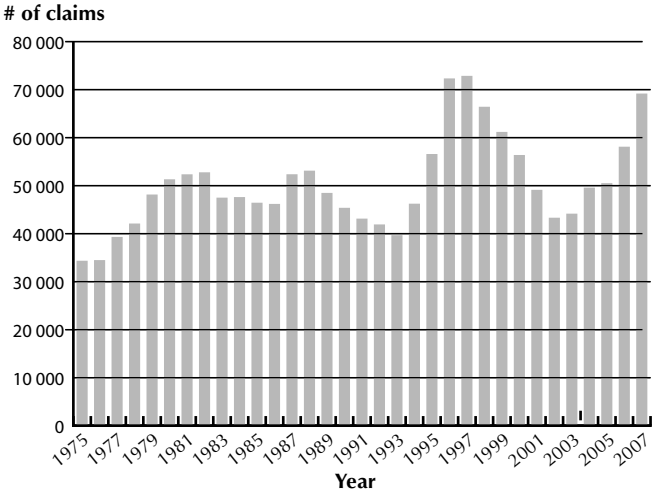


Figure 4. *Mineral claims in good standing, 1975–2007.*

expansion from 1563 tonnes per day to 2400 tonnes per day was completed ahead of schedule on December 15, 2007 (Fig. 6). A prefeasibility study has also been completed that lays out the basis for a Phase 3 mill expansion, to 3500 tonnes per day of throughput, and incorporates a significant portion of the Area 2 resources, resulting in a more than 40% increase in copper and gold production in comparison with its original feasibility study. Current total resources at the Minto mine, at a 0.5% copper cut-off grade, are Measured and Indicated 16 656 000 tonnes grading 1.54% Cu, 0.56 g/t Au, 5.95 g/t Ag plus an Inferred resource of 1 471 000 tonnes grading 1.00% Cu, 0.32 g/t Au, 2.05 g/t Ag (National Instrument 43-101 standard (NI)).

Figure 5. *Open pit at Minto mine. Truck (circled) for scale.*

Figure 6. *Mill at Minto mine site.*

Yukon Zinc Corporation *(www.yukonzinc.com)* further advanced the Wolverine project (Yukon MINFILE 105G 072). This included receiving both a Type A Water Licence and a Quartz Mining Licence which allows the company to construct and operate the mine until 2027. Access to the property was significantly upgraded with the completion of the all-weather tote road connecting to the Robert Campbell highway (Fig. 7). Civil engineering work consisting of site preparation for the construction camp was also completed. Construction of the project will occur when final project financing is secured and a production decision is made.

Figure 7. *Wolverine mine access road development. Photo by Yukon Zinc Corp.*

PRECIOUS METALS – GOLD

SKARN/REPLACEMENT

Yukon Nevada Gold Corp. *(www.yukon-nevadagold.com),* formerly YGC Resources Ltd., conducted a year-round exploration program that included geological mapping, geochemistry, trenching, airborne geophysical surveys and extensive diamond drilling at its **Ketza River gold-silver** property (Yukon MINFILE 105F 019) located 50 km south of Ross River (Fig. 8). Mineralization at Ketza consists of massive pyrrhotite-pyrite manto deposits hosted in Lower Cambrian limestone, as well as quartz-pyrrhotite-pyrite veins hosted in Lower Cambrian argillite, which stratigraphically underlie the limestone unit. Oxidized mantos mined at the Ketza River deposit between 1988 and 2000 produced approximately 3.1 million grams of gold. Just under 50 000 m of diamond drilling were completed in 363 holes making this the Yukon's largest drilling program in 2007. The company will be using drilling results from 2006 and 2007 to update the resource calculation on the property, complete the prefeasibility study, and make a production decision for an operation with an annual production of up to 100,000 ounces (300 million grams). Recent results from manto zones not included in the previous resource calculation include the following: Lab zone – DDH KR-06-892 at 4.94 g/t Au over 6.09 m; Penguin zone – DDH KR-07-1042 at 11.16 g/t Au over 10.26 m, including 18.27 g/t over 2.68 m; Hoodoo zone – DDH KR-07-1108 at 5.97 g/t Au over 16.3 m, including 1.7 m of 23.3 g/t Au; and Tarn zone – DDH KR07-1228 at 2.85 m of 2.26 g/t Au and 1.22 m of 4.28 g/t Au. Vein style mineralization in the Shamrock zone returned values up to 7.8 m grading 4.89 g/t Au from the Gully vein and 2.3 m of 15.89 g/t Au in hole KR01-1071 and 3.83 m grading 14.5 g/t in hole KR07-1166 at the QB vein.

Figure 8. *Ketza property, camp and existing mill.*

Dynamite Resources Ltd. *(www.dynamiteresources.com)* explored three areas on the **Mike Lake** property (Yukon MINFILE 116A 012) during 2007 with 1827 m of diamond drilling in nine holes. The property, located 90 km east-northeast of Dawson, covers a number of intrusive-related gold targets associated with Cretaceous Tombstone Suite intrusive stocks, dykes and sills. The upper skarn ridge area was drilled for the first time and resulted in a new discovery. Diamond drillhole SK-07-01 returned 89.31 m grading 0.61% Cu, 1.383 g/t Au and 13.6 g/t Ag. Within this interval a 2.66-m section returned values of 0.64% Cu, 12.30 g/t Au and 14.6 g/t Ag. Mineralization consists of calc-silicate skarn with pyrrhotite and chalcopyrite

Figure 9. *Chalcopyrite mineralized skarn in Mike Lake property core. Photo by Dynamite Resources.*

(Fig. 9). Drilling targeted a 1500 m by 700 m area with soils strongly anomalous in copper and gold which overlies a thick section of calcareous phyllite of the Cambro-Ordovician Rabbitkettle Formation that has been intruded by granodiorite sills. The other eight holes were drilled to test bulk tonnage copper-gold and high-grade, shear-controlled gold mineralization on the extreme northern and southern parts of the property. Results are pending for those holes.

Figure 10. *Drilling at the Heidi property. Photo by Logan Resources.*

Figure 11. *Arne Bakke of Kinross Gold Corporation working at faulted vein on the Dublin Gulch property.*

At the **Heidi** property (Yukon MINFILE 116A 037), located 95 km east-northeast of Dawson, Logan Resources *(www.loganresources.ca)* conducted airborne magnetic and radiometric geophysical surveys, additional claim staking and the diamond drilling of 19 holes for a total of 2686 m (Fig. 10). Drilling targeted stratabound gold-bearing pyrite-arsenopyrite replacement zones in carbonate-rich horizons within Upper Proterozoic to Lower Cambrian Hyland Group sedimentary rocks and sulphide-bearing breccia/veins. The mineralization is associated with what is believed to be a buried Cretaceous Tombstone suite intrusion. Best results from drilling were 3 m grading 1.51 g/t Au in hole HD07-07.

On the **May Creek** property (Yukon MINFILE 115P 008), Logan Resources drilled five reverse-circulation drillholes targeting skarn mineralization associated with a mid-Cretaceous Tombstone Suite intrusion. Results from the drilling have not been released.

PORPHYRY/SHEETED VEIN

StrataGold Corp. *(www.stratagold.com)* discovered a new gold zone at its **Dublin Gulch** property (Yukon MINFILE 106D 025) near Elsa. The Shamrock zone is located 3 km north-northeast of the Eagle zone gold deposit. The company drilled 868 m in five diamond drillholes at the Shamrock zone in order to follow up highly anomalous gold in soils and trenching results from the 2006 exploration program. Mineralization consists of sheeted quartz-sulphide veins in a structural zone cutting the Cretaceous Dublin Gulch granodiorite stock (Fig. 11). Highlights from the 2007 program include DDH 321, which averaged 1.12 g/t Au over 15.24 m, DDH 326 that returned 16.76 m averaging 1.42 g/t Au, and DDH 328 at 9.34 m of 2.058 g/t Au. The new zone has been intersected over a strike length of 325 m and remains open in both directions along strike and down dip. DDH 329 intersected 14.6 m averaging 1.16 g/t Au in what appears to be a parallel zone immediately north of the Shamrock zone. Extensive soil sampling was also completed on the Shamrock zone in 2007, tripling the

size of the grid completed the previous season. StrataGold's exploration efforts to date have focused primarily on the Eagle zone deposit which hosts the current NI 43-101-compliant resource estimate comprising an Indicated resource of 1.96 million ounces Au (60 963 000 g) at 0.916 g/t Au and an Inferred resource of 371,000 ounces Au (11 539 390 g) at 0.803 g/t using a 0.50 g/t Au cut-off grade. In 2007, 20 diamond drillholes were completed for a total of 5528 m at the Dublin Gulch property. The bulk of the drilling was outside the known resource area to test the potential to expand the deposit to the north, south and east (15 holes totaling 4660 m). Drilling was successful in intersecting additional mineralization outside of the resource area. Drillhole 334C, south of the Eagle zone, intersected 361 m of 0.98 g/t Au. The company also began relogging and resampling of historical drill core from the Ray Gulch tungsten deposit located 2.5 km east of the Eagle zone gold deposit.

In mid-July, International Gold Resources, Inc. *(www.intlgold.com)* mobilized a camp and commenced a seven-hole, 998-m diamond-drilling program on the **Mahtin** property (Yukon MINFILE 115P 007) located 135 km southeast of Dawson City. The property had never been drilled prior to this year's program. The property is underlain by the Cretaceous Sprague Creek stock, which intrudes Upper Cambrian to Ordovician Rabbitkettle Formation limestone. Mineralization at surface consists of calc-silicate skarn and sheeted quartz-sulphide veins within the intrusion. The initial program consisted of two set-ups where holes were fanned out to test the contact of the intrusive and limestone. Drilling intersected quartz-veined and altered intrusive and calc-silicate skarn with pyrrhotite and arsenopyrite (Fig. 12). Results from the program are pending.

Northern Freegold Resources *(www.northernfreegold.com)* completed an extensive $5 million exploration program on its **Freegold Mountain** property including diamond drilling of 57 holes totaling 11 428 m on six different targets, rotary air blast (RAB) drilling of 4635 m in 116 holes on two targets. Other work included

Figure 12. *Mineralized quartz vein at Mahtin property.*

Figure 13. *Jean Pautler and Danièle Héon examine core at the Freegold Mountain property.*

geophysical and geochemical surveys, trenching, prospecting and geological mapping. The main focus was on the Nucleus zone (Yukon MINFILE 115I 042), located 58 km west of Carmacks, with 6313 m of diamond drilling in 27 holes. The Nucleus zone consists of Cretaceous granodiorite sills of the Dawson Range Suite intruding metasedimentary rocks of the Yukon-Tanana terrane, intruded by later quartz-feldspar porphyry dykes. Mineralization occurs as quartz-sulphide veins and stringers, disseminated sulphide minerals, breccias and fault zones with associated phyllic and argillic alteration (Fig. 13). The first hole of the season, GRD07-41, returned 72.35 m of 2.5 g/t Au and 0.14% Cu including 2.00 m of 45.0 g/t Au. Other highlights from Nucleus include hole GRD07-50, the widest mineralized intercept drilled to date: 207.4 m of 0.59 g/t Au including 11.40 m of 1.36 g/t Au; and 11.90 m of 1.25 g/t Au and 0.17% Cu. The highest grade intercept released to date was hole GRN07-58, which intersected 74.97 m of 4.26 g/t Au including 10.6 m of 20.26 g/t Au. This hole was drilled 50 m east of hole GRD07-41 and appears to define an easterly trending high-grade zone, which remains open to the east. Approximately 1100 m of diamond drilling in eight holes were done in the Revenue zone located approximately 3.5 km east of Nucleus. The Revenue zone (Yukon MINFILE 115I 042) hosts similar gold-rich copper-porphyry mineralization, and the two zones are connected by anomalous copper-gold soil geochemistry. Results for the drilling at Revenue were pending at year end.

Firestone Ventures Inc. *(www.firestoneventures.com)* continued drilling at **Sonora Gulch** (Yukon MINFILE 115J 008), situated 110 km northwest of Carmacks. The program consisted of 2025 m of diamond drilling in 12 holes testing 3 target areas. The Amadeus zone, a gold-silver-copper-molybenum target within a mid-Cretaceous monzonite stock was tested with seven holes totaling 1730 m, six of which targeted potential extensions of the high-grade intercept of 6.21 g/t Au over

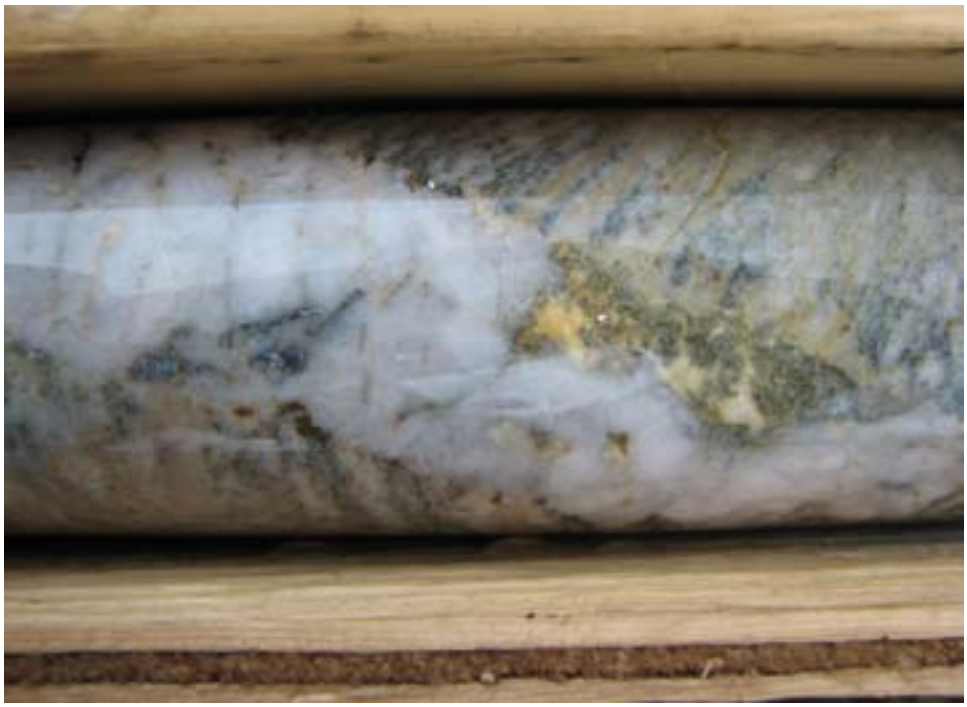


Figure 14. *Mineralized vein at Sonora Gulch property.*

the bottom 15.3 m of DDH SG-06-06. Drillhole SG-07-12 returned 4.0 m of 5.22 g/t Au within a larger intersection measuring 64 m of 1.0 g/t Au. High-grade mineralization appears to be controlled in a near-vertical structural zone while the stock is consistently mineralized with lower grade gold and silver values. Mineralization consists of polymetallic quartz-sulphide veins, breccias and disseminated sulphide minerals (Fig. 14). DDH SG-06-16 returned 2 m of 1.12 g/t Au and 817 g/t Ag with anomalous base metal values, while DDH SG-07-17, collared 200 m west of the discovery hole, returned a 2.0 m sample of 91.7 g/t (2.95 ounces per ton) Ag with 0.464 g/t Au and 0.93% Pb. Hole SG-07-22 targeted an ultramafic horizon located immediately to the north of the Amadeus zone. Anomalous gold and silver values were returned from surface to the upper contact of the horizon, including a value of 0.66 g/t Au with 6.5 g/t Ag across 2.0 m and another of 0.939 g/t Au with 2.7 g/t Ag across 1.5 m. Firestone conducted geochemical surveys, mapping and prospecting on its surrounding claims and developed additional target areas for follow-up.

At the **Typhoon** property (Yukon MINFILE 115P 060), located 100 km east-southeast of Dawson, Curlew Lake Resources *(www.curlew-lake.com)* completed line-cutting, an IP survey, additional magnetometer and geochemical surveys, and geological mapping. The property is within the Tombstone strain zone, and geophysical results suggest an underlying intrusive body. A six-hole, 1001-m diamond-drilling program commenced in July and results are pending.

Cariboo Rose Resources Ltd. *(www.caribooorose.com)* diamond drilled five holes totalling 879 m at the **Canadian Creek** copper-gold-molybdenum property (Yukon MINFILE 115J 036), located approximately 300 km northwest of Whitehorse. Veraz Petroleum Ltd. is financing the $400 000 program under an option that gives Veraz

(formerly North American Vanadium Inc.) the right to earn a 60% interest in the property. Highlights of this year's program include hole 07-04, which returned 0.31 g/t Au over 139.9 m. A narrower interval in this hole returned 2.96 g/t Au over 6.0 m. Drilling was completed on targets located 1000 to 1500 m to the west of the Casino deposit (Yukon MINFILE 115J 028).

VEIN/BRECCIA

Tagish Lake Gold *(www.tagishgold.com)* continued its year-round underground exploration at the **Skukum Creek** property (Yukon MINFILE 105D 022), located 80 km southwest of Whitehorse (Fig. 15). The company is conducting prefeasibility work examining the economics of a 270 000 tonne-per-year operation producing 1368 kg (44,000 ounces) of gold and 31 100 000 kg (1 million ounces) of silver per year. Early in the year, a Memorandum of Understanding was signed with the Carcross-Tagish First Nation on the shared values, principles and interests in developing the project. Continued deposit definition, engineering studies and development of the main access at the 1100-m level will form the basis for a feasibility study. The portal site for the 1100-m level access was prepared in 2007. Permitting of the project is planned for 2008. Tagish Lake Gold released an updated NI 43-101-compliant resource calculation in mid-November. With the addition of resources from the Rainbow Two and the Berg zones, Measured and Indicated resources at Skukum Creek are now calculated to be 1 066 000 tonnes at 6.4 g/t Au and 187 g/t Ag, and the Inferred resources to be 206 000 tonnes at 6.8 g/t Au and 155 g/t Ag, both at a cut-off grade of 4 g/t. The resource calculation incorporated drilling from last year's program.

Significant results released in 2007 included hole SC06-95 which intersected 6.91 g/t Au and 72.4 g/t Ag over 9.72 m (6.32 m true width) from the Rainbow Two zone. Chip samples of newly exposed mineralization from recent drifting ranged from 1.50 m grading 1.18 g/t Au and 104.0 g/t Ag, up to 4.51 m of 33.21 g/t Au and 51.8 g/t Ag from the Rainbow Two zone, with a further notable intersection of 1.50 m grading 94.08 g/t Au and 654.0 g/t Ag. The newly discovered Rainbow Three zone returned widths of up to 2.60 m of 5.67 g/t Au and 86.1 g/t Ag, while the Berg zone intersections ranged from 1.50 m grading 1.60 g/t Au and 67.7 g/t Ag, up to 1.5 m of 15.2 g/t Au and 211 g/t Ag. The company is currently conducting a 5000-m diamond drilling program, undertaken from the exploration crosscuts driven on the 1300-m level this year. The

Figure 15. *Skukum Creek property adit.*

Figure 16. *Bill Mann examines trench samples at the Lone Star property.*

program will focus on exploring the upward and downward extensions of the Rainbow Two and Berg zones, and will also test the Rainbow Three zone and provide information on the extensions of these zones to facilitate mine planning.

Klondike Star Mineral Corp. *(www.klondikestar.com)* was active on its large mineral property south of Dawson City in the heart of the Klondike again this season. One of its main targets on the property is the historic **Lone Star** (Yukon MINFILE 115O 072) gold mine. The company followed up results from the 2006 season including diamond-drilling results released early in the year. In general, fairly narrow higher grade sections occur within broad envelopes of anomalous gold mineralization. Mineralization consists of quartz veining and/or disseminated sulphide minerals with visible gold in schists within a structural trend (see also Mackenzie, this volume, a and b). Hole 06-LS-23, drilled beneath a 1987 trench along the west side of the Lone Star zone, returned 0.46 g/t Au over 40.0 m including 8.40 g/t Au over 0.8 m. This trench was also the target of a bulk-sampling program where ten samples, ranging in weight from 2.9 to 8.1 tonnes, collected across widths varying from 6 to 10 m, were taken along a 67-m length of the trench (Fig. 16). Results varied between 1.41 g/t Au over 6.0 m in sample 06LS-B5 to 0.054 g/t Au over 10.0 m in sample 06LS-B8, and averaged 0.67 g/t Au over the entire 67-m interval, including 1.33 g/t Au over 24 m from the southern end of the bulk sampling. Elsewhere, excavator trenching discovered a new gold zone, dubbed the JF, near the centre of the Lone Star property. A 95-m-long trench 06TR-06 returned values up to 2.32 g/t Au over a 5-m interval.

The **Buckland** zone (Yukon MINFILE 115O 077) located approximately 1 km southwest of the Lone Star was drilled with five holes totalling 856 m. The drilling targeted a similar structural trend to that at the Lone Star, where a zone of chargeability was identified in an induced-polarization survey. Highlights of the

Figure 17. *Vein at the Mount Hinton property.*

drilling include 2.06 g/t Au over 21.0 m, including 22.6 g/t Au over 1.0 m in hole 07BU-3, and 1.29 g/t Au over 16.0 m, including 24.9 g/t over 0.5 m in hole 07BU-4.

The Dominion project of Klondike Star includes the **Mitchell-Sheba** veins (Yukon MINFILE 115O 068) and other surrounding claims. Work this season included detailed geological mapping, surveying, grid cutting, trenching, chip sampling and bulk sampling.

The **Spice** property (Yukon MINFILE 105G 150), located 25 km east of Ross River, optioned by Klondike Star was drilled with three holes totaling 440 m. The drilling was the first drilling to be conducted on the property. The exploration target on the property is a low-sulphidation epithermal system. Rhyolitic rocks on the property are interpreted to be Eocene volcanic rocks similar to those hosting the Grew Creek deposit (Yukon MINFILE 105K 009) located 60 km to the west. Results from the drilling have not been released.

International Gold Resources *(www.intlgold.com)* conducted geochemical surveys on the **Crown Jewel** and **Bonanza** properties (Yukon MINFILE 115O 139, 080) in 2007. The properties are located in the heart of the Klondike goldfields south of Dawson City.

Yukon Gold Corp. Inc. *(www.yukongoldcorp.com)* completed an airborne versatile time-domain electromagnetic (VTEM) geophysical survey, trenching and drilling of three holes totalling 366 m at its **Mount Hinton** property (Yukon MINFILE 105M 052), located 8 km north of Keno Hill. Four trenches were located in McNeil Gulch along strike from known quartz-sulphide veins exposed on the north face of Mount Hinton and a newly discovered vein on the ridge opposite Mount Hinton (Fig. 17). The trenches are approximately 1 km from any previously known vein. Trench 3 exposed two sheared/crushed quartz veins, one of which grades a weighted average of 1.36 g/t Au, 183 g/t Ag and 2.1% Pb over 6 m. The second vein grades 0.41 g/t Au, 110 g/t Ag and 0.9% Pb over 1 m. Trench 4 exposed a mineralized vein that returned a grade of 1.27 g/t Au, 116 g/t Ag and 1.7% Pb over 3.1 m. The small drilling program provided inconclusive results due to poor core recovery and holes that had to be abandoned short of their targets.

Atac Resources performed soil geochemical sampling and prospecting, flew a property-wide helicopter-borne, versatile time-domain electromagnetic (VTEM) survey, and performed a reconnaissance-scale induced-polarization (IP) survey on the **Hartless Joe** property (Yukon MINFILE 105D 203) north of Whitehorse. Mineralization on the property consists of low-sulphidation gold- and silver-rich quartz veins, breccias and replacement zones

Northern Freegold Resources *(www.northernfreegold.com)* explored the central and eastern parts of its **Freegold Mountain** property with prospecting, soil sampling, trenching and drilling. New mineralization was found from trenching on historical

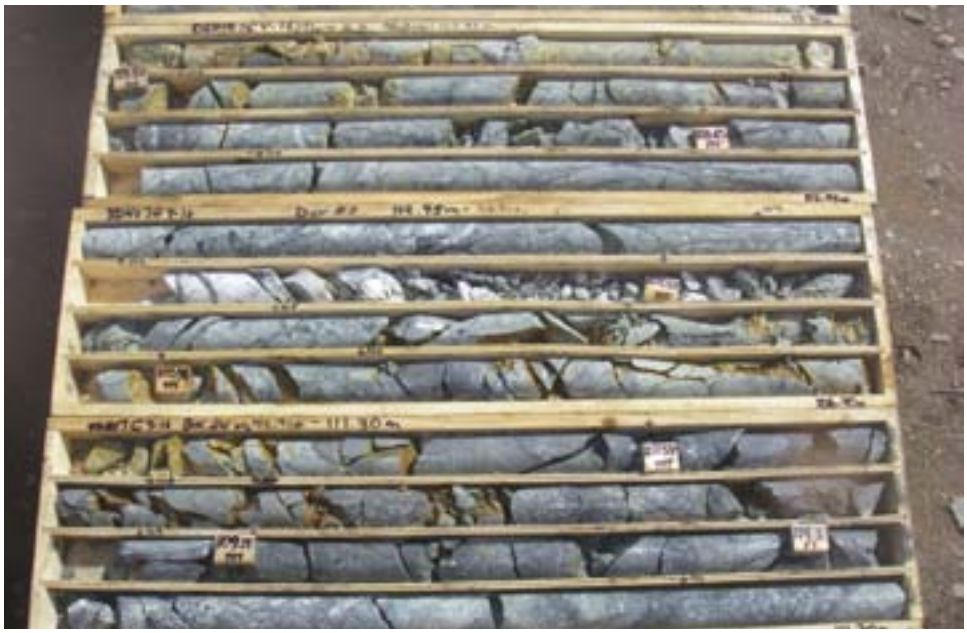


Figure 18. *High-grade section of core (15.45 g/t Au) in the Goldy zone, from 103 to 112.3 m. Photo by Northern Freegold Resources.*

geochemical anomalies, an example being the newly discovered **Ridge** Zone, situated 46 km northeast of Carmacks. The company excavated a highly gossanous zone of 4.7 m grading 3.72 g/t Au, 60.3 g/t Ag, 0.59% Cu, 0.51% Pb and 0.23% Zn. Two other trenches in the immediate area returned 37.86 g/t Au and 18.02 g/t Au with significant silver and several percent copper over true widths of 0.68 m and 1.70 m, respectively. At the **Goldy** zone (Yukon MINFILE 115I 112), the company conducted trenching and geophysical surveys followed by diamond drilling. The target is epithermal-style quartz veining and silicified zones associated with an altered quartz-feldspar porphyry body. Drilling intersected 53.75 m averaging 3.5 g/t Au, including a section of alternating altered porphyry and syenite/ hornblendite containing abundant quartz-sulphide veinlets and fine-grained pyrite and arsenopyrite needles replacing mafic minerals that graded 8.03 g/t Au over 19.05 m, including an interval grading 15.45 g/t Au over 9.3 m (Fig. 18). At the **Tinta Hill** zone (Yukon MINFILE 115I 058), diamond drilling was successful in expanding the zone, which is an intrusion-hosted polymetallic vein deposit. Drilling intersected the vein to a depth of 300 m over 100 m of strike length. Mineralization consists of sulphide mineralization including tetrahedrite, chalcopyrite, galena and sphalerite in vuggy quartz-carbonate veins. Results from hole TH07-08 graded 1.7 m of 14.90 g/t Au, 446 g/t Ag , 3.3% Cu, 5.2% Pb and 0.66% Zn. Four drillholes totaling 711 m were drilled in the **Dart** property (Yukon MINFILE 115I 055), which is an epithermal vein target. Assays from this drill program are pending.

Underworld Resources *(www.underworldresources.com)* conducted soil geochemical surveys, geological mapping, trenching and IP surveys on the **White Gold** and **Blackfox** properties (Yukon MINFILE 1150 011, 014) 100 km southwest of Dawson. The two properties host multiple styles of gold mineralization including wide quartz veins, hydrothermal breccias and disseminated targets, hosted within widespread soil geochemical anomalies. Poorly exposed quartz veins, ranging from 0.5 to 3.0 m wide hosting visible gold, have been discovered on both properties. Significant placer gold has been historically mined in the area.

Aurchem Exploration, a private company, conducted a trenching and sampling program on the **VG (Vic)** property (Yukon MINFILE 115I 068), 47 km west of Carmacks. Quartz veins on the property carry high-grade gold values, and the company is currently evaluating the potential of the veins to support small-scale mining.

PRECIOUS METALS – SILVER

VEIN/BRECCIA

Alexco Resources Corporation *(www.alexcoresource.com)* continued a comprehensive exploration program that included HQ diamond drilling, regional geological mapping, compilation work and geophysical and geochemical programs on its **Keno Hill** properties (Yukon MINFILE 105M 001). Over the past century, the silver mines at Keno Hill have produced approximately 214 million ounces (6 656 000 kg) Ag at an average grade of 40.4 ounces/ton (1389 g/t) Ag, 5.62% Pb and 3.14% Zn. The district contains three distinctive styles of mineralization including high-sulphidation epithermal silver-gold as seen in the Husky Southwest, native silver ± sulphosalts and base metals at the Lucky Queen, and massive base-metal sulphide veins like those present at Bellekeno.

In March 2007, the corporation entered into a Memorandum of Understanding with the First Nation of Na-Cho Nyak Dun (NND) that provided NND with opportunities in terms of employment, preferential contract positioning, training and other benefits, while NND provided support for the Corporation's ongoing activities at Keno Hill. In September 2007, the Corporation and NND entered into a negotiation agreement relating to the Corporation's current and future activities on and around the former UKHM property.

Figure 19. *Keno Hill core room.*

In November, 2007, the company released a new NI 43-101 resource calculation for the historic Bellekeno mine. The total Inferred resource is stated as 356 000 tonnes grading 1630 g/t Ag, 20.3% Pb and 5.9% Zn. The new estimate represents a tonnage increase of 35% over the historic UKHM resource. Both silver and lead grades have increased: 37% and 75%, respectively. The current consolidated Bellekeno resource estimate incorporates 2006/2007 Alexco drill results for the Southwest zone only, but does not include recent work from the 99 and East zones.

Prior to this resource estimate, the company had released a

number of notable intersections on each of its targets drilled in late 2006 and into 2007. Released in January, results from hole K06-027, drilled approximately 50 m below the lowest working of the **Bellekeno** deposit, show an intersection of 7.5 m interval grading 670.2 g/t Ag, 1.99 g/t Au, 8.83% Pb and 8.81% Zn, including a 3-m section that returned 1522 g/t Ag, 1.26 g/t Au, 20.02% Pb and 7.22% Zn, as well as a separate 1.5 m section that ran 206.9 g/t Ag, 6.02 g/t Au, 1.39% Pb and 20.31% Zn (Fig. 19). This hole confirms the down-plunge continuation of the southwest ore zone. Grade potential of this zone is demonstrated by hole K07-0101 which cut an interval grading 3279 g/t Ag, 0.718 g/t Au, 59.7% Pb and 5.7% Zn over 9.64 m, occurring within a broader 13.84 m zone grading 2350 g/t Ag, 0.878 g/t Au, 42.3% Pb and 8.2% Zn. At **Bellekeno East**, hole K07-066 returned a 4.44 m interval grading 1642 g/t Ag, 0.406 g/t Au, 8.46% Pb and 11.18% Zn, including a 1.51 m intersection grading 3058 g/t Ag, 0.574 g/t Au, 19.63% Pb and 15.89% Zn. Drilling at Bellekeno has extended the East zone mineralization approximately 250 m down plunge from the initial 1995 drilling. The zone remains open along strike and down plunge. The East zone mineralization occurs below a major greenstone sill that has historically been interpreted to truncate Bellekeno mineralization at depth. This recent drilling confirms the presence of high-grade mineralization below this unit adding significant potential for discovery of down-plunge extensions of mineralization related to the high-grade 99 and Southwest zones. Adjacent to the Bellekeno mine area, drilling at the **Onek** mine intersected significant intervals of high-grade zinc/precious metals mineralization 70 m down plunge of mine workings. Hole K07-069 cut an intersection grading 29.45% Zn, 0.842 g/t Au, 85.4 g/t Ag and 0.14% Pb over 6 m. Mineralization remains open at depth and along strike.

At **Silver King**, hole K07-0112 cut an interval grading 10 534 g/t Ag, 2.15 g/t Au, 6.61% Pb and 0.72% Zn over 0.8 m. Highlights from **Husky Southwest** include DDH K06-036 which cut a 1.4 m interval grading 2010 g/t Ag and 1.94 g/t Au within a 12.75-m section which assayed 284.2 g/t Ag. Shallower reconnaissance drilling in 2006 and early 2007 by Alexco in the Husky Southwest zone intersected thin, high-grade silver zones within broader intervals of intense pyrite and clay-altered quartzite. This is interpreted to be associated with a higher level (vapour phase) of mineralization which may transition to increased silver and base-metal mineralization (fluid stage) deeper within the hydrothermal system. Subsequent deeper exploration drilling in 2007 intersected progressively greater widths of stockwork. This mineralization remains open along strike and to depth. Drilling on the **Townsite** vein cut an interval grading 1804 g/t Ag, 0.31 g/t Au, 3.95% Pb and 2.5% Zn in hole K07-0088.

At **Lucky Queen**, hole K07-0114 intersected a 1.12-m native silver, galena and silver sulphosalt mineralized zone grading 17 380 g/t Ag, 0.201 g/t Au, 6.37% Pb and 1.36% Zn including a 0.52 m zone of native silver-dominated mineralization which assayed 35 618 g/t Ag, 6.95% Pb and 0.58% Zn. Hole K07-0114 was drilled 170 m southwest of the 2006 drillhole K06-018 which carried similar values. At both Lucky Queen and Shamrock, bonanza-grade intercepts are present within thicker zones of mineralization. **Shamrock** drilling results released in February of this year, returned 0.6 m grading 2405 g/t Ag, 0.31 g/t Au and 43.14% Pb with a larger 7.6-m intersection grading 343 g/t Ag, 1.45 g/t Au and 4.92% Pb from K06-025. Announced at the same time, **Ruby** drillhole K06-029 cut a 1-m intersection grading 10 480 g/t Ag, 1.50 g/t Au, 29.87% Pb and 17.42% Zn.

Figure 20. *Drilling at CMC silver property.*

In the Rancheria district, CMC Metals *(www.cmcmetals.ca)* released results from a bulk sampling program on its **CMC** silver property (formerly Silverhart; Yukon MINFILE 105B 021), located 111 km east of Teslin. The property is host to high-grade silver veins and replacement mineralization. Based on the SGS Lakefield Laboratories Ltd.'s metallurgical test results, metal recoveries from the raw ore are 96.7% Ag, 97.0% Pb and 80.0% Zn by flotation methods. The 2007 condemnation drilling under the proposed 80-tonne-per-day mill site area confirmed no potential mineralization at that site. Twinning of several holes at the TM zone was designed to test the confidence of the historical data and to allow the calculation of a NI 43-101-compliant resource estimate (Fig. 20). Partial results from drilling of the TM zone returned values grading up to 3181 g/t Ag, 8.46% Pb and 27.95% Zn over 0.65 m. Diamond drilling has been completed to test the strike and depth of mineralization at several of the other known surface vein structures explored previously with only trenching. At the M zone, drilling intersected mineralization grading up to 2055 g/t Ag, 40.98% Pb and 8.57% Zn over 0.60 m. In late October, the company submitted a development and operating plan to the Yukon government, Yukon Environmental and Socio-economic Assessment Board (YESAB) and the Yukon Water Board for review and approval of the Silver Hart mine. The development and operating plans are for a 20 000-tonne-per-year mine and an 80-tonne-per-day mill facility to concentrate the run-of-mine ore. Mining of the TM and S zones will be on a seasonal (June to October) basis with milling continuing year-round. CMC has also acquired a camp facility for the Silver Hart mine site. The facilities include sleeping quarters for 24 people, a mess hall, a recreation area, wash facilities and a first aid room.

Yukon Nevada Gold *(www.yukon-nevadagold.com)* completed 57 holes for approximately 8500 m of drilling at its Silver Valley (**Ketzakey**) property (Yukon MINFILE 105F 057) located 8 km east of its Ketza River mine and 50 km south of Ross River. Drilling to date has focused on the moderate to deep portions of the vein. Drillhole SV-07-62 returned 913.0 g/t Ag, 23.3% Pb, 0.49 g/t Au and 0.9% Cu over a true thickness of 1.83 m. Best grades were intersected in hole SV-07-59 which contained three intercepts, including 1170 g/t Ag, 12.9% Pb, 0.72 g/t Au and 1.0% Cu over a true thickness of 0.67 m. As well, the company completed line cutting in preparation for a ground geophysical survey to identify extensions of this vein system to complement the airborne geophysical survey which was completed in the spring. Induced-polarization surveys produced some intriguing anomalies that will be followed up on in the 2008 drilling campaign, in addition to exploring the shallow portions of the vein system.

Valencia Ventures Inc. *(www.valenciaventures.com)* continued exploration on its Rancheria project which includes the **Blue Heaven** and **Qb** properties (Yukon

MINFILE 105B 20, 98; Fig. 21). The properties are host to high-grade veins and carbonate replacement mineralization. The project is located approximately 300 km east of Whitehorse in a 130-km by 50-km belt that straddles the Yukon and British Columbia border. In 2007, excavator trenching totaling 1535 m in 21 trenches and diamond drilling of 605 m in six holes were focused on the Hall and Don zones on the Blue Heaven property. At the Hall zone, trench TR-06-05 exposed 11.20 m of 555.2 g/t Ag, including 7.90 m of 769.5 g/t Ag, and including 1.70 m of 3050 g/t Ag; drilling intersected 1.48 m grading 600 g/t Ag, 9.1% Pb, 0.54% Zn in hole BH-07-03, while the Don zone trenching revealed 3.70 m of 778 g/t Ag, including 0.65 m of 4350 g/t Ag from trench TR-07-31. A 180 line-km VTEM airborne geophysical survey was flown over the **QB** property to locate the source of very anomalous mineralized float boulders located on the property. Initial results from the VTEM survey show a series of sharp anomalies in the southeastern part of the grid, roughly 1-1.5 km southeast of the main geochemical anomaly and historical 1998 drill area.

Figure 21. *Gord Smarch (left) and Don Pilsworth at the newly discovered Don vein on the Blue Heaven property. Photo by Archer Cathro and Associates (1981) Ltd.*

The **Connaught** (CN) property (Yukon MINFILE 115N 040) hosts an extensive system of silver-lead-gold veins located within the Sixty Mile placer gold camp 65 km west of Dawson. The property, which was optioned and explored by Klondike Silver Corp. in 2007, covers roughly 4100 hectares. A VTEM survey flown across the property identified four conductors along strike of the known showings, in an area that also returned the highest lead values obtained from stream sediment samples. The company drilled seven holes totaling 557 m; results are pending.

Klondike Silver Corp. *(www.klondikesilver.com)* explored for lead and silver mineralization at its **Stump** property (Yukon MINFILE 105F 056) located in southern Yukon, about 55 km southeast of the community of Ross River and 6 km east of the former Ketza gold mine. The showing discovered in the late 1960s was trenched this season exposing the vein for a 350 m strike length. The results show that most of the metal is concentrated in discrete lenses, making it potentially amenable to small-scale mining without on-site processing. The company excavated a 72.6-tonne bulk sample of galena from four lenses along different parts of the vein and shipped the material to Klondike Silver's mill at Sandon, B.C., where it will be crushed and assayed. Depending upon the grade, the bulk sample may be milled to produce a concentrate or directly shipped to the Teck Cominco Ltd. smelter at Trail, BC.

Klondike Silver Corp. released results from a five-hole percussion drill program it completed in 2006 on the **Idaho Creek** (Yukon MINFILE 115J 099) property located approximately 100 km northwest of Carmacks. Anomalous gold and silver values were encountered in most holes, however, the program was initiated prior to receiving IP survey interpretations. In 2007, 1188 m of diamond drilling in four holes were completed. The best intersection averaged 60.35 g/t Ag, 0.9% Pb and 0.8% Zn across 11.4 m.

BASE METALS – ZINC

SEDIMENTARY

Selwyn Resources Ltd. *(www.selwynresources.com)* completed an aggressive drilling program at its **Selwyn** property (Howards Pass) (Yukon MINFILE 105I 12, 37, 38) which straddles the Yukon/NWT border, 160 km northwest of Ross River. The program focused on expanding high-grade zones and upgrading mineral resources (Fig. 22). The company also continued comprehensive baseline environmental studies and a technical program focused on metallurgy, mining techniques and project infrastructure. These data will form the basis for prefeasibility studies. A scoping study completed in January indicates a very robust project with net present value (NPV), discounted at 8%, of $836 million and very attractive cash cost of zinc production after deducting lead credits of US$0.48 per pound (calculated prior to the new mineral resource estimate). In April, Selwyn released an updated NI 43-101-compliant resource estimate on the nine deposits that occur over a strike length of 26.2 km. The new mineral resource contains 86 600 000 t in the Indicated category at a grade of 4.93% Zn, 1.73% Pb and 215 460 000 t in the Inferred category grading 4.71% Zn and 1.48% Pb, including a higher grade underground resource of 7 394 860 t grading 9.88% Zn and 4.32% Pb. This season, numerous areas received drilling, mostly focused on the Don and Don East zones discovered in 2005. Drilling highlights for the season include deeper intersections at the Don zone where a number of holes returned greater than 10% Zn and 5% Pb over intervals in the 1.8 m to 6.25 m range, including Hole Don-074 which intersected 31.63 m true thickness of mineralization at a depth of 241.7 m with a grade 10.2% Zn and 3.91% Pb, including 4.3 m grading 35.97% Zn and 16.01% Pb.

Figure 22. *(left) Geoff Newton and J.J. O'Donnell, examining core from Selwyn (Howards Pass) property.*

Zinccorp Resources Inc., a private company, conducted drilling on the **Bar** (Yukon MINFILE 105C 003) property, located 45 km northeast of Teslin. The claims occur in Carboniferous shale, chert sandstone and chert-pebble conglomerate overlain by Mississippian tuff and limestone. Bedded barite and laminated sulphide minerals occur on the property. The company drilled three holes, totalling 622 m.

VOLCANIC

Yukon Gold Corp. Inc. *(www.yukongoldcorp.com)* completed a seven-hole, 2395-m drill program on the **Marg** deposit (Yukon MINFILE 106D 009) located approximately 80 km northeast of Mayo in central Yukon. The deposit is hosted in Devonian to Mississippian

Earn Group volcaniclastic and sedimentary rocks of the Selwyn basin. Drilling was directed at expanding the deposit along strike and down-dip. The most significant intersection was in hole M07-97, which intersected 7.3 m grading 2.7% Cu, 4.4% Zn, 2.1% Pb, 60.3 g/t Ag and 0.88 g/t Au. Results from drilling are being incorporated into a 3D model. Additional drilling of 603 m was completed for the first time on targets outside the main deposit area. Initial results were very encouraging with intersections of a carbonate-rich exhalative and strata containing laminated pyrite and pyrrhotite.

Figure 23. *Geologists at the MM property.*

Eagle Plains Resources Ltd. *(www.eagleplains.com)* completed an exploration program on its Pelly Mountain VMS Project which includes the **Fire, Ice, Melt** and **MM** properties (Yukon MINFILE 105F 71, 73 and 128, 012), located 40 km south of Ross River. The numerous showings in the district (Fig. 23) are hosted in Devono-Mississippian rocks of the Cassiar platform, coeval with those in the Finlayson Lake district. The company has developed a database of historical information linked to an advanced Geographic Information System to aid in directing the exploration program that included geochemistry, geological mapping and prospecting. The most significant exploration result was the discovery of a silver-lead-zinc±copper mineralized barite horizon in the eastern half of the MM property. Grab samples returned up to 39 ppm Ag, 1.3% Pb and 3.5% Zn. The 2- to 8-m-wide mineralized zone was traced on surface along strike for at least 100 m.

Zinccorp conducted drilling on the **Convert** (Yukon MINFILE 105B 143) property, 79 km northeast of Teslin. The claims are underlain by rock units that have recently been mapped as Yukon-Tanana terrane. The company drilled three holes, totalling 479 m.

VEIN/BRECCIA

In January, Eagle Plains Resources Ltd. *(www.eagleplains.com)* and Blind Creek Resources Ltd. *(www.blindcreekresources.com)* released results from the 2006, 23-hole 4233-m diamond drilling program at the **Blende** property (Yukon MINFILE 106D 064), located in central Yukon approximately 65 km northeast of Keno Hill.

Figure 24. *Drill Core from Blende property.*

The deposit is a structurally controlled carbonate-hosted zinc-lead-silver deposit. Highlights consist of 65.5 m of 3.9% Zn, 1.9% Pb and 31.9 g/t Ag, including 3.1 m of 8.1% Zn, 6.4% Pb and 52.8 g/t Ag from hole BE06088. New Zn-Pb-Ag-Cu mineralization along the trend from existing showings was discovered in 2006. Results of the 2007 drill program, which consisted of 3210 m in 13 holes, were pending at year end (Fig. 24).

The **Andrew** deposit (Yukon MINFILE 105K 089), located 105 km north of Ross River, was acquired by Overland Resources *(www.overlandresources.com)*, an Australian-based exploration company. The deposit consists of coarse sphalerite and galena in quartz-carbonate veins and breccias. The company compiled historical data on the property, explored by Noranda in 2001-2003. Overland calculated a Joint Ore Reserves Committee (JORC)-compliant Indicated and Inferred mineral resource on the property of 5.92 million tonnes at 5.84% Zn, 2.03% Pb, 9.49 g/t Ag and 14.86 g/t Ge. In 2007, the company completed 2800 m of drilling in 10 holes. In addition to exploration work, the company has initiated a prefeasibility study. Initial metallurgical testwork has achieved metal recoveries of up to 96.3% Zn and 98.4% Pb. Exploration drilling was directed at expanding the known deposit and upgrading existing resources. Several drillholes returned significant results and the deposit remains open in all directions (Fig. 25). Hole AN07-30, the deepest hole on the deposit, returned 10.9% Zn and 20.2 g/t Ge over 13.0 m. Hole AN07-33 intersected 35.5 m grading 17.6% Zn, 1.0% Pb, 8.76 g/t Ag and 26.9 g/t Ge at a vertical depth of 40 m, highlighting the open-pit potential of the deposit.

Full Metal Minerals Corp. *(www.fullmetalminerals.com)* conducted an exploration program of geological mapping, soil geochemistry and ground-based gravity

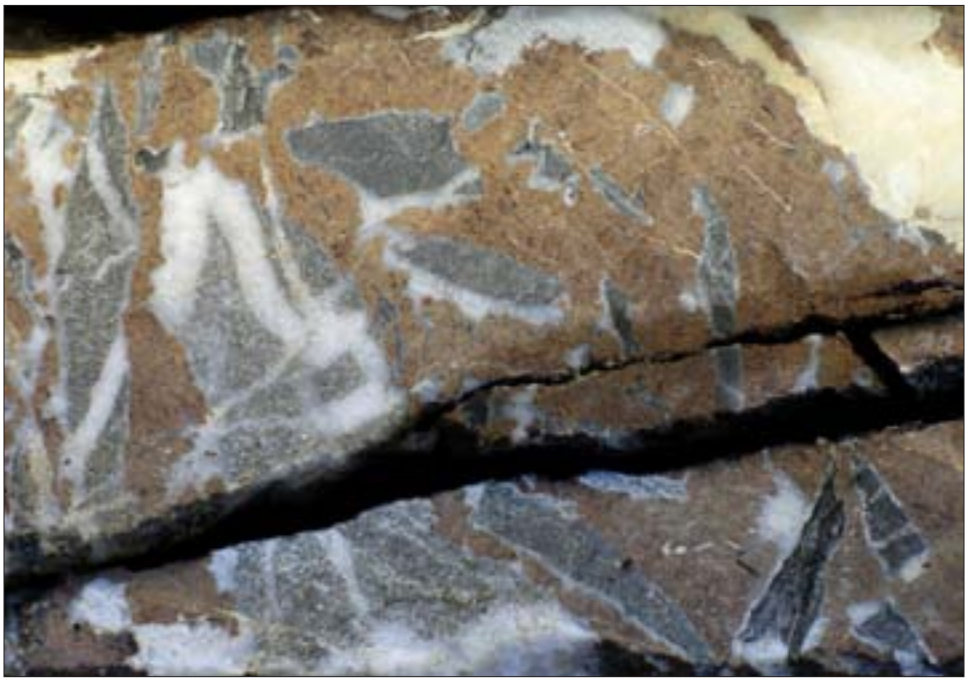


Figure 25. *Drill Core from the Andrew property.*

surveys on the **OG** property (Yukon MINFILE 116B 083), located 90 km north of Dawson. The property covers carbonate-hosted lead-zinc occurrences in Lower Proterozoic Quartet Group dolomite, minor shale and quartzite. The property was last explored in the mid-70s by Hudson Bay Mining and Smelting; drilling intersected values up to 16.3 m of 7.61% Zn, 2.06% Pb and 63 g/t Ag.

Zinccorp conducted exploration programs that included drilling seven holes, totalling 850 m, on the **Michelle**, and two holes, totalling 477 m, on the **Kit** properties (Yukon MINFILE 116A 016, 116B 086). The properties are Mississippi Valley-type occurrences located north of Dawson City.

BASE METALS – COPPER

PORPHYRY/SHEETED VEIN

Sherwood Copper Corporation *(www.sherwoodcopper.com)* explored the Minto copper-gold mine area (Yukon MINFILE 115I 021) with 23 618 m of drilling in 102 holes. The objective of the 2007 exploration program was to define more fully the limits of the Area 2 deposit and provide technical information for the prefeasibility study, but mostly to test a wide swath of the Minto property to the south, west, and between the Minto and Area 2 deposits (Fig. 26). The program was very successful in producing many ore-grade intersections throughout the property that indicate the

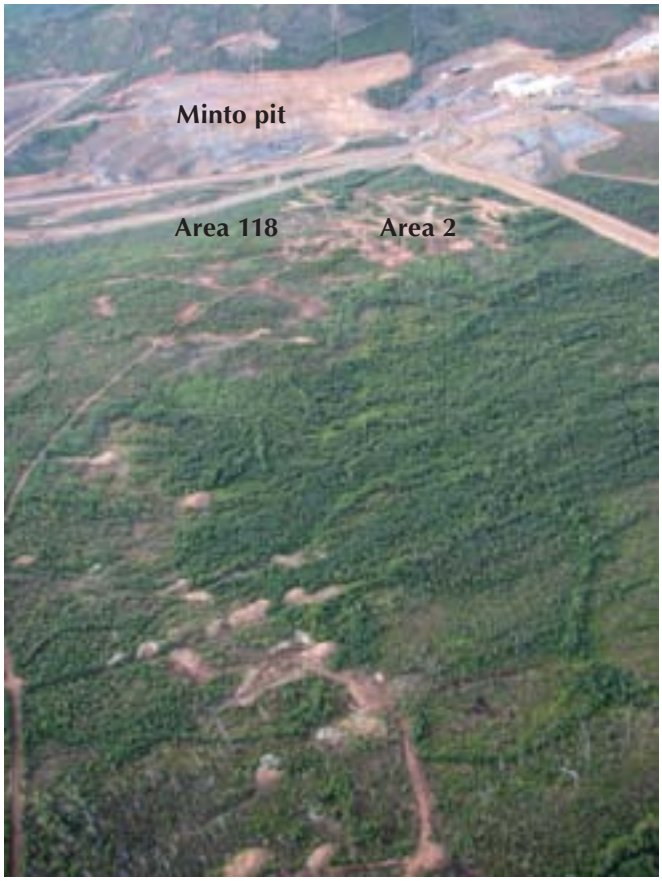


Figure 26. *Minto mine site, showing exploration drilling sites in the foreground.*

Figure 27. *Greg Komaromi (left) and Scott Casselman at the Carmacks Copper property.*

potential to add significantly to the mineral resources on the property and extend the mine life. The exploration established the presence of multiple stacked zones of mineralization and has demonstrated continuity between the main Minto deposit and the Area 2 deposit, and possibly the newly explored Ridgetop zone. The work will allow the Area 2 resource model to be upgraded and new resource models to be calculated on the Area 118 and Ridgetop zones. New discoveries were made in the Copper Keel and Airstrip zones. Examples of drill intersections include 8.4 m grading 3.68% Cu, 1.34 g/t Au and 10.5 g/t Ag from Area 118 and 88.8 m grading 0.75% Cu, 0.15 g/t Au and 2.0 g/t Ag from the Ridgetop. The full scope of the success of this drilling can be obtained by visiting Sherwood's website for complete results.

Western Copper Corp. *(www.westerncoppercorp.com)* reported the key findings of the independent feasibility study by M3 Engineering and Technology Inc. of Tucson and announced that the study supports the development of the **Carmacks Copper** property (Yukon MINFILE 115I 008; Fig. 27). Based on the new reserve (proven and probable) estimate of 10.6 million tonnes, the deposit has a six-year mine life. The feasibility study indicates initial capital development costs of $144 million, which includes a contingency of $14.1 million. An additional sum of $7.3 million is attributable to owner's costs, which include the Company's project team salaries, spare parts, and bond costs. The life-of-mine operating costs are estimated to be CDN$0.98/lb. of copper (US$0.83/lb. of copper using an exchange rate of US$0.85 = CDN$1). Using a rolling average of three years' historical and two years' future copper prices of US$2.32 per lb., based on 100% equity, the project has an internal rate of return of 15.7% and an undiscounted NPV of $122.9 million. The feasibility study indicates a payback period of 3.9 years.

The NI 43-101 resource estimate for the Carmacks Copper property was updated in November 2007. The new estimate includes geological and assay results from an additional 64 diamond drillholes totaling 9900 m drilled in 2007 in the No. 1, 4 and 7 zones. At a 0.25% total Cu cut-off grade, the deposit now boasts an oxide resource of 11.98 Mt in the Measured and Indicated category grading 1.06% total Cu, 0.84% oxide Cu, 0.46 g/t Au and 4.6 g/t Ag, and an Inferred oxide resource of 90 000 t grading 0.73% total Cu, 0.53% oxide Cu, 0.13 g/t Au and 1.8 g/t Ag. The deposit contains a significant Measured and Indicated sulphide resource of 4.34 Mt grading 0.75% Cu, 0.21 g/t Au, 2.3 g/t Ag plus an Inferred resource of 4.03 Mt grading 0.71% Cu, 0.18 g/t Au and 1.9 g/t Ag, both beneath oxide reserves in the main zones and in newly discovered targets peripheral to the planned open pits.

Exploration highlights for the year include the discovery of significant copper sulphide and native copper mineralization at the No. 13 zone which is not included

in the resource calculation. Best results include 89.0 m grading 0.62% Cu and 0.14 g/t Au from hole WC-022. Approximately 600 m east of No. 13 zone, the company discovered sulphide mineralization which has been named the No. 14 zone. Drillholes here returned values of 8.8 m grading 1.39% Cu, 0.02% Mo, 0.108 g/t Au and 9 g/t Ag from WC-130 and 16.37 m grading 1.04% Cu, 0.01% Mo, 0.093 g/t Au and 7.5 g/t Ag from hole WC-140. The zone appears to have a strike length of at least 480 m.

BCGold *(www.bcgoldcorp.com)* is the largest mineral claim holder in the Carmacks copper-gold belt, holding title to 17 mineral properties (16 274 hectares) situated proximal and adjacent to Sherwood Copper Corp.'s Minto deposit and Western Copper Corp.'s Carmacks (Williams Creek) deposit. The company began an aggressive exploration program on its **Carmacks** copper-gold properties (Yukon MINFILE 115I 006, 024) this year, completing 3295 line-km of combined magnetic-radiometric airborne geophysics, a 4040-sample Mobile Metal Ion (MMI) geochemical survey, geological mapping, prospecting, trenching, regional structural analysis and the diamond drilling of seven holes totaling 1360 m. Geochemical survey results immediately south of Western Copper Corp.'s Carmacks property define a number of copper-in-soils anomalies that appear to be the surface expression and extension of the Carmacks copper-gold trend. This corridor measures up to 1 km wide and can be traced southeastward for 4 km before being possibly offset approximately 1.5 km northward. The anomalous trend can then be traced another 3 km to the southeast and remains open along strike. Rock samples from the newly discovered **Ice zone** located 7 km south of the Carmacks Copper deposit returned values up to 1.83% Cu and 0.25 g/t Au, and 1.28% Cu and 0.41 g/t Au. The samples were collected from a series of granitic outcrops over a partially exposed strike length of 80 m. Drilling underneath the surface showings intersected mineralization grading up to 0.46% Cu over 4.69 m.

Copper Ridge Explorations Inc. *(www.copper-ridge.com)* completed a 13-hole diamond drill program totaling 2400 m on its **Lucky Joe** (Yukon MINFILE 115O 051)

Figure 28. *Drilling at the Lucky Joe property.*

property located 50 km south of Dawson City (Fig. 28). The drilling targeted the Ryan's Creek trend, a linear copper-gold geochemical anomaly with an associated geophysical (IP) anomaly. The horizon is defined by pyrite mineralization that occurs as both disseminated and massive to semi-massive blebs throughout the host quartz-biotite-chlorite schist, with malachite and disseminated chalcopyrite at depth. Highlights include 7.3 m of 0.905% Cu and 0.5 g/t Au from LJ07-19, 26.6 m grading 0.152% Cu in hole LJ07-18, and 15.3 m of 0.176% Cu in LJ07-22. These three holes define a copper-gold mineralized horizon that extends for at least 1500 m. A further 2000 m south along the trend, hole LJ06-09, drilled in 2006, intersected 12.05 m of 0.370% Cu and 0.8 g/t Au, including 3.05 m of 0.76% Cu and 0.38 g/t Au, and 2.4 m of 0.17% Cu and 3.24 g/t Au.

The **Rage** property (Yukon MINFILE 115I 050), located in the centre of the Freegold Mountain property, was drilled by Northern Freegold Resources *(www.northernfreegold.com)* for the first time, with two holes totaling approximately 500 m. The target was a 1.5 by 0.5 km copper-gold-in-soil geochemical anomaly. Both drillholes intersected significant stockwork and disseminated chalcopyrite and molybdenite mineralization in granodiorite. Results from the drilling are pending.

Results from last year's drilling program at the **Tidd** property (Yukon MINFILE 105J 029) were released this past February by Sedex Mining Corp. *(www.sedexmining.com).* The property is located in central Yukon, approximately 60 km east of Ross River. Two styles of mineralization have been discovered on the property to date. The first and most abundant type is copper-silver-indium-lead-zinc mineralization that occurs at the Indium zone in the eastern part of the 18 000-hectare property. Mineralization occurs as quartz-chalcopyrite-pyrrhotite associated with shallow-dipping granitic sills. Best results from a 16-hole diamond-drill program targeting the 3000 by 1000 m area of moderate to strong copper-in-soil geochemical response, included short intervals with peak values of 182 g/t Ag, 4.64% Cu, 113.5 g/t In, 0.96% Pb and 4.04% Zn from various holes. The Road River target consists of massive, crudely bedded pyrite located 5 km west of the Indium zone. Cobbles of massive sulphide mineralization, consisting of crudely banded, coarse pyrite material returned up to 17.5 g/t Ag, 0.11% Pb and 0.69% Zn. Wide-spaced deep soil auger samples collected across an electromagnetic conductor in the vicinity of the sulphide mineralization returned elevated silver, copper, lead and zinc. In 2007, the company completed approximately 2000 m of excavator trenching, and collected over 2000 soil samples from six grids across the property. At the Indium zone, 23 trenches explored untested IP anomalies and areas of anomalous copper-silver response. Most of these trenches exposed either mineralized float in till and/or mineralized bedrock of variable thickness (Fig. 29). The company drilled two holes, totalling 394 m. Assays for this work are pending.

Figure 29. *Geologist at the Tidd property.*

Figure 30. *Geologist Jeff Bond (YGS) demonstrating how to conduct an MMI survey at King Lake copper property.*

On the **Timber** property (Yukon MINFILE 105J 035) Strategic Metals Ltd. *(www.strategicmetalsltd.com)*, conducted a three-hole, 1000-m drill program on a strong soil geochemical anomaly that is characterized by a molybdenum core surrounded by a copper-silver-zinc halo. A quartz stockwork with copper and molybdenum mineralization outcrops in the area of the geochemical anomaly. Results were pending at year end.

On the **King Lake Copper** property (Yukon MINFILE 105D 104) 39231 Yukon Inc. carried out MMI geochemical sampling and prospecting during 2007. Preliminary interpretation of the MMI data shows multiple high-contrast copper and gold anomalies coincident with a large area underlain by pervasively altered and highly magnetic diorite (Fig. 30). Fifteen samples of fracture-controlled and vein mineralization collected from within this area averaged 1.82% Cu, 15.3 ppm Ag, 325 ppb Au and 129 ppm Mo, with values grading up to 11.5% Cu, 86.1 g/t Ag, 2.02 g/t Au and 878.8 ppm Mo.

VOLCANIC

Tarsis Capital Corp. (www.tarsis.ca) completed an exploration program consisting of an airborne geophysical survey (VTEM) and diamond drilling of four holes totaling 685 m on the Mor property (Yukon Minfile 105C 061). Massive sulphide minerals were intersected in each of the four diamond drill holes completed on the property. Highlights included 5.46 m of 1.2% Cu, 2.85% Zn, 1.36 g/t Au and 55.8 g/t Ag from drill hole MOR 07-03 and 7.8 m of 1.18% Cu, 1.52% Zn, 1.26 g/t Au and 52.2 g/t Ag from drill hole MOR 07-02. Based on the results of the program the company staked additional claims covering a series of preliminary VTEM anomalies outlined during the airborne survey. Some of the anomalies occur along the inferred trend of the sulphide horizons encountered in the drill holes.

WERNECKE BRECCIA

Cash Minerals Ltd. *(www.cashminerals.com)* and joint-venture partner Mega Uranium Ltd. *(www.megauranium.com)* conducted an extensive drill program at the **Igor** IOCG-U (iron-oxide copper-gold-uranium) property (Yukon MINFILE 106E 009) in the Wernecke Mountains. The first phase of drilling intersected 0.055% U_3O_8, 2.82% Cu, 5.2 g/t Ag and 0.03 g/t Au over 22.25 m. A high-grade section of 0.993% U_3O_8, 2.70% Cu, 0.07 g/t Au and 5.7 g/t Ag over 4.5 m was also intercepted. Approximately 9043 m of drilling in 31 holes has been completed at Igor this year. The last phase of the drill program at Igor is designed to test buried gravimetric anomalies identified in 2006 and to attempt to extend the known mineralization to the north.

Cash and Mega drilled 3050 m in six holes at the **Odie** property in the Wernecke Mountains to test coincident magnetic and gravimetric anomalies in 2007. They drilled through overburden and intersected native copper in two holes. One zone included a 16.6 m section of 0.14% Cu (518.90 to 535.45 m) within a higher grade interval of 0.27% Cu over 3.7 m between 522 and 525.7 m. Gold up to 0.33 ppm occurs in anomalous concentrations within zones of elevated copper.

Cash's and Mega Uranium's **Vic** property, an IOCG-U target, is located near the western limit of the Wernecke Supergroup rock package in the Wernecke Mountains. Samples have assayed up to 6.86% U_3O_8, 6.13% Cu, 0.398% Mo and 4.46 g/t Au. The property appears to be structurally controlled and exhibits characteristic IOCG-U mineralization similar to that of the Igor property. Ten holes were drilled for a total of 3012 m.

Fronteer Development Group Inc. *(www.fronteergroup.com)* and joint venture partner Rimfire Minerals Corp. *(www.rimfire.bc.ca)* completed eight widely spaced drillholes for 2400 m at the **Hoover** property (Yukon MINFILE 106E 002) in the Wernecke Mountains. Drill-intersection highlights include hole HV07-22 with 0.56% Cu and 0.11 g/t Au over 89 m (including 0.82% Cu and 0.17 g/t Au over 39 m) and hole HV07-27 with 0.56% Cu and 0.16 g/t Au over 45.5 m, including 1.84% Cu and 0.53 g/t Au over 17.3 m. Mineralization at Hoover has been intersected in a total of 11 widely space holes over a strike length of 500 m, and remains open along strike and at depth.

Figure 31. *Drilling at Shell Creek.*

Fjordland Exploration Inc. *(www.fjordlandex.com)* optioned the 3675-hectare **Olympic-Rob** IOCG-U property (Yukon MINFILE 116B 113) from Commander Resources Ltd. in 2006. The Olympic-Rob property occurs within Wernecke Supergroup rocks in the Ogilvie Mountains region. The 2007 drill program included two holes on the undrilled Rob zone for a total of 404 m to test coincident surface mineralization and a magnetometer anomaly. Both holes intersected copper and uranium mineralization associated with altered and brecciated quartz-dolomite within a package of hematite-altered siltstone and shale. One intersection ran 0.21% Cu and 27 ppm U_3O_8 over 11 m. A number of anomalous gold values at Rob

exceeded 0.10 g/t, with the best 1-m intersection running 0.33 g/t Au. On the Olympic zone, grab samples assaying from 100 ppm to 21.4% Cu lie within a 2-km-diameter copper-in-soil anomaly. A strong magnetic anomaly also underlies the area. Drilling on the Olympic zone in 2007 encountered poor ground conditions and the target depths were not reached.

CVRD Inco Ltd., now renamed Vale Inco *(www.inco.com)*, optioned the **Ironman** property (Yukon MINFILE 116A 017) from Copper Ridge Explorations in June 2007. The property is situated approximately 160 km northeast of Dawson City. CVRD completed a 7 km IP geophysical program over this IOCG target to confirm and extend the IP chargeability anomaly originally defined by Copper Ridge.

SEDIMENTARY

Logan Resources *(www.loganresources.ca)* continued mapping, prospecting, conducting geophysical and geochemical survey, and diamond drilling at its **Shell Creek** copper project (Yukon MINFILE 116C 029) this season (Fig. 31). The property is situated 75 km northwest of Dawson City. This year's program followed up a 2006 geochemical sampling program that expanded the area of anomalous copper in soils to an area of over 13.4 by 1.8 km. This past season, company personnel believe they have found characteristics similar to redbed-type copper deposits. The sedimentary copper mineralization has been discovered proximal and stratigraphically above the banded magnetite iron formation, which forms a plunging syncline to the northwest. Chalcocite, minor bornite and chalcopyrite occur as disseminations and fracture-fillings hosted primarily by a chloritic phyllite. Surface grab sampling returned grades up to 1.8% Cu and 9.08 g/t Au. Logan drilled 1535 m in 10 holes at Shell Creek in 2007; results of this program are pending.

BASE METALS – NICKEL + PLATINUM GROUP ELEMENTS (PGE)

MAFIC/ULTRAMAFIC

Coronation Minerals Inc. *(www.coronationminerals.com)* continued exploration on the **Wellgreen** property, situated in the Kluane area, with surface trenching, mapping and sampling on the relatively unexplored eastern portion of the property (Fig. 32). This year's program also included infill and confirmation drilling, bringing the resource estimate at Wellgreen to NI 43-101 standards. The company deepened drillhole WS-06-153, which had been extended last season to 480 m. The hole was targeted to test the thickness of the body and was still in ultramafic rock when the drill program was shut down because of inclement weather. The

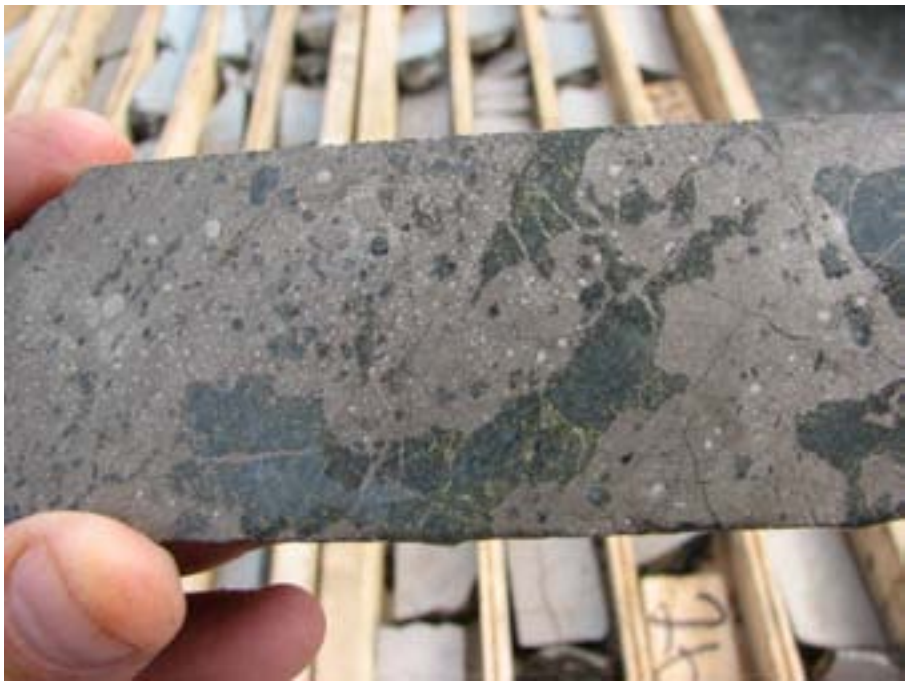


Figure 32. *Massive sulphide core at Wellgreen.*

hole ended at 561.14 m. Further underground drilling was completed to explore the deposit at depth. Assay results are pending.

White River Resources, a subsidiary of Umbono Capital Partners LLC, conducted geological mapping, prospecting and airborne VTEM geophysical surveying this past summer on the **Canalask** property (Yukon MINFILE 115F 045) situated in southwest Yukon.

SEDIMENTARY

Southampton Ventures *(www.southamptonventures.com)* optioned the **Nick** (Yukon MINFILE 106D 092), **Mon, Pe, El, Rich, Fox** and **Deer** (Yukon MINFILE 116B 170) properties from Strategic Metals Ltd., and the **Sun** from prospector Shawn Ryan, and conducted a regional-scale diamond-drilling program on several properties. The properties, termed the NiMo Project, are targeting a unique style of mineralization, which consists of stratiform vaesite (nickel disulphide) that occurs in Lower to Middle Devonian shale in an outlier of Selwyn basin rocks preserved in an east-west graben. The narrow massive sulphide horizon lies at the contact between Middle Devonian black chert of the Earn Group and a distinctive concretionary unit of Lower Devonian age, which forms the top of the Road River Formation in this area. The horizon can be enriched in a wide range of commodities including nickel, molybdenum, zinc, gold, platinum, palladium, selenium and rhenium. A total of 6796.21 m of diamond drilling was done in 59 holes on the El, Pe, Rich, Sun and Fox claims (see table at left). On the El claims, the thickest intersection graded 5.2% Ni, 0.16% Mo, 1.86% Zn, 120 ppb Au, 317 ppb Pt, 183 ppb Pd and 28.5 ppm Re, over 14 cm. Exploratory drilling tested the horizon in two areas located about 6 km apart. At the Rich property, the thickest intersection averaged 1.31% Ni, 0.041% Mo, 0.104% Zn, 46 ppb Au, 92 ppb Pt, 41 ppb Pd and 9.68 ppm Re over 1.96 m.

NiMo Project, drill summary

	Total (m)	holes
El property	2839.55	19
Pe property	749.82	8
Rich property	2485.98	25
Sun property	295.66	3
Fox property	425.2	4
Total	**6796.21**	**59**

BASE METALS – TUNGSTEN + MOLYBDENUM

SKARN

North American Tungsten Corporation Ltd. *(www.natungsten.com)* carried out a definitive feasibility study on the **Mactung** deposit (Yukon MINFILE 105O 002), located off the North Canol road on the Yukon/NWT border, following a geotechnical drilling and test-pitting program this past summer. The drilling was conducted to aid planning of potential placement for developmental infrastructure such as mill, tailings ponds and an employee camp. A total of 23 locations was explored with 42 boreholes and 42 test pits. The Mactung deposit has NI 43-101-compliant Indicated resources of 33.0 million tonnes grading 0.88% WO_3 (tungsten oxide) and an Inferred mineral resource estimate of 11.9 million tonnes grading at 0.78% WO_3.

Playfair Mining Ltd. *(www.playfairmining.com)* released a NI 43-101-compliant resource calculation on its **Risby** property (Yukon MINFILE 105F 034). The study reports an Inferred resource of 6 385 000 tonnes at an average grade of 0.462% WO_3 at a 0.20% WO_3 cut-off, an increase of 38% over the relevant historic estimate of 2 651 975 tonnes at an average grade of 0.808% WO_3 at a 0.4% WO_3 cut-off prepared by the Hudson Bay Exploration and Development Company Ltd. (HBED) in 1982. Risby is located roughly 50 km west-southwest of Ross River.

PORPHYRY/SHEETED VEIN

Largo Resources Ltd. *(www.largoresources.com)* has completed a new block model and updated mineral resource estimate incorporating all recent and historical drilling results for the **Northern Dancer** (Logtung) deposit (Yukon MINFILE 105C 009), located in the south-central region of the Yukon Territory (Fig. 33). The Inferred mineral resource for the overall deposit at a cut-off grade of 0.05% WO_3 is estimated at 242.0 million tonnes grading 0.10% WO_3 and 0.047% MoS_2. Preliminary pit modeling was done in order to help maximize the effectiveness of the recently completed diamond-drill program of 26 holes and a total of 8494 m, which will further upgrade the mineral resource. Initial results from this season's drilling include 53.6 m grading 0.32% WO_3 and 0.02% Mo within a much broader zone of 339.9 m grading 0.15% WO_3 and 0.03% Mo from drillhole LT07-73.

Figure 33. *Northern Dancer (Logtung) camp.*

Prospector Consolidated Resources Inc. *(www.prospectorresources.com)* optioned the **Kalzas** property from Copper Ridge Explorations in mid-August, 2007 and planned a program of surface bulk sampling during the current field season in preparation for a major drill test of Kalzas in 2008. The Kalzas property is located 70 km southeast of Mayo and is a porphyry-style tungsten deposit that contains tabular, high-grade zones in the central part of a larger, low-grade deposit.

On the **Molygarchy** (Hig) property (Yukon MINFILE 105E 024), located 40 km northeast of Whitehorse, 37999 Yukon Inc. conducted geological mapping, prospecting and blast trenching in 2007 as a follow-up to soil sampling and magnetic field surveying completed the previous year. Disseminated fine to coarse crystalline molybdenite, grading up to 0.44% Mo, is hosted in an extensive limonite ± K feldspar ± calcite alteration zone within granodiorite and associated quartz veins (Fig. 34). The main zone, which is coincident with a magnetic field low, remains open at either end.

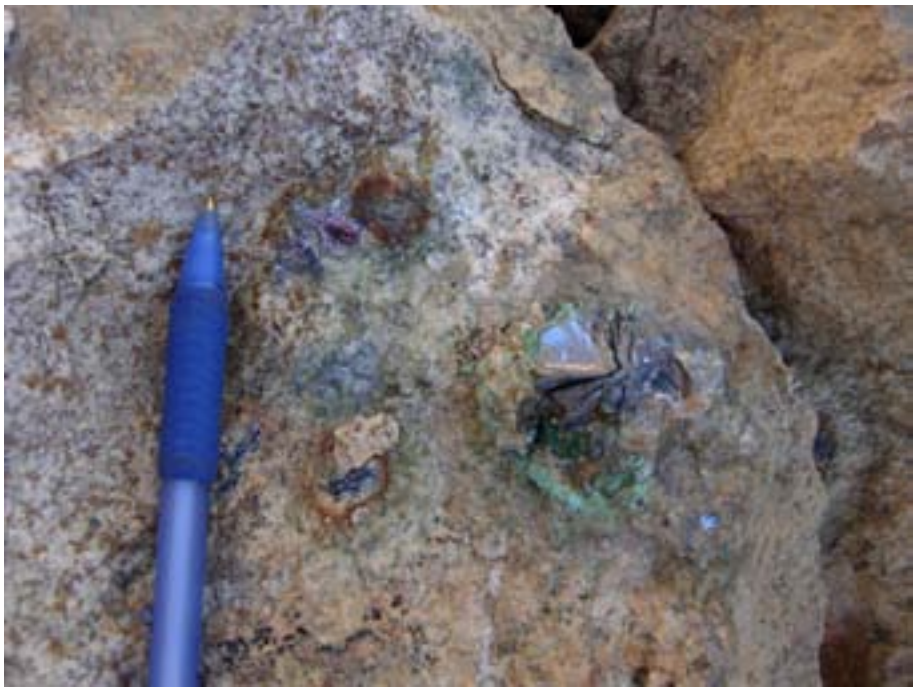


Figure 34. *Molybdenite mineralization at the Molgarchy property.*

URANIUM

The bulk of expenditures on uranium exploration in 2007 occurred in the Wernecke Mountains, focusing on iron oxide-copper-gold-uranium (IOCG-U) and structurally controlled uranium models. Overall, nearly $25 million were spent on uranium exploration in 2007, and several new and under-explored properties were drilled for the first time.

IRON-OXIDE COPPER-GOLD+URANIUM AND STRUCTURALLY CONTROLLED URANIUM

The **Lumina** property (Yukon MINFILE 106C 069), located at the easternmost extent of Wernecke Supergroup rocks in the Wernecke Mountains, has been recently characterized as a uranium-molybdenum-gold polymetallic target. Drilling by Cash minerals and Mega Uranium extended the sub-surface distribution of mineralization to the south of the Jack Flash showing in 2007 (Fig. 35). Over 4000 m were drilled this year on the property. One good intersection graded 0.14% U_3O_8, 0.035% Mo and 0.08 g/t Au over 1.5 m. Fieldwork demonstrated that uranium mineralization outcrops along the same 6-km-long north-trending structure to the north of the Jack Flash showing at the Flash Gordon and Eagle Eye localities.

Figure 35. *Russell Smits examines drill core at the Lumina property.*

Cash and Mega Uranium conducted exploration on their **Angel, Bonnie, Nad, Doh** and **Win** properties in the Wernecke Mountains in 2007. Two holes were completed on the Bonnie property, and five holes, for a total of 1478 m, were completed on the Angel property. The company also performed sampling and mapping on the Nad, the Doh and the Win, and completed sampling on the **Asap** and **Per** properties.

A 10 000-m drill program was undertaken by Fronteer Development Group Inc. *(www.fronteergroup.com)* and joint venture partner Rimfire Minerals Corp. (*www.rimfire.bc.ca*) on their Wernecke Mountain properties in 2007. This exploration program was designed to drill test high-priority targets, including the Fireweed, Hail, Pagisteel fault and TVA properties. A total of 6520 m of drilling in 28

holes was completed on seven different target areas, with assay results pending.

Fronteer identified a new high-grade uranium drill target at the Rio zone on its **TVA** property (Yukon MINFILE 106D 062), located 170 km northeast of Mayo (Fig. 36). Assays returned an average grade of 0.31% U_3O_8 from 41 surface samples, and mineralized rocks at Rio have been identified over an area measuring at least 15 by 150 m. Assays range from 0.08% to 0.60% U_3O_8. The Rio zone is thought to parallel another nearby mineralized radioactive zone that is exposed in outcrop over a 500-m distance.

International KRL *(www.krl.net)* Resources Corp.'s **Nor** IOCG-U property (Yukon MINFILE 106L 061) covers 9363 hectares on the east side of the Richardson Mountains in Yukon, approximately 310 km northeast of Dawson City. Seven diamond drillholes were completed in 2007 on the Nor property. The company also conducted an airborne-radiometric survey and a high-resolution magnetic survey to delineate alteration and known mineralization. Extensive prospecting and mapping were also performed. The company discovered additional uranium showings on the northern part of the property. Grab samples from new showings (Fig. 37) returned values from 0.11% to 5.54% U_3O_8 over 1.1 km. The uranium mineral is brannerite, and it is hosted in a potassic feldspar-altered siliceous structure. Trench mapping suggests that the structure is north to north-northwest-striking and steeply dipping.

Figure 36. *Geologists from Equity Engineering and Fronteer use a scintillometer to check radioactivity on the Rio zone of the TVA property.*

INTRUSION-RELATED

International KRL Resources *(www.krl.net)* optioned the **U** claims, which cover 1881 hectares approximately 170 km south of Dawson City. Several uranium geochemical anomalies on the property are thought to be associated with the Coffee Creek Intrusive Group. International KRL conducted a high-resolution airborne magnetic and radiometric survey in the 2007 field season. Results from the survey are pending.

International KRL *(www.krl.net)* and Logan Resources Ltd. *(www.loganresources.ca)* undertook a large staking operation to secure land with uranium potential northeast of Whitehorse. The **Turn River** project covers 743 km^2 and is located approximately

Figure 37. *Uranium showing at the Nor property.*

95 km from Whitehorse. The highest known uranium-silt geochemical values in the Yukon (up to 291 ppm) are found in the Cassiar Plateau physiographic region. High-resolution airborne radiometric and magnetic surveys over the property were completed during the 2007 field season.

Cash Minerals Ltd. *(www.cashminerals.com)* acquired the 627-hectare **Murphy** property (Yukon MINFILE 105F 079) from Signet Minerals in 2007. The property is located 85 km northeast of Whitehorse and covers intrusion-hosted uranium occurrences. The highest radioactivity was found in two zones (showings A and B) 600 m apart within a Cretaceous granitic batholith. The mineralization is associated with secondary yellow and green uranium oxides coating leached cavities within biotite-rich phases of the intrusion. Samples at showing A assayed up to 0.018% U_3O_8. The larger, talus-covered showing B assayed up to 0.137% U_3O_8 for material exposed in bedrock. Float samples taken from talus nearby assayed up to 0.226% U_3O_8. Silt and soil samples from the Murphy property are also strongly anomalous in lead, silver and molybdenum. The property is centred on a strong aeromagnetic high.

Copper Ridge Explorations Inc. *(www.copper-ridge.com)* explored its **Borealis** uranium project northeast of Dawson city. A 1108-km airborne radiometric and magnetic survey successfully defined a large uranium anomaly within and at the margins of the mid-Cretaceous Deadman stock. Uranium mineralization is associated with late-stage syenite dykes within the stock, and occurs as structurally controlled lenses of pitchblende and as disseminated uraninite within the syenite. Prospecting and silt, soil and rock sampling has identified targets for follow-up.

ACKNOWLEDGEMENTS

This report is based on public information gathered from a variety of sources. It also includes information provided by companies through press releases, personal communications, and property visits conducted during the 2007 field season. The cooperation of companies and individuals in providing information, as well as their hospitality, time and access to properties during field tours, is gratefully acknowledged.

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APPENDIX 1: 2007 EXPLORATION PROJECTS

Project name	Optioner/Owner	MINFILE number	NTS	Work type	Primary commodity	Deposit
PRECIOUS METALS - GOLD						
Black Fox	Underworld Resources Inc./ RyanWood Exploration Inc.	115O 014	115O/3	G, GP, GC, T	Au	vein/breccia
Dart	Northern Freegold Resources Ltd.	115I 055	115I/6	DD	Au	vein/breccia
Dublin Gulch	StrataGold Corp.	106D 025	106D/4	GC, DD	Au	porphyry/ sheeted vein
Goldy	Northern Freegold Resources Ltd.	115I 112	115I/6	GP, T, DD	Au	vein/breccia
Heidi	Logan Resources Ltd.	116A 037	116A/5	AGP, DD	Au	skarn/ replacement
Ketza River	Yukon-Nevada Gold Corp.	105F 019	105F/9	DD, PF	Au	skarn/ replacement
Lone Star	Klondike Star Mineral Corp.	115O 072	115O/14	G, T, BS, DD	Au	vein/breccia
Mahtin	International Gold Resources Inc./ RyanWood Exploration Inc.	115P 007	115P/15	DD	Au	skarn/ replacement
May Creek	Logan Resources Ltd./ RyanWood Exploration Inc.	115P 008	115P/15	GC, RC/P	Au	porphyry/ sheeted vein
Mike Lake	Dynamite Resources Ltd.	116A 012A	116A/5	DD	Au	skarn/ replacement
Moosehorn	Mountain Rio Resources	115N 024	115N/2	DD	Au	vein/breccia
Mount Hinton	Yukon Gold Corporation Inc.	105M 052	105M/14	AGP, T, DD	Au	vein/breccia
Nana	H. Coyne and Sons/McKeown, Sid	105D 076	105D/11	G, DD	Au	skarn/ replacement
Nucleus	Northern Freegold Resources Ltd.	115I 107	115I/6	DD	Au	porphyry/ sheeted vein
Revenue	Northern Freegold Resources Ltd.	115I 042	115I/6	GC, DD	Au	porphyry/ sheeted vein
Rosy	ATAC Resources Ltd.	105C 024	105C/13	AGP	Au	vein/breccia
Scheelite Dome	Riverside Resources Inc./ Copper Ridge Explorations Inc.	115P 004	115P/9, 16	DD	Au	skarn/ replacement
Skukum Creek	Tagish Lake Gold Corp.	105D 022A	105D/3	DD, U/GD, PF	Au	vein/breccia
Sonora Gulch	Firestone Ventures Inc./ Martensson, Jan	115J 008	115J/9	P, G, GC, DD	Au	porphyry/ sheeted vein
Spice	Klondike Star Mineral Corp./ Tanana Exploration Inc.	105G 150	105G/13	DD	Au	vein/breccia
Tinta Hill	Northern Freegold Resources Ltd.	115I 058	115I/7	DD	Au	vein/breccia
Typhoon	Curlew Lake Resources Inc.	115P 060	115P/14	G, GP, GC	Au	porphyry/ sheeted vein
VG (Vic)	Aurchem Exploration Ltd.	115I 068	115I/3	T, BS	Au	vein/breccia
White River	Underworld Resources Inc./ RyanWood Exploration Inc.	115O 011	115O/4	G, GP, BS	Au	vein/breccia

Abbreviations

AGP - airborne geophysics
BS - bulk sample
DD - diamond drilling
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GC - geochemistry
GP - geophysics
IOCG - iron-oxide copper-gold
MD - mine development
P - prospecting
PF - prefeasibility
PGE - platinum group elements
RC/P - reverse circulation/percussion drilling
RD - road construction
T - trenching
U/GD - underground development

Appendix 1 (continued): 2007 EXPLORATION PROJECTS

Project name	Optioner/Owner	MINFILE number	NTS	Work type	Primary commodity	Deposit
PRECIOUS METALS - SILVER						
Blue Heaven	Valencia Ventures Inc./ Strategic Metals Ltd.	105B 020	105B/7	AGP, T, DD	Ag	vein/breccia
CMC Silver (Hart)	CMC Metals Ltd.	105B 021	105B/7	DD, RD, MD	Ag	vein/breccia
Connaught	Klondike Silver Corp./ ATAC Resources Ltd.	115N 040	115N/15	P, GC, T, DD	Ag	vein/breccia
Gram	Yukon Gold Corporation Inc.	105M 057	105M/15	P, AGP, GC	Ag	vein/breccia
Hopeful	ATAC Resources Ltd./Berdahl, Ron	115P 047	115P/14	P, AGP, GC	Ag	vein/breccia
Idaho Creek	Klondike Silver Corp./ ATAC Resources Ltd.	115J 099	115J/10	DD	Ag	vein/breccia
Keno Hill	Alexco Resource Corp.	105M 001	105M/14	DD	Ag	vein/breccia
Kuda	International KRL Resources Corp./ Tarsis Capital Corp.	105B 140	105B/1	GC, T, DD	Ag	skarn/ replacement
Plata	Strategic Metals Ltd.	105N 003	105N/9	P, AGP, GC	Ag	vein/breccia
Qb	Valencia Ventures Inc./ Strategic Metals Ltd.	105B 098	105B/8	AGP, GC	Ag	skarn/ replacement
Rancheria Silver	Tanana Exploration Inc.	various	105B	P, GP, GC, T	Ag	skarn/ replacement
Silver Valley	Yukon-Nevada Gold Corp.	105F 057	105F/9	DD	Ag	vein/breccia
Stump	Klondike Silver Corp.	105F 056	105F/9	G, GC, T, BS	Ag	vein/breccia
BASE METALS - ZINC-LEAD						
Andrew	Overland Resources Ltd./ Berdahl, Ron	105K 089	105K/16	P, G, GC, DD, PF	Zn-Pb	vein/breccia
Bar	Zinccorp Resources Inc./ Strategic Metals Ltd.	105C 003	105C/9	DD	Zn-Pb	sediment associated
Blende	Blind Creek Resources Ltd./ Eagle Plains Resources Ltd.	106D 064	106D/7	GC, DD	Zn-Pb	vein/breccia
Convert	Zinccorp Resources Inc./ Strategic Metals Ltd.	105B 143	105B/5	DD	Zn-Pb	volcanic associated
Gentian	Overland Resources Ltd./ Berdahl, Ron	new	105K/16	G, GC	Zn-Pb	sediment associated
Goz Creek	Tarsis Capital Corp.	106C 020	106C/7	P, GC	Zn-Pb	vein/breccia
Hy(land)	Strategic Metals Ltd.	105H 010	105H/7	P, G, AGP, GC	Zn-Pb	skarn/ replacement
Jake	Strategic Metals Ltd.	105G 060	105G/16	AGP	Zn-Pb	skarn/ replacement
Kit (MVT)	Zinccorp Resources Inc./ Strategic Metals Ltd.	116B 086	116B/14	DD	Zn-Pb	Mississippi-Valley type
Liberty Fork	Ross, John Peter	116C 172	116C/10	P, GC	Zn-Pb	volcanic associated

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Appendix 1 (continued): 2007 EXPLORATION PROJECTS

Project name	Optioner/Owner	MINFILE number	NTS	Work type	Primary commodity	Deposit
Marg	Yukon Gold Corporation Inc.	106D 009	106D/1	DD	Zn-Pb	volcanic associated
Michelle	Zinccorp Resources Inc./ Strategic Metals Ltd.	116A 016	116A/13	DD	Zn-Pb	Mississippi-Valley type
OG	Full Metal Minerals Corp./ Ryan, Shawn	116B 083	116B/13	G, GP, GC	Zn-Pb	Mississippi-Valley type
Pelly Mountain VMS	Eagle Plains Resources Ltd.	105F 012	105F/7	G, GC	Zn-Pb	volcanic associated
Selwyn Project	Selwyn Resources Ltd.	105I 012	105I/6	DD, PF	Zn-Pb	sediment associated
Top	Strategic Metals Ltd.	116B 041	116B/4	AGP	Zn-Pb	volcanic associated
Uno	Strategic Metals Ltd.	105J 030	105J/1	AGP	Zn-Pb	skarn/ replacement
Wolverine	Yukon Zinc Corp.	105G 072	105G/8	PF, MD	Zn-Pb	volcanic associated
BASE METALS - COPPER						
(Merr) Ice	BCGold Corp/ RyanWood Exploration Inc.	new	115I/7	G, AGP, GC, T, DD	Cu	porphyry/ sheeted vein
Canadian Creek	North American Vanadium Inc./ Cariboo Rose Resources Ltd.	115J 101	115J/10	DD	Cu	porphyry/ sheeted vein
Carmacks Copper	Western Copper Corp.	115I 008	115I/7	DD, PF	Cu	porphyry/ sheeted vein
Casino	Western Copper Corp.	115J 028	115J/10	G	Cu	porphyry/ sheeted vein
DR	Fronteer Development Group Inc./ Rimfire Minerals Corp.	new	106D/16	DD	Cu	Wernecke breccia
Fairweather	Strategic Metals Ltd./ RyanWood Exploration Inc.	105J 010	105J/13	AGP, GC	Cu	porphyry/ sheeted vein
Gin	H. Coyne and Sons	105D 055	105D/11	DD	Cu	skarn/ replacement
Highway	Strategic Metals Ltd.	new	105C/1	AGP	Cu	volcanic associated
Hoover	Fronteer Development Group Inc./ Rimfire Minerals Corp.	106E 002	106E/1	DD	Cu	Wernecke breccia
Hopper	Strategic Metals Ltd.	115H 019	115H/7	P, G, AGP, T	Cu	porphyry/ sheeted vein
Igor	Cash Minerals Ltd./ Mega Uranium Ltd.	106E 009	106E/2	DD	Cu	Wernecke breccia
Ironman	Vale Inco/ Copper Ridge Explorations Inc.	116A 017	116A/15	GP	Cu	Wernecke breccia

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Appendix 1 (continued): 2007 EXPLORATION PROJECTS

Project name	Optioner/Owner	MINFILE number	NTS	Work type	Primary commodity	Deposit
King Lake Copper	39231 Yukon Inc.	105D 104	105D/14	P, GP, GC	Cu	porphyry/ sheeted vein
Lucky Joe	Copper Ridge Explorations Inc.	115O 051	115O/11, 12	GC, DD	Cu	porphyry/ sheeted vein
Minto	Sherwood Copper Corp.	115I 021	115I/11	GP, DD, PF, MD	Cu	IOCG
Mor	Tarsis Capital Corp.	105C 061	105C/1	P, G, AGP, GC, DD	Cu	volcanic associated
Nor	International KRL Resources Corp./ RyanWood Exploration Inc.	106L 061	106L/6	P, G, AGP, GP, GC, DD	Cu	Wernecke breccia
Odie	Cash Minerals Ltd./ Mega Uranium Ltd.	new	106E/7	DD	Cu	Wernecke breccia
Pagisteel Fault	Fronteer Development Group Inc./ Rimfire Minerals Corp.	new	106D/16	DD	Cu	Wernecke breccia
Rage	Northern Freegold Resources Ltd.	115I 050	115I/6	GC, T, DD	Cu	porphyry/ sheeted vein
Rob	Fjordland Exploration Inc./ Commander Resources Ltd.	116B 113	116B/14	DD	Cu	Wernecke breccia
Shell Creek	Logan Resources Ltd.	116C 029	116C/9	P, G, GP, GC, DD	Cu	sediment associated
Tidd	Sedex Mining Corp./ Strategic Metals Ltd.	105J 029	105J/3	P, G, AGP, GC, T, DD	Cu	skarn/ replacement
Timber	Strategic Metals Ltd.	105J 035	105J/4	AGP, DD	Cu	porphyry/ sheeted vein
WS Total	BCGold Corp./ RyanWood Exploration Inc.	115I 006	115I/7	G, AGP, GC, DD	Cu	porphyry/ sheeted vein
Yukon Olympic	Richmond Capital Corp./ Copper Ridge Explorations Inc.	116G 082	116G/1	G	Cu	Wernecke breccia
BASE METALS - NICKEL ± PLATINUM GROUP ELEMENTS (PGE)						
Burwash	Golden Chalice Resources Inc./ Strategic Metals Ltd.	115G 100	115G/6	AGP	Ni/PGE	mafic/ultramafic associated
Canalask	White River Resources/ StrataGold Corp.	115F 045	115F/15	P, G, AGP	Ni/PGE	mafic/ultramafic associated
Deer	Southampton Venture Inc./ Strategic Metals Ltd.	116B 170	116B/9	DD	Ni/PGE	sediment associated
NiMo	Southampton Venture Inc./ Strategic Metals Ltd.	new	106E/13	P, G, DD	Ni/PGE	sediment associated
Rich	Southampton Venture Inc. /Strategic Metals Ltd.	new	116I/8	AGP, DD	Ni/PGE	sediment associated
Sun	Southampton Venture Inc./ Strategic Metals Ltd.	new	116I/16	DD	Ni/PGE	sediment associated
Wellgreen	Coronation Minerals Inc./ Northern Platinum Ltd.	115G 024	115G/5	DD	Ni/PGE	mafic/ultramafic associated

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Appendix 1 (continued): 2007 EXPLORATION PROJECTS

Project name	Optioner/Owner	MINFILE number	NTS	Work type	Primary commodity	Deposit
BASE METALS - TUNGSTEN						
Hidden	Strategic Metals Ltd.	105F 129	105F/6	AGP	W	skarn/ replacement
Kalzas	Prospector Consolidated Resources Inc./Copper Ridge Explorations Inc.	105M 066	105M/7	GC, T, BS	W	porphyry/ sheeted vein
Logtung (Northern Dancer)	Largo Resources Ltd./ Strategic Metals Ltd.	105B 039	105B/4	DD, PF	W	porphyry/ sheeted vein
MacTung	North American Tungsten Corp. Ltd.	105O 002	105O/8	T, RC/P, PF	W	skarn/ replacement
Obvious	Strategic Metals Ltd.	105F 094	105F/6	AGP	W	skarn/ replacement
Rau	ATAC Resources Ltd.	106D 005	106D/1	P, G, AGP, GC	W	porphyry/ sheeted vein
Track	Strategic Metals Ltd.	116C 137	116C/8	AGP	W	skarn/ replacement
BASE METALS - MOLYBDENUM						
Red Mountain	Tintina Mines Ltd.	105C 009	105C/13	RD, PF	Mo	porphyry/ sheeted vein
BASE METALS - URANIUM						
Angel	Cash Minerals Ltd./ Mega Uranium Ltd.	new	106D/15	DD	U	Wernecke breccia
Bonnie	Cash Minerals Ltd./ Mega Uranium Ltd.	new	106C/13	DD	U	Wernecke breccia
Borealis	Copper Ridge Explorations Inc./ RyanWood Exploration Inc.	116B 098	116B/11	G, AGP, GC	U	porphyry/ sheeted vein
Fireweed	Fronteer Development Group Inc./ Rimfire Minerals Corp.	106E 001	106E/1	DD	U	Wernecke breccia
Lumina	Cash Minerals Ltd./ Mega Uranium Ltd.	106C 069	106C/14	P,G, GC, DD	U	vein/breccia
Slats	Fronteer Development Group Inc./ Rimfire Minerals Corp.	106D 075	106D/16	DD	U	Wernecke breccia
Turn River	Longview Capital Partners/ Logan Resources Ltd.	various	105E/4	AGP	U	porphyry/ sheeted vein
TVA	Fronteer Development Group Inc./ Rimfire Minerals Corp.	106D 062	106D/16	DD	U	Wernecke breccia
Vic	Cash Minerals Ltd./ Mega Uranium Ltd.	106D 072	106D/10	DD	U	Wernecke breccia
REGIONAL PROGRAMS						
Regional - NTS 115I	BCGold Corp./RyanWood Exploration Inc.	various	115I	AGP, GC		

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APPENDIX 2: 2007 DRILLING STATISTICS

Property	Optioner/Owner	# drillholes	# of metres
	Diamond drilling		
Andrew	Overland Resources Ltd./Berdahl, Ron	10	2837
Angel	Cash Minerals Ltd./Mega Uranium Ltd.	5	1478
Bar	Zinccorp Resources Inc./Strategic Metals Ltd.	3	622
Blende	Blind Creek Resources Ltd./Eagle Plains Resources Ltd.	13	3209
Blue Heaven	Valencia Ventures Inc./Strategic Metals Ltd.	6	605
Bonnie	Cash Minerals Ltd./Mega Uranium Ltd.	2	1000
Canadian Creek	North American Vanadium Inc./Cariboo Rose Resources Ltd.	5	879
Carmacks Copper	Western Copper Corp.	122	17 830
CMC Silver (Hart)	CMC Metals Ltd.	11	787
Connaught	Klondike Silver Corp./ATAC Resources Ltd.	7	557
Convert	Zinccorp Resources Inc./Strategic Metals Ltd.	3	479
Dart	Northern Freegold Resources Ltd.	4	259
DR	Fronteer Development Group Inc./Rimfire Minerals Corp.	2	350
Dublin Gulch	StrataGold Corp.	20	5528
EL	Southampton Venture Inc./Strategic Metals Ltd.	19	2840
Fireweed	Fronteer Development Group Inc./Rimfire Minerals Corp.	5	1028
Gin	H. Coyne and Sons		975
Goldy	Northern Freegold Resources Ltd.	5	696
Heidi	Logan Resources Ltd.	19	2686
Hoover	Fronteer Development Group Inc./Rimfire Minerals Corp.	10	3150
Idaho Creek	ATAC Resources Ltd.	4	1188
Igor	Cash Minerals Ltd./Mega Uranium Ltd.	31	9043
Ketza River	Yukon-Nevada Gold Corp.	360	51 104
Kit (MVT)	Zinccorp Resources Inc./Strategic Metals Ltd.	2	477
Lone Star	Klondike Star Mineral Corp.		846
Lucky Joe	Copper Ridge Explorations Inc.	13	2400
Lumina	Cash Minerals Ltd./Mega Uranium Ltd.	25	4367
Mahtin	International Gold Resources Inc./RyanWood Exploration Inc.	7	998
Marg	Yukon Gold Corp. Inc.	10	2998
(Merr) Ice	BCGold Corp./RyanWood Exploration Inc.	4	860
Michelle	Zinccorp Resources Inc./Strategic Metals Ltd.	7	850
Mike Lake	Dynamite Resources Ltd.	9	1827
Minto	Sherwood Copper Corp.	102	23 618
Moosehorn	Mountain Rio Resources	12	2805
Mor	Tarsis Capital Corp.	4	685
Mount Hinton	Yukon Gold Corp. Inc.		1000
Nana	H. Coyne and Sons/McKeown, Sid	2	305
Nor	International KRL Resources Corp./RyanWood Exploration Inc.	7	1040
(Northern Dancer) Logtung	Largo Resources Ltd./Strategic Metals Ltd.	26	8494

Appendix 2 (continued): 2007 DRILLING STATISTICS

Property	Optioner/Owner	# drillholes	# of metres
Nucleus	Northern Freegold Resources Ltd.	27	6313
Odie	Cash Minerals Ltd./Mega Uranium Ltd.	6	3050
Pagisteel Fault	Fronteer Development Group Inc./Rimfire Minerals Corp.	1	300
PE	Southampton Venture Inc./Strategic Metals Ltd.	8	750
Rage	Northern Freegold Resources Ltd.	2	509
Revenue	Northern Freegold Resources Ltd.	7	1451
Rich	Southampton Venture Inc./Strategic Metals Ltd.	25	2486
Rob	Fjordland Exploration Inc./Commander Resources Ltd.	6	2000
Scheelite Dome	Riverside Resources Inc./Copper Ridge Explorations Inc.	5	601
Selwyn project	Selwyn Resources Ltd.	101	34 385
Shell Creek	Logan Resources Ltd.	10	1535
Silver Valley	Yukon-Nevada Gold Corp.	57	8494
Skukum Creek	Tagish Lake Gold Corp.	18	1700
Slats	Fronteer Development Group Inc./Rimfire Minerals Corp.	6	886
Sonora Gulch	Firestone Ventures Inc./Martensson, Jan	12	2113
Spice	Klondike Star Mineral Corp./Tanana Exploration Inc.	3	440
Sun	Southampton Venture Inc./Strategic Metals Ltd.	3	296
Tidd	Sedex Mining Corp./Strategic Metals Ltd.	2	314
Timber	Strategic Metals Ltd.	3	830
Tinta Hill	Northern Freegold Resources Ltd.	12	2200
TVA	Fronteer Development Group Inc./Rimfire Minerals Corp.	5	855
Typhoon	Curlew Lake Resources Inc.	6	1001
Vic	Cash Minerals Ltd./Mega Uranium Ltd.	10	3012
Wellgreen	Coronation Minerals Inc./Northern Platinum Ltd.	3	657
WS Total	BCGold Corp./RyanWood Exploration Inc.	7	1360
	Total	**1241**	**240 238**
	Percussion/Reverse Circulation		
MacTung	North American Tungsten Corp. Ltd.	42	225
May Creek	Logan Resources Ltd./RyanWood Exploration Inc.	5	
	Total	**47**	**225**

Yukon Placer Mining Overview, 2007

***William LeBarge*[1]**
Yukon Geological Survey

LeBarge, W., 2008. Yukon Placer Mining Overview, 2007. *In:* Yukon Exploration and Geology 2007, D.S. Emond, L.R. Blackburn, R.P. Hill and L.H. Weston (eds.), Yukon Geological Survey, p. 43-47.

PLACER MINING

Today, more than 100 years after the discovery of gold in the Yukon, placer mining is still an important sector in the Yukon's economy. Royalty records, which represent the minimum amount of gold production, show that over 16.6 million crude ounces (518 tonnes) of placer gold have been produced to date in the Yukon — at today's prices that would be worth more than $9.8 billion.

In 2007, there were 107 active placer mining operations employing approximately 350 people directly. Although the total number of operations was only one more than in 2006, the industry saw a fair amount of transition: ten operations moved to new drainages, four operations closed, nine operations were sold and five new mines began operating. Although most placer operations are still small and family-run (with an average of three or four employees), there has been a recent trend for small, relatively inactive properties being sold to new owners and re-activated. In addition, several mine owners now own more than one active property, so there appears to be a shift towards larger operators.

As in past years, weather played a factor in the mining process, heavy snowfall over the winter in central and southern Yukon delayed the start of the season for many operators, but warm weather in September and October allowed many miners to sluice well into the fall.

There are ten placer mining areas (Fig. 1) distributed throughout the four Yukon Mining Districts. The majority of active placer mining operations were in the Dawson Mining District, followed by the Whitehorse Mining District and the Mayo Mining District. No mines are currently active in the Watson Lake Mining District, although there are a few exploratory properties along the Pelly and Liard rivers.

The total Yukon placer gold production in 2007 was 63,929 crude ounces (1 988 400 g), compared to 58,294 crude ounces (1 813 100 g) in 2006. The value of this 2007 gold production was CDN$38.13 million or US$35.63 million (Fig. 2).

Approximately 88% of the Yukon's placer gold was produced in the Dawson Mining District, which includes the unglaciated drainages of Klondike River, Indian River, west Yukon (Fortymile and Sixtymile rivers) and lower Stewart River. The remaining gold came from the unglaciated Moosehorn Range in the Whitehorse Mining District, and other placer mining areas in the glaciated Mayo and Whitehorse mining districts which include Clear Creek, Mayo, Dawson Range, Kluane, Livingstone and Whitehorse South.

Reported placer gold production from Indian River drainages in 2007 increased dramatically over 2006, from 18,008 crude ounces (560 110 g) to 24,436 crude ounces (760 050 g). With the exception of Quartz Creek, all other drainage production increased, with the most dramatic rise seen on Dominion Creek.

[1]*bill.lebarge@gov.yk.ca*

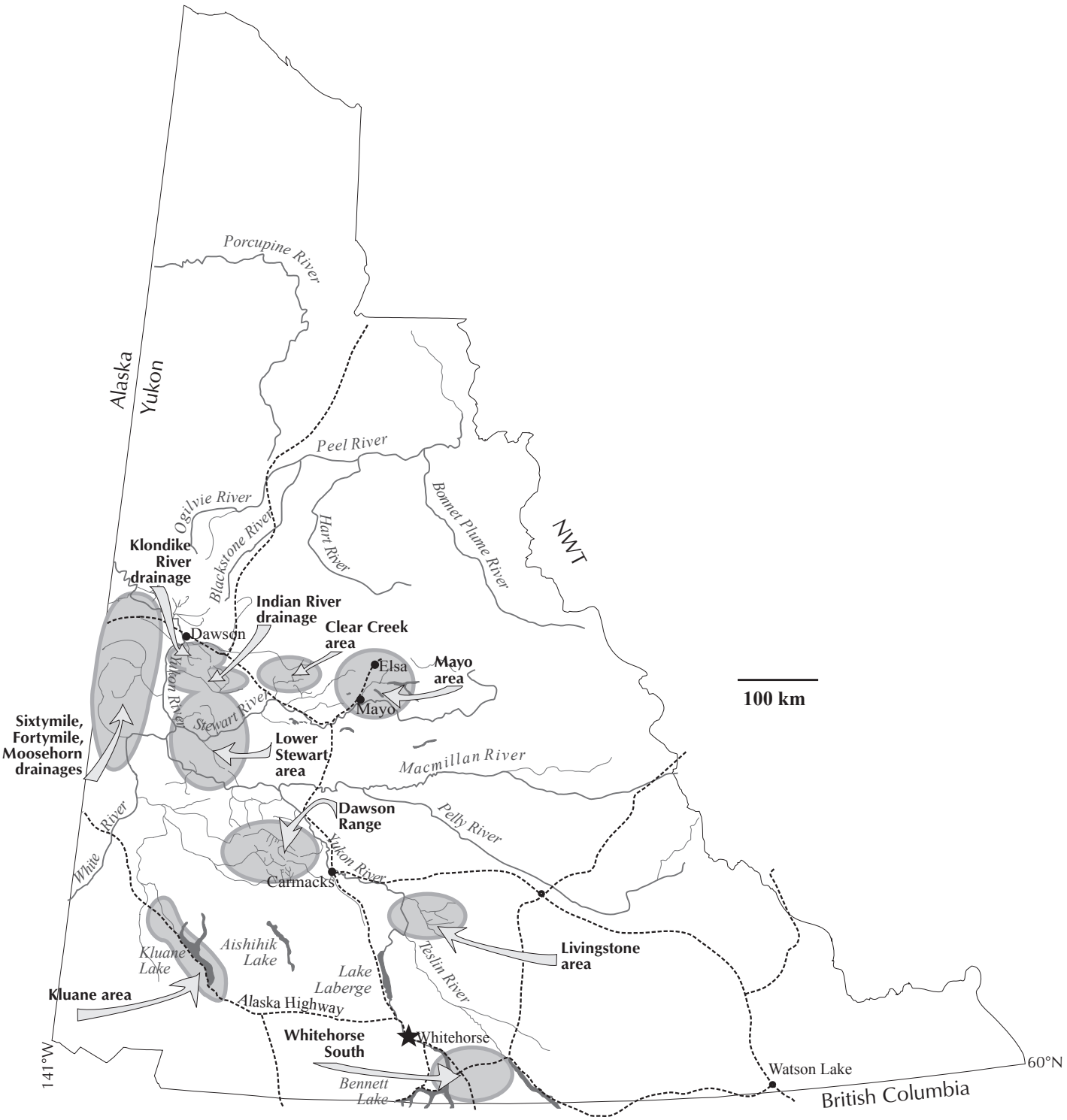

Figure 1. *Yukon placer mining areas.*

In Klondike area drainages, production decreased from 15,442 crude ounces (480 300 g) in 2006 to 11,621 crude ounces (361 450 g) in 2007. Notable decreases were seen on Hunker and Eldorado creeks, while Bear, Lindow and Bonanza creeks all saw increases.

West Yukon (Sixtymile, Fortymile and Moosehorn Range) placer gold production increased from 9333 crude ounces (290 300 g) in 2006 to 14,914 crude ounces (463 880 g) in 2007. The largest increase was from Sixtymile River, while Matson Creek and Ten Mile Creek also saw significant increases.

Reported production from operations in the Lower Stewart drainages was down in 2007, to a total of 5424 crude ounces (168 700 g) from 7884 crude ounces (245 200 g) the previous year. Black Hills, Maisy May and Kirkman creeks increased substantially while Thistle and Scroggie saw a drop in reported production.

Clear Creek drainages saw an increase in gold reported over the year, from 232 crude ounces (7220 g) in 2006 to 363 crude ounces (11 290 g) in 2007.

In the Dawson Range, reported placer gold production increased from 735 crude ounces (22 900 g) in 2006 to 912 crude ounces (28 370 g) in 2007.

In the Mayo area, gold production increased substantially from 1471 crude ounces (45 750 g) to 2755 crude ounces (85 690 g). A dramatic increase was seen in reported royalties from Owl Creek.

In the Kluane area, reported placer gold production dropped from 2260 crude ounces (70 290 g) to 887 crude ounces (27 590 g). Burwash Creek saw an increase while Gladstone Creek had a significant drop in reported gold.

The Livingstone area saw some active mining on Little Violet Creek, with 52 crude ounces (1600 g) of gold reported, down from 64 crude ounces (2000 g) the year before.

In the Whitehorse South area, no gold was reported in 2007, in contrast with last year's 24.8 crude ounces (771 g) reported from Iron Creek.

PLACER EXPLORATION

There were at least 24 exploratory operations in 2007, up from 9 the year before. Placer miners throughout the Yukon continue to explore for new deposits, using traditional methods such as excavator trenching and bulk sampling, as well as auger, reverse circulation and churn drilling. Newer methods such as ground-penetrating radar, magnetometer surveys and resistivity surveys are also becoming popular.

One exploration highlight of the 2007 season was the continuing testing by Klondike Star Ltd. of the Indian River drainage between McKinnon Creek and Montana Creek. Several test pits were mined and an access road was

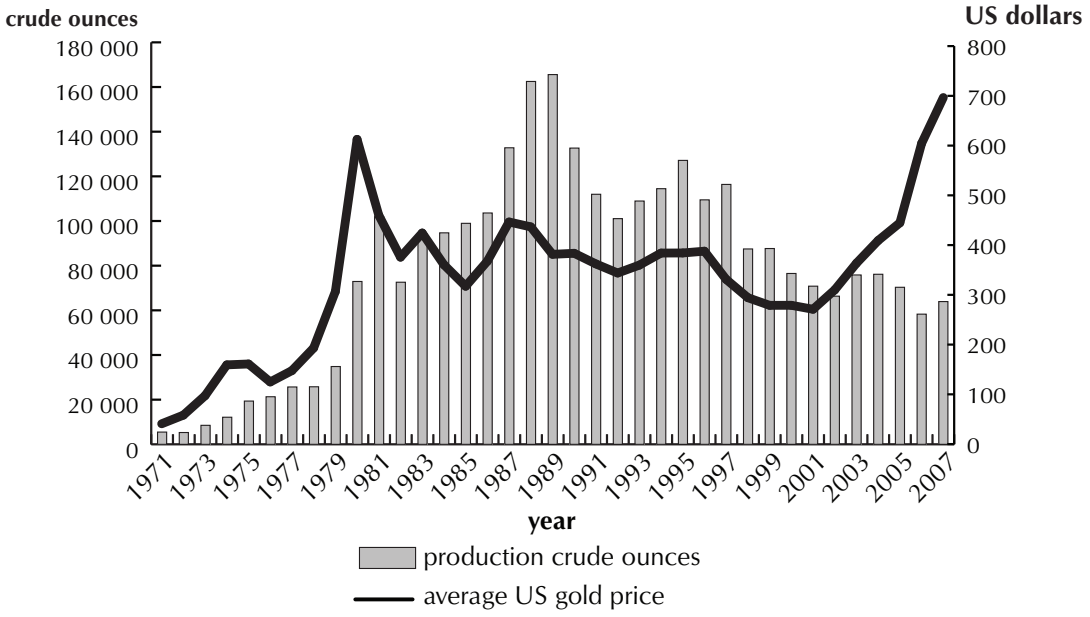

Figure 2. *Yukon placer gold production figures and average US gold price, 1971-2007.*

constructed, which may eventually link the middle reaches of the Indian River to its upstream reaches and Dominion Creek (Fig. 3).

The extensive development of the lower Sixtymile River drainage between the mouth of Ten Mile Creek and the confluence of Sixtymile River and Yukon River continued in 2007. In addition to the construction of several kilometres of road and an airstrip, a bridge was installed over the Sixtymile River. This improved access is favourable for increased development and testing of nearby drainages such as Twenty Mile Creek and Thirteen Mile Creek, as well as the upstream reaches of the Sixtymile River.

The staff at the Yukon Geological Survey and the Client Services and Inspection Division (Department of Energy, Mines and Resources, Yukon government) can provide information and advice regarding placer mining in the Yukon. Publications on placer mining in the Yukon are available through the Yukon Geological Survey office at Room 102, Elijah Smith Building, 300 Main St. Whitehorse, Yukon. Many recent publications and maps can be downloaded for free from our website at www.geology.gov.yk.ca.

APERÇU

Aujourd'hui, plus de cent ans après la découverte des premiers gisements d'or dans le Yukon, l'exploitation des placers reste un important secteur de l'économie du Yukon. Plus de 16,6 millions d'onces brutes (518 tonnes) d'or placérien ont été produites à ce jour au Yukon, ce qui représente plus de 9,8 milliards de dollars au prix actuel de l'or.

En 2007, on a dénombré 107 sites d'exploitation directement sur des placers. Près de 350 personnes étaient employées directement sur ces placers. Bien que l'on ait compté qu'un seul site exploité de plus qu'en 2006, les transitions se sont avérées nombreuses dans cette industrie : dix sites ont été déplacés vers de nouveaux bassins versants, quatre sites ont été fermés,

Figure 3. *Aerial view of Klondike Star Ltd. test pits on Indian River, July 2007.*

neuf sites ont été vendus et cinq nouvelles mines sont entrées en exploitation. Bien que la majorité des sites d'exploitation sur placers soient de petites entreprises familiales qui emploient en moyenne de trois à quatre employés, on a observé récemment une tendance à vendre les petites propriétés relativement inactives à de nouveaux propriétaires et à les remettre en activité. En outre, plusieurs propriétaires de mines possèdent aujourd'hui plus d'une propriété active, alors il semble y avoir une tendance vers de plus grands exploitants.

Comme ce fut le cas au cours des dernières années, les conditions météorologiques ont joué un rôle important dans les activités minières et les chutes de neige importantes au cours de l'hiver dans le centre et dans la partie sud du Yukon ont retardé le début de la saison pour de nombreux exploitants. Cependant, les températures chaudes du mois de septembre et du mois d'octobre ont permis à de nombreux mineurs de poursuivre efficacement leurs activités à l'automne.

On compte dix zones d'exploitation de placers réparties dans l'ensemble des quatre districts miniers du Yukon (Fig. 1). La majorité des placers encore actifs sont situés dans le district minier de Dawson, le reste se trouvant dans les districts miniers de Whitehorse et de Mayo. Il n'y a présentement aucune mine active dans le district minier de Watson Lake, malgré la présence de quelques propriétés de prospection le long des rivières Pelly et Liard.

La production d'or dans les placers du Yukon a totalisé 63 929 d'onces brutes (1 988 400 g) en 2007 alors qu'elle s'élevait à 58 294 d'onces brutes (1 813 100 g) en 2006. La production d'or en 2007 est évaluée à 38,13 millions de dollars canadiens ou 35,63 millions de dollars americains (Fig. 2).

Approximativement 88 % de l'or placérien du Yukon a été produit dans le district minier de Dawson qui inclut les drainages non englacés de la rivière Klondike, de la rivière Indian, de l'Ouest du Yukon (rivières Fortymile et Sixtymile) et le cours inférieur de la rivière Stewart. Le reste de l'or a été extrait de la chaîne non englacée Moosehorn dans le district minier de Whitehorse et d'autres districts placériens dans les districts miniers englacés de Mayo et de Whitehorse qui comprennent Clear Creek, Mayo, la chaîne Dawson, Kluane, Livingstone et le Whitehorse Sud.

On dénombre au moins 24 activités d'exploration en 2007, soit neuf de plus que l'année précédente. Les exploitants de placers continuent à explorer de nouveaux gisements en utilisant des méthodes classiques, comme l'emploi d'excavatrice pour le creusement des tranchées, l'échantillonnage massif, ainsi que l'utilisation de tarières (ou mèches), le recours à la méthode de la circulation inverse et le forage au battage. De nouvelles méthodes, comme celles utilisant des géoradars, des levés magnétométriques et des levés de résistivité deviennent également de plus en plus populaires.

YUKON OIL AND GAS OVERVIEW 2007

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Energy, Mines and Resouces, Government of Yukon

Adilman, B., 2008. Yukon Oil and Gas Overview 2007. *In:* Yukon Exploration and Geology 2007, D.S. Emond, L.R. Blackburn, R.P. Hill and L.H. Weston (eds.), Yukon Geological Survey, p. 49-58.

ABSTRACT

This summer, Oil and Gas Resources' (OGR) had its most successful oil and gas rights disposition process to date. The Government of Yukon awarded Northern Cross (Yukon) Ltd. with exploration rights for 13 locations in the Eagle Plain basin. Northern Cross bid a record $20 million for these rights. In the second disposition process of 2007, in mid-December AustroCan Petroleum Corporation was awarded exploration rights for one location in the Peel Plateau-Plain area in north Yukon.

Production of natural gas yielded more than 80 000 10^3m^3 of natural gas from two wells in southeast Yukon.

Other OGR activities in 2007 included the following: participation in the development of a Yukon Energy Strategy; continued participation in preparations for the Mackenzie Gas Project and the Alaska Highway Pipeline Project; participation in several offshore oil and gas initiatives; continued consultation and cooperation with affected First Nations on a variety of oil and gas issues; development of Oil and Gas Royalty Regulations; ensuring oil and gas interests are taken into account during the Land Use Planning process; and ongoing cooperation with the Yukon Geological Survey in field work and associated analytical work to discover potential source rocks and petroleum reservoir rocks.

RÉSUMÉ

Cet été, la division des Ressources pétrolières et gazières (RPG) du gouvernement du Yukon a connu sa meilleure disposition des droits sur le pétrole et le gaz. Elle a accordé à la Northern Cross (Yukon) Ltd. les droits d'exploration pour 13 emplacements dans le bassin d'Eagle Plain au Yukon septentrional. La soumission de la Northern Cross pour l'obtention de ces droits atteint la somme inégalée de 20 millions de dollars. Lors du deuxième processus de vente de droits à la mi-décembre de 2007, la société pétrolière d'AustoCan s'est vue accorder des droits d'exploration pour un emplacement dans la région du plateau et de la plaine de Peel dans le nord du Yukon.

La production de gaz naturel de deux puits au sud-est du Yukon s'est élevée à plus de 80 000 10^3m^3.

Parmi les autres activités de RPG en 2007 mentionnons : la participation à l'élaboration de la stratégie du Yukon en matière d'énergie ; la poursuite de la participation aux préparatifs du Projet gazier Mackenzie et du Projet du gazoduc de la route de l'Alaska ; la participation à plusieurs initiatives pétrolières et gazières sur le talus continental ; la poursuite de consultations et de la collaboration avec plusieurs Premières nations concernées par toute une gamme de problèmes reliés au pétrole et au gaz ; l'élaboration du Règlement sur les redevances sur le pétrole et le gaz ; s'assurer que les intérêts pétroliers et gaziers soient pris en compte dans le processus de planification de l'utilisation des terres ; la collaboration permanente avec la Commission géologique du Yukon pour les travaux sur le terrain et les travaux d'analyse associés menés à la recherche de potentielles roches mères et roches réservoirs de pétrole

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INTRODUCTION

This was a busy year for the newly reorganized Oil and Gas Resources (OGR) branch of the Department of Energy, Mines and Resources. While industry activity was limited in 2007, much work was done by OGR staff in preparation for future exploration and development in Yukon's oil and gas sector. This work has already translated into significant interest by industry.

Yukon has eight onshore sedimentary basins containing an estimated 17 trillion cubic feet (Tcf) (480 billion m^3) of natural gas and 770 million barrels (120 million m^3) of oil (Government of Yukon, 2007, p. 25; Fig. 1). Offshore estimates in the Beaufort Sea north of Yukon consist of an additional 53 Tcf (1.5 trillion m^3) of natural gas and 4.5 billion barrels (720 billion m^3) of oil (Government of Yukon, 2007, p. 9), contributing to Yukon's vast and virtually untapped petroleum resources.

New dispositions of oil and gas rights in the Eagle Plain basin, opportunities in southeast Yukon, and the construction of the Mackenzie and/or Alaska Highway pipelines would significantly expand Yukon's oil and gas sector. The two producing natural gas wells in southeast Yukon continue to provide revenue for Yukon.

OGR continues to develop partnerships with other jurisdictions and governments, including First Nations. A unique and competitive oil and gas common regime, jointly crafted by Yukon and First Nation governments, is in place in preparation for potential expansion of exploration and production. Although Yukon resources are remote and pipeline infrastructure is presently lacking, OGR has created an attractive economic environment and legislative framework that bodes well for future activity.

YUKON'S OIL AND GAS RIGHTS DISPOSITION PROCESS

In response to First Nations and the petroleum industry recommendations, Oil and Gas Resources has developed a more streamlined and efficient process to grant oil and gas rights. This new disposition process runs twice annually, and OGR's first process, initiated in February of this year, resulted in 25 expressions of interest that ultimately led to successful bids of $20 million by Northern Cross for exploration and test production on 13 locations in the Eagle Plain basin in north Yukon (Fig. 2). It was the largest single disposition of oil and gas rights in Yukon's history. The second disposition process of 2007 was completed on December 12. AustroCan Petroleum Corporation was the successful bidder on one location in the Peel Plateau and Plain oil and gas basin, with a bid of $2.28 million (Fig. 3).

Pursuant to the Government of Yukon's *Oil and Gas Act* and *Oil and Gas Disposition Regulations*, rights to oil and gas are granted by the Minister through a competitive disposition process. The disposition process, which is designed to be completed in approximately five months, consists of the following:

- submission for consideration of Requests for Postings (RFP) for locations of interest to explore for oil and gas;
- review of the RFP, wherein the public, First Nations and government agencies may submit presentations on environmental, socio-economic and surface access concerns related to the requested locations;
- a Call for Bids, where persons or companies are invited to submit bids on posted locations; and
- issuance of oil and gas permits to successful bidders.

A successful bidder is required to submit a work deposit equal to 25% of their bid. The work deposit is returned proportionally as work is completed.

The initial term of the Permit is six years. Permits may be renewed for a further four-year term if a well is drilled during the initial term. Before any activity takes place, companies are required to obtain all regulatory approvals and undergo environmental screening through the *Yukon Environmental and Socio-Economic Assessment Act*. Companies are also encouraged to follow best management practices as outlined by OGR.

In summary, the Government of Yukon's oil and gas rights disposition process provides:

- an attractive investment climate for future development since it is efficient, streamlined and offers certainty;
- a two-year rolling schedule, providing companies with an opportunity to plan ahead; and
- a minimum work commitment which has been lowered from $1 million to $400 000.

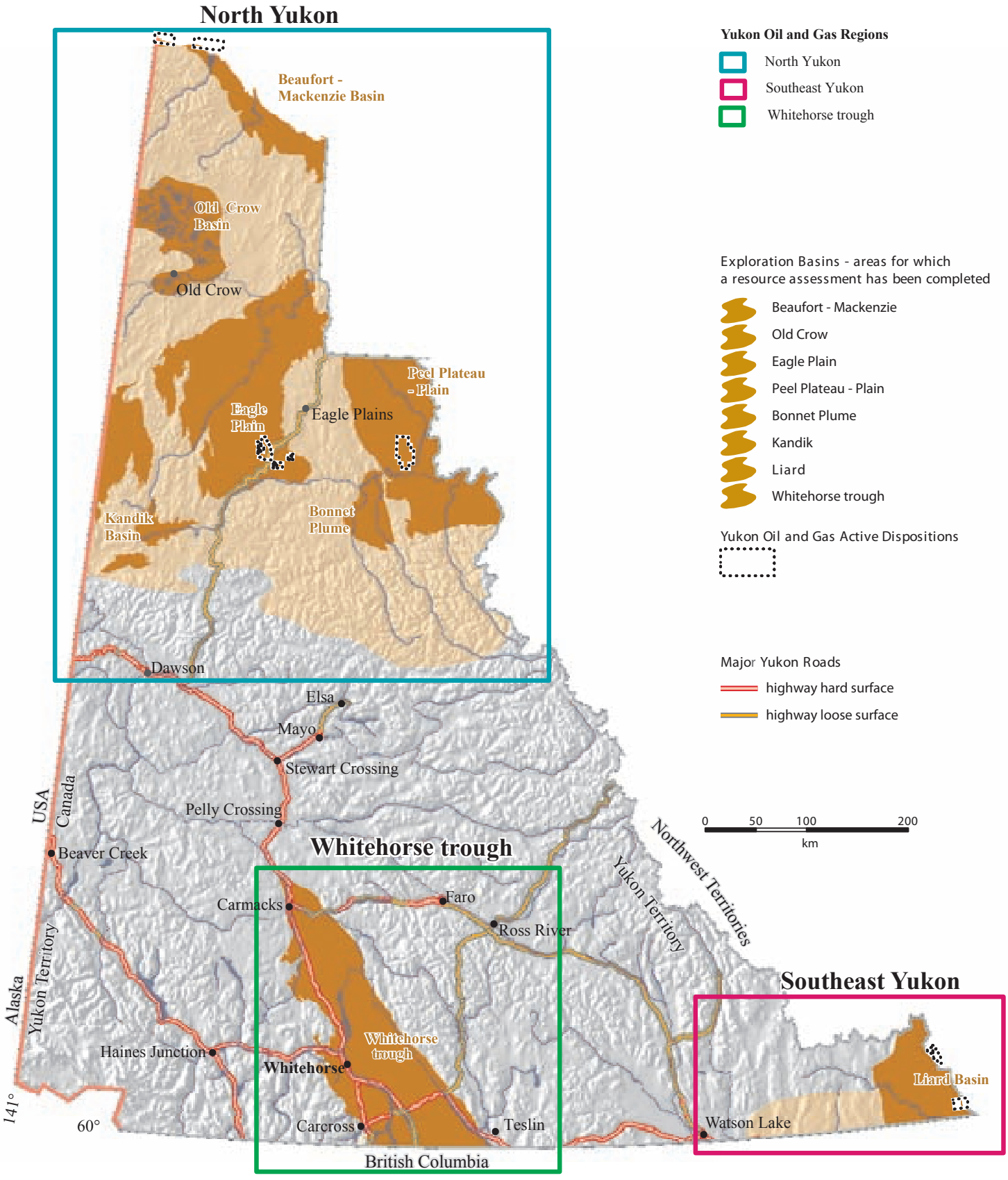
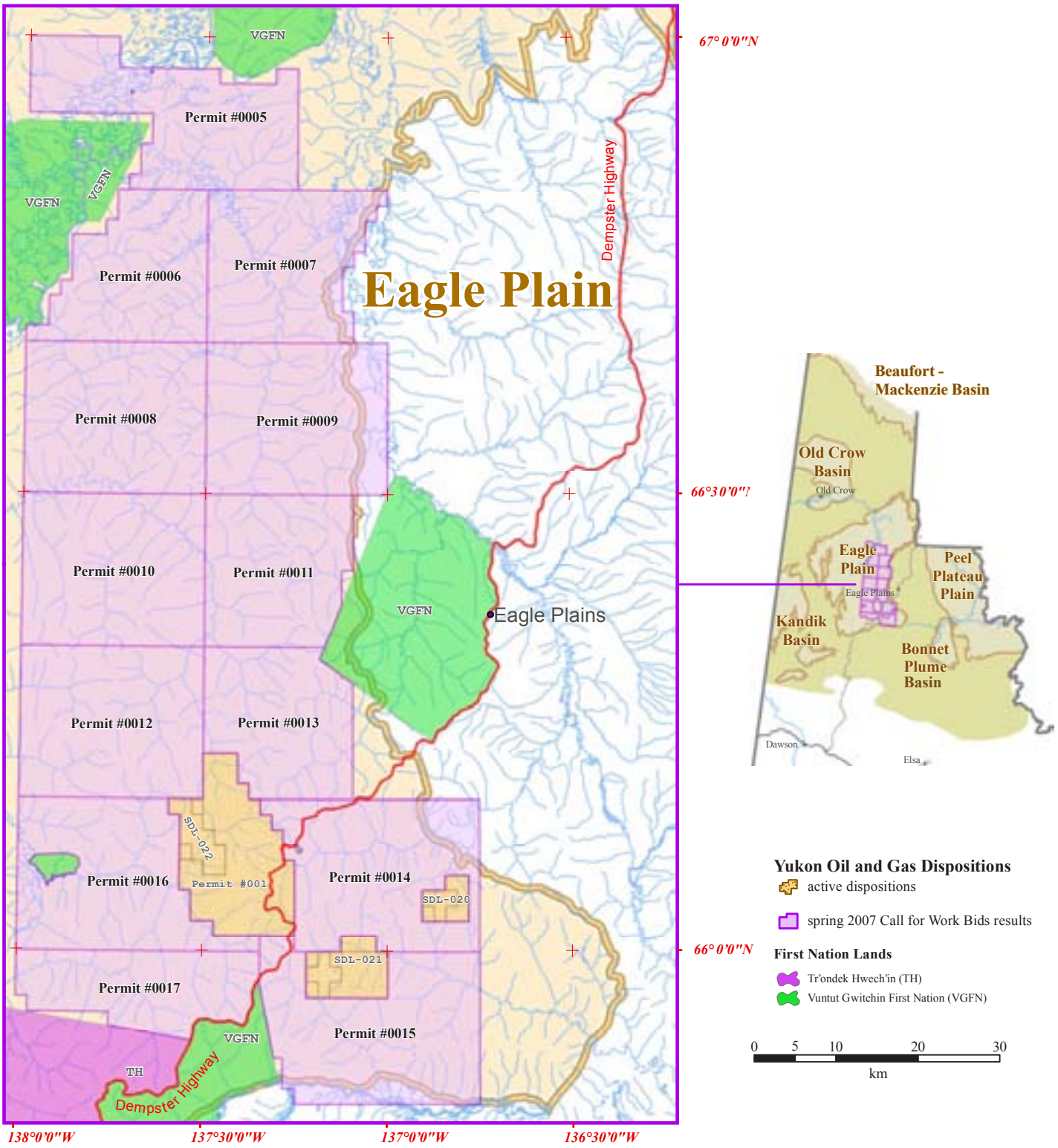


Figure 1. *Yukon's oil and gas exploration regions.*



Request for Postings submissions are a result of an invitation from the Minister of Energy, Mines and Resources of Yukon for expressions of interest for the identification of locations for Oil and Gas Permits. For an explanation of the Yukon Oil and Gas Land Division System, refer to the Yukon Oil and Gas Disposition Regulations, sections 2 to 4. The Oil and Gas Land Division System Poster is available at http://www.emr.gov.yk.ca/oilandgas/mapsdata.html.

Figure 2. *Spring 2007 oil and gas disposition locations.*

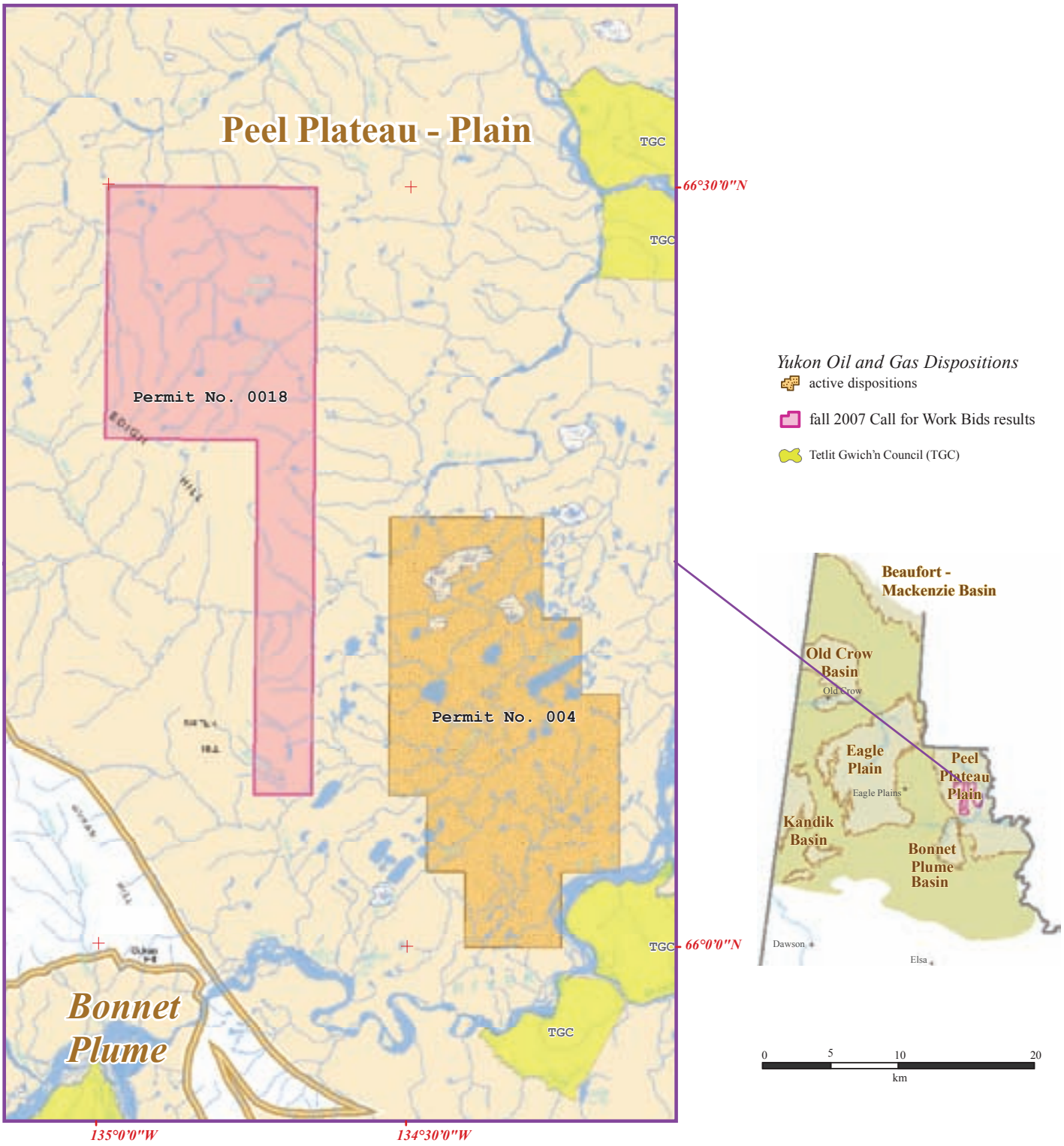


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Figure 3. *Fall 2007 oil and gas disposition locations.*

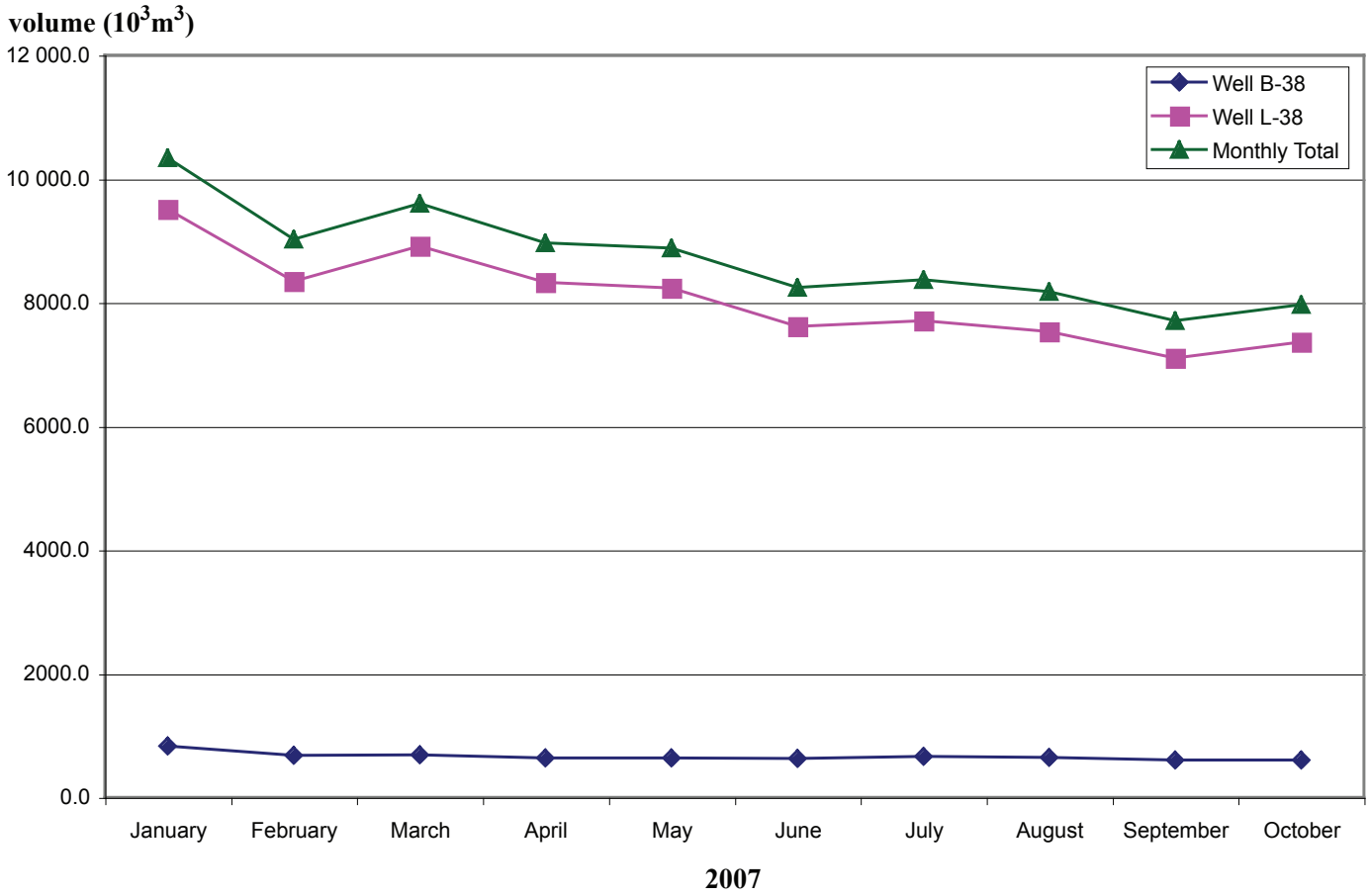

Figure 4. *Yukon natural gas production, from Kotaneelee field, southeast Yukon..*

NATURAL GAS PRODUCTION

In southeast Yukon, natural gas is produced from the Kotaneelee Field in the Liard Basin. The two producing wells (B-38 and L-38) yielded 87 265 10^3m^3 of natural gas in the period from January 2007 to October 2007 (Fig. 4)[1]. The field is in the later stages of life, with gas production and reservoir pressure declining slowly and water cuts increasing. Recovery factor to date is 54% of initial gas-in-place, which is considerably better than similar nearby fields in the basin.

FIRST NATIONS

OGR continues to build strong working relationships with First Nations through the ongoing development of a common oil and gas regime, and through regular consultation during the disposition and licensing processes. OGR supports the Aboriginal Pipeline Coalition and believes it has a very important role in ensuring that First Nations, the Yukon and federal governments are prepared for the Alaska Highway Pipeline Project. First Nation engagement and participation is essential to the development and implementation of an efficient pipeline regulatory process. The Government of Yukon, Natural Resources Canada and the Aboriginal Pipeline Coalition are continuing to work cooperatively to establish work plans and conclude long-term funding arrangements.

PIPELINES

Both the Mackenzie Gas Project (MGP) and the Alaska Highway Pipeline Project (AHPP) offer enormous economic opportunities for the north (Fig. 5). The Government of Yukon continues to work hard in order to ensure Yukon is pipeline-ready, benefits are maximized, and potential negative impacts are minimized. Work will

[1]*www.emr.gov.yk.ca/pdf/Non-Cofidential_Production.pdf*

also continue with our neighbouring jurisdictions — Alaska, BC, NWT and Alberta — to prepare for both projects.

AHPP will generate an estimated 375 000 person-years of employment over 24 years[2], while MGP estimates are 181 000 person-years over the same 24-year span[3]. The construction of these two projects will also inject billions of dollars into the North American economy. These projects would provide access for the Government of Yukon natural gas to southern markets, which could earn the Government of Yukon more than $40 million annually in royalty revenues from the production of natural gas resources.

ALASKA HIGHWAY PIPELINE PROJECT

OGR is encouraged by the recent response to the *Alaska Gasline Inducement Act* (AGIA), State of Alaska legislation intended to encourage the construction of an Alaska natural gas pipeline. Five companies expressed interest under the AGIA by the November 30, 2007 deadline for application, including TransCanada PipeLines Ltd., whose proposal would follow the Alaska Highway through Yukon to southern markets. ConocoPhillips, a major

[2]*www.emr.gov.yk.ca/pdf/informetrica_econreport_02.pdf*

[3]*www.iti.gov.nt.ca/pipeline/pdf/wright_mansell2004.pdf*

Figure 5. *Northern natural gas pipeline options.*

producer of natural gas in the North, submitted a bid that did not conform to AGIA's guidelines. Its proposed pipeline would also follow the Alaska Highway.

Should the route ultimately chosen follow the Alaska Highway, this will be important to the interests of the Government of Yukon. Yukon has seven well-documented Alaska Highway Pipeline Project interests: ensuring a net fiscal benefit to Yukon; enhancing positive socio-cultural impacts while mitigating negative socio-cultural impacts; promoting environmental stewardship; recognizing community and First Nation interests; advancing a clear and efficient regulatory process; supporting economic pipeline access for Yukon natural gas; and requiring gas take-off points.

OGR is also working closely with other jurisdictions that would be affected by an Alaska Highway pipeline. One initiative is the Strategic Action Plan Working Group, comprised of Yukon, BC and Alberta, which was created to deal with common issues expected to arise from the various inter-jurisdictional concerns over the Alaska project. Yukon continues to urge the Canadian government to demonstrate that they are prepared with a streamlined, efficient regulatory process.

MACKENZIE GAS PROJECT

OGR's intervention in the Mackenzie Gas Project hearings is also important. Yukon's interest in the construction of this project is significant, as there are benefits for Yukon to be derived from this pipeline both during and after construction. During construction, supplies will be transported to the Northwest Territories through Yukon. Construction will also provide employment opportunities for Yukon residents. The presence of a pipeline provides a means for Yukon gas to be transported competitively to southern markets, which means that potential Yukon gas would no longer be stranded.

OGR's intervention included written submissions, representation and presentations at both the National Energy Board (NEB) and Joint Review Panel (JRP) hearings. The NEB hearings are likely on hold until the fall of 2008 while they await receipt of a final report from the JRP. The JRP hearings concluded in late November 2007 and the panel has begun writing its final report.

OGR's intervention in the JRP hearings has resulted in the proponent, Imperial Oil, committing to take actions intended to enhance potential positive effects from construction and operation of the project and to mitigate potential adverse effects from the proposed project on Yukon's environment, communities and transportation infrastructure.

OFFSHORE

Although the federal government transferred responsibility for onshore oil and gas to the Government of Yukon, it continues to have responsibility for oil and gas management and development in the Beaufort Sea. Imperial Oil/ExxonMobil's recent record $585-million successful bid for exploration rights in the Beaufort Sea is clear indication that industry remains interested in the offshore, and that governments will need to respond to this renewed interest.

The Governmment of Yukon remains committed to finalizing a shared offshore oil and gas management regime and revenue-sharing arrangement with Canada in accordance with the Canada Yukon Oil and Gas Accord. As an interim step, Yukon is drafting with Canada a Memorandum of Agreement to identify Yukon's enhanced role in offshore management. OGR is developing an Offshore Strategy to advance Yukon's offshore interests, including the following: governance, economic benefits, resource revenues, financial considerations, infrastructure, capacity development and sustainable development.

OGR is actively participating with other governments and industry on a number of Beaufort Sea planning initiatives, with the most important from an oil and gas perspective being the Beaufort Sea Strategic Regional Plan of Action. Another is the Beaufort Sea Regional Coordination Committee, which is tasked with developing an integrated management plan for the offshore.

Taking an integrated management approach to all offshore planning is essential to ensuring an efficient and effective planning and decision process. OGR is jointly working with Indian and Northern Affairs Canada in undertaking a review of the call for nominations map for the Beaufort Sea to look at the possibility of including the area immediately off the Yukon coast in future disposition processes. Yukon is actively involved in the Frontier/Offshore Regulatory Renewal Initiative, which is a process to review and update the offshore oil and gas regulations. This is a federal/provincial/territorial government joint initiative, involving regulators such as the National Energy Board and the East Coast offshore petroleum boards.

Finally, Yukon is pleased that Canada has made northern sovereignty and security a national priority. Given the

significant oil and gas resources in the Beaufort Sea and international interest in the Northwest Passage, Canada's sovereignty in the region must be recognized.

Federal Indian and Northern Affairs Minister Chuck Strahl recently appointed an adviser to find ways to improve the northern regulatory system, which has long been criticized for being too complicated and costly. This will have implications to Yukon's interests in the Beaufort Sea and northern pipeline development. The goal is to strike a balance between economic development and environmental protection, while making the regulatory system more predictable.

OIL AND GAS ROYALTY REGULATIONS

In conjunction with Yukon First Nations and industry representatives, the Government of Yukon has just completed development of Oil and Gas Royalty Regulations and expects to bring them into effect shortly. The purpose of the draft regulations is to provide compensation to the Yukon for the use and depletion of a public resource. The proposed regulations are fair, competitive and simple to administer, and will provide economic certainty to industry.

The Government of Yukon is proposing a royalty rate of between 10 to 25% of the gross value of oil and gas production. The actual royalty rate will vary depending on the price of oil and gas, but it is important to note that a lower rate of only 2.5% will apply to the initial production from each well.

OIL AND GAS CONSENT AND ECONOMIC DEVELOPMENT AGREEMENT IN SOUTHEAST YUKON

There continues to be interest in oil and gas prospects in southeast Yukon. This region is of high interest to industry because there is existing pipeline infrastructure. If the area is further developed, it will also mean a significant economic boost to the residents in the area.

Discussions continue between affected Yukon First Nations and the Government of Yukon toward concluding a Consent and Economic Development agreement. OGR believes significant progress has been made, and looks forward to the conclusion of these discussions. If an agreement is reached, the Government of Yukon will begin consultations with all six First Nations who assert claims within the southeast Yukon and work with them to arrive at a common goal. Throughout the licensing process, the Government of Yukon will be consulting with affected First Nations about proposed oil and gas activities. The agreement contains provisions that facilitate economic development, as well as providing the certainty needed by industry. Once concluded, the agreement will be made public.

YUKON GEOLOGICAL SURVEY

Yukon Geological Survey geologists continued oil and gas related research studies on three projects. Two of these projects are located in northern Yukon, and one is located in southern Yukon.

Grant Lowey completed a short reconnaissance field investigation of Mesozoic and Tertiary sedimentary rocks in the Bonnet Plume basin as a precursor to a more detailed study in the 2008 field season.

The Government of Yukon continued its partnership with the Geological Survey of Canada, the Northwest Territories Geoscience Office, and industry and university affiliates to form a working relationship under the title 'Regional Geoscience Studies and Petroleum Potential, Peel Plateau and Plain, Northwest Territories and Yukon'. This four-year endeavour began in 2005. The project aims to gain a better understanding of the petroleum potential of the Peel Plateau and Plain in north Yukon. Tammy Allen and Tiffani Fraser are studying Upper Paleozoic and Cretaceous strata to better determine their potential as source rocks and reservoir rocks as part of this partnership (Allen and Fraser, this volume).

Stratigraphic (Grant Lowey) and structural (Maurice Colpron) studies are continuing in the Whitehorse trough (Lowey, this volume; Colpron and Friedman, this volume).

OTHER ACTIVITIES

OGR is assisting in the development of an over-arching Yukon Energy Strategy, designed to provide direction for the sustainable development, management and use of energy in Yukon. The scope of the strategy includes Government of Yukon roles and responsibilities in all aspects of energy development, management and use in the territory.

OGR also continues to ensure the Government of Yukon's oil and gas interests are taken into account during the land use planning process.

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Yukon Mining Incentives Program, 2007

Steve Traynor
Yukon Geological Survey

Traynor, S., 2008. Yukon Mining Incentives Program, 2007. *In:* Yukon Exploration and Geology 2007, D.S. Emond, L.R. Blackburn, R.P. Hill and L.H. Weston (eds.), Yukon Geological Survey, p. 59-60.

The Yukon Mining Incentive Program (YMIP) received 56 applications for funding by the March 1, 2007 submission deadline. Contribution agreements totaling $719 850 were subsequently issued to 45 successful applicants. Proposals approved for funding included 4 under the Grassroots Prospecting module, 17 under the Focused Regional module and 24 under the Target Evaluation module.

The distribution of project proposals followed a pattern similar to that of recent years. Placer exploration and testing programs, all targeting gold, accounted for 25% of the applications. Hard rock projects accounted for the remaining 75% of the total and included 17 proposed programs targeting gold, 11 exploring for copper ± gold, 8 focused on zinc/lead, 3 on silver, 2 on uranium and 1 on molybdenum.

Success during the current program year is easily measurable; within the previous nine months, ten option deals have been signed on existing projects that had been advanced significantly with the assistance of YMIP funding. Additionally, a comparable number of new discoveries, which are already generating significant interest from junior companies, resulted from YMIP-supported exploration during this past field season (Fig. 1).

Analysis of recent exploration statistics reveals just how important the Yukon Mining Incentive Program is to the health of the Yukon's mining industry. In the past year, 75% of known greenfields exploration projects were undertaken through the YMIP program.

Continued positive response to the Focused Regional module, which assists prospectors and junior companies appraise the potential of under-explored or greenfield areas, contributed to a doubling of projects approved under this module in the last three years.

Greenfield prospecting and exploration generates new discoveries and attracts increasing amounts of junior exploration capital to the Territory as these projects are advanced.

Further analysis indicates that 14% of this year's advanced projects (projects with annual expenditures greater than $100 000) had earlier greenfield exploration supported by YMIP funding. During the 2007 season, these projects accounted for $6.4 million of exploration spending in the Territory and over 15 000 m of diamond drilling.

The Yukon Mining Incentives Program, the existence of which currently depends upon discretionary funding approved on an annual basis (Fig. 2), has assisted prospectors, partnerships and junior companies since 1986. Having survived its growing pains of the late 1980s and early 1990s, this program has evolved into a highly successful generator of early-stage exploration projects. Through continued and stable levels of funding, it has the potential to provide the foundation to Yukon's growing mining industry for years to come.

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RÉSUMÉ

Avant la date butoir du 1er mars 2007, 56 demandes de financement ont été formulées dans le cadre du Yukon Mining Incentive Program (YMIP), qui vise à stimuler l'industrie minière. Au total, 45 demandes ont été jugées admissibles et 719 850 $ ont été octroyés. Parmi celles-ci, quatre ont été acceptées dans le cadre du programme d'exploration primaire et de prospection du YMIP, 17 dans celui du programme régional du YMIP et 24 dans celui du programme d'évaluation de cibles.

La répartition annuelle des demandes est similaire depuis quelques années. Les projets de recherche et de sondage de placers, tous des placers aurifères, comptaient pour 25 % de toutes les demandes. Ceux visant des minéraux logés dans la roche dure représentaient les 75 % restants et comprenaient 17 projets ciblant l'or, 11 ciblant le cuivre et, dans une certaine mesure, l'or, huit le zinc et le plomb, trois l'argent, deux l'uranium et un le molybdène.

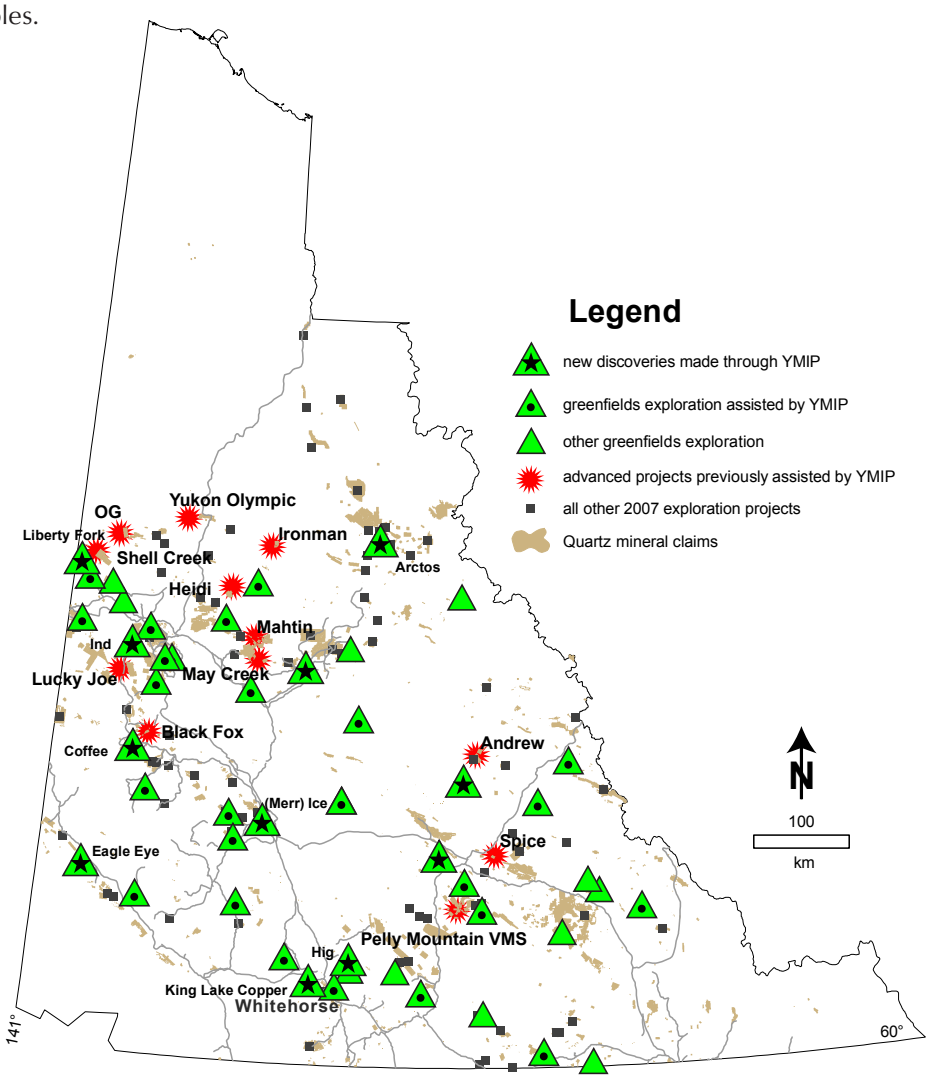

Figure 1. Yukon exploration projects.

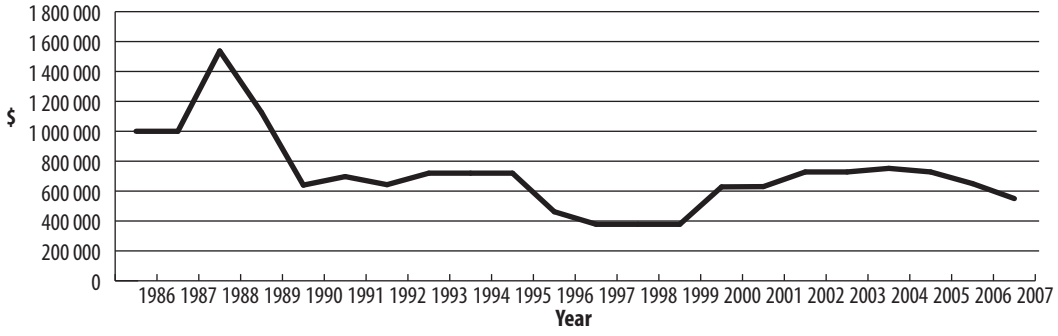

Figure 2. Yukon Mining Incentives Program funding since program inception.

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Grant Abbott

RETIREMENT

In this 2007 edition of Yukon Exploration and Geology, we would like to make special mention of Grant Abbott, who will retire as the Director of the Yukon Geological Survey (YGS) in 2008. Grant's unwavering professionalism and dedication to excellence has been a hallmark of Yukon geology for more than 30 years.

Grant graduated from the University of British Columbia in 1971 with a BSc in Geological Engineering, followed by a MSc in Geological Engineering from Queen's University in 1977. He wrote his MSc thesis on the structure and stratigraphy of the Mt. Hundere silver-lead-zinc property, which later became the Sa Dena Hes mine near Watson Lake. Since 1970, his career as a geologist has largely been spent in the Yukon, first as a student when he worked for Archer, Cathro and the Geological Survey of Canada, and subsequently as an exploration geologist for Archer, Cathro. Grant is widely credited for his part in the discovery of the Williams Creek copper deposit near Carmacks.

Grant (left) with running and geology buddies, Dirk Tempelman-Kluit and Charlie Roots, Midnight Dome, 1980.

Grant moved to Whitehorse in 1980 and joined the Exploration and Geological Services Division, Northern Affairs Program, Department of Indian Affairs and Northern Development as a project geologist. He undertook regional mapping and metallogenic studies throughout the Yukon. For the last decade Grant has been Chief Geologist for the YGS and its predecessor, the Yukon Geology Program.

Kusawa Lake, May, 2007.

During his career, Grant conferred with exploration geologists and prospectors, collected key samples and wrote germane articles that elucidated Yukon's geology. As a manager, he has skillfully led the Yukon Geological Survey, always soliciting advice before making decisions.

The staff of YGS, and Grant's colleagues in Yukon's Department of Energy, Mines and Resources, wish him the very best as he begins another of life's chapters, with a rock hammer in one hand and an airplane ticket in the other.

Skiing in the Yukon, 1982.

Yukon Geological Survey

Grant Abbott[1] and staff

Abbott, J.G. and staff, 2008. Yukon Geological Survey. *In:* Yukon Exploration and Geology 2007, D.S. Emond, L.R. Blackburn, R.P. Hill and L.H. Weston (eds.), Yukon Geological Survey, p 63-79.

OVERVIEW

The Yukon Geological Survey (YGS, Fig. 1) is rebounding from a difficult period in 2006 and is rebuilding with a number of personnel changes (Fig. 2). It is a pleasure to welcome Robert Deklerk back to the Mineral Services unit after his successful recovery from cancer. Ken Galambos is also back after a time with Economic Development. Ken has switched places with Steve Traynor to work on MINFILE alongside Rob while Steve takes over the Yukon Mining Incentives Program (YMIP). Mineral Services was also given a big boost from Lauren Blackburn and Catherine Welsh who are on temporary assignments. Our Map Sales desk is also in transition after the retirement of Ali Wagner last spring with Kim Murray temporarily filling in. Our GIS capacity was also given a boost with the addition of Aubrey Sicotte in a permanent position, and Bailey Staffen for the year. We were unable to recruit a project geologist and mineral assessment geologist in 2007, but are optimistic that these

Figure 1. *Yukon Geological Survey staff from left to right: Olwyn Bruce, Karen Pelletier, Tiffani Fraser, Don Murphy, Lee Pigage, Bailey Staffen, Charlie Roots, Grant Abbott, Steve Israel, Diane Emond, Ken Galambos, Lara Lewis, Maurice Colpron, Leyla Weston, Kim Murray, Tammy Allen, Jeff Bond, Carrie Labonte, Aubrey Sicotte, Panya Lipovsky, Lauren Blackburn, Grant Lowey, Steve Traynor, Catherine Welsh, Mike Burke, Rod Hill, Robert Deklerk and Bill LeBarge.*

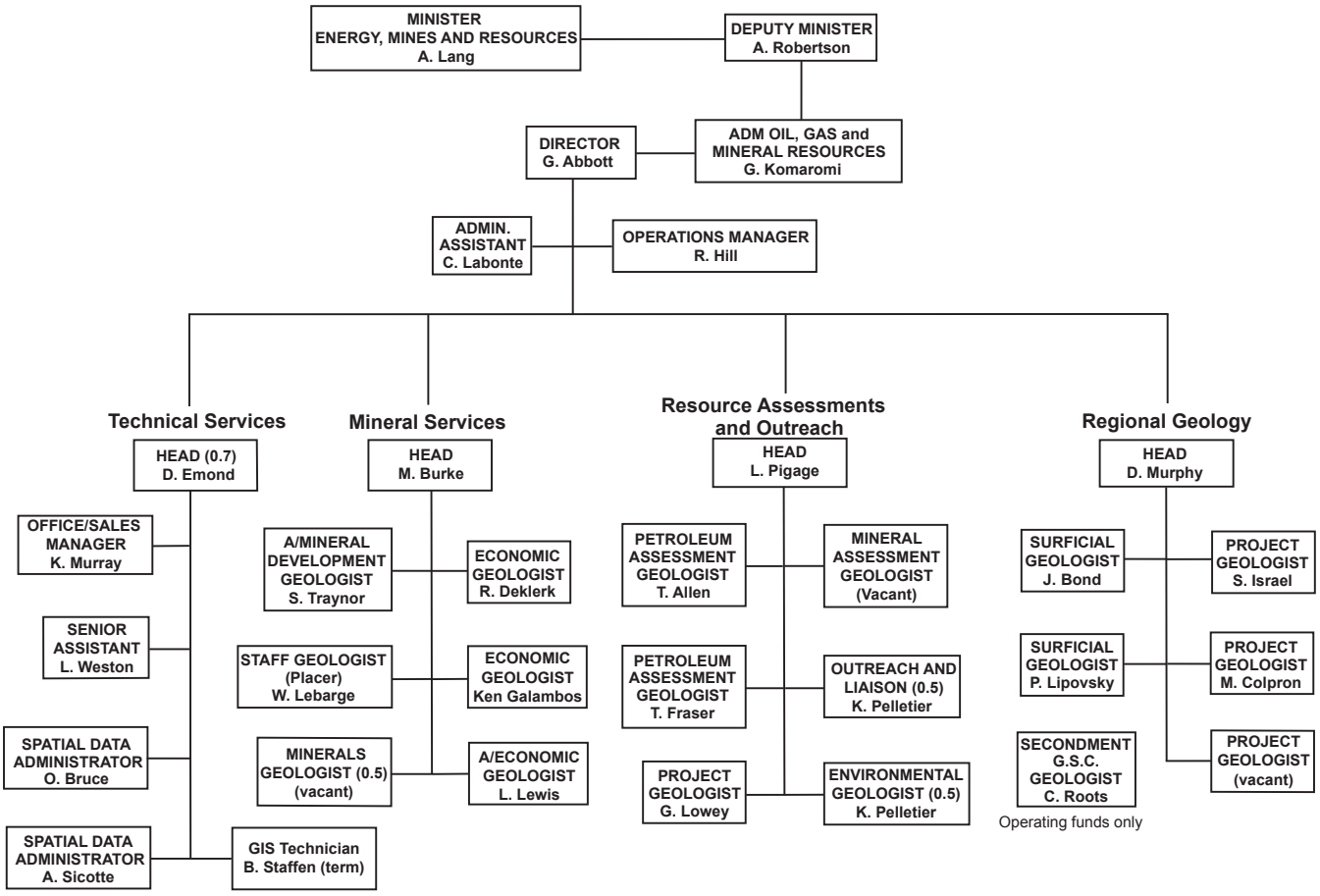

Figure 2. *Yukon Geological Survey organization chart.*

positions will be filled in 2008. Finally we are pleased to welcome Dr. Carolyn Relf as incoming Director behind Grant Abbott who is retiring in the spring. Carolyn comes to the position with an exemplary record as a scientist and manager, and we look forward to her leadership.

The Technical Liaison Committee to YGS reviews our program twice a year. We are grateful to Chair, Gerry Carlson and members Carmel Lowe, Jim Mortensen, Al Doherty, Rob Carne, Jean Pautler, Forest Pearson, Shawn Ryan and Jim Christie for their valuable support and constructive advice.

CURRENT PROJECTS

YGS continues to benefit from stable funding from the Government of Yukon; and Indian and Northern Affairs Canada (DIAND) funding programs such as SINED (Strategic Investments in Northern Economic Development). This has enabled the Yukon Geological Survey to undertake a wide range of projects that fulfill our mandate to provide the geoscience information needed to support the sustainable development of Yukon's non-renewable resources. Capacity constraints within YGS, the Geological Survey of Canada (GSC), universities and among geophysical contractors impeded our ability to undertake some projects and slowed others. For example, some promising mineral deposits studies could not proceed because of difficulty in attracting students and researchers. Regardless, we managed to carry out or fund over 24 field projects (Fig. 3), including bedrock and surficial mapping; mineral deposit, placer, hydrocarbon-related, surficial and topical studies; geophysical surveys; and outreach. We are partnering with GSC on many projects and are also supporting the research of a number of graduate students. Much of this work is put into context in Figure 4, which summarizes the coverage for bedrock mapping, surficial mapping, regional stream sediment and till geochemical surveys, and geophysical surveys for the Yukon.

BEDROCK MAPPING

1. **Don Murphy** is leading the multidisciplinary project to study the poorly exposed and little known Windy-McKinley terrane in the Stevenson Ridge map area of southwest Yukon. The project is a partnership with GSC, and benefited greatly from the participation of Cees van Staal. A significant proportion of funding was provided by SINED. The project also included a surficial mapping component lead by Jeff Bond. Initial reinterpretation of the regional geology indicates that the area may have significant mineral potential that has gone unrecognized. A high-resolution multispectral (magnetics, radiometrics, VLF) or versatile time-domain electromagnetic (VTEM) airborne geophysical survey planned for next year is expected to shed more light on these enigmatic rocks.

2. **Steve Israel** completed his mapping in the western part of the Kluane Ranges where magmatic nickel-copper-PGE (platinum group elements) targets such as Canalask are the focus of industry attention. Steve has made significant progress in unraveling the complex tectonic history of Wrangellia that includes Triassic extension, Cretaceous compression and younger transcurrent movement that continues to the present. Studies of recent deformation associated with the Denali fault are also taking place in collaboration with Don Murphy (YGS) and workers from the United States Geological Survey in Alaska.

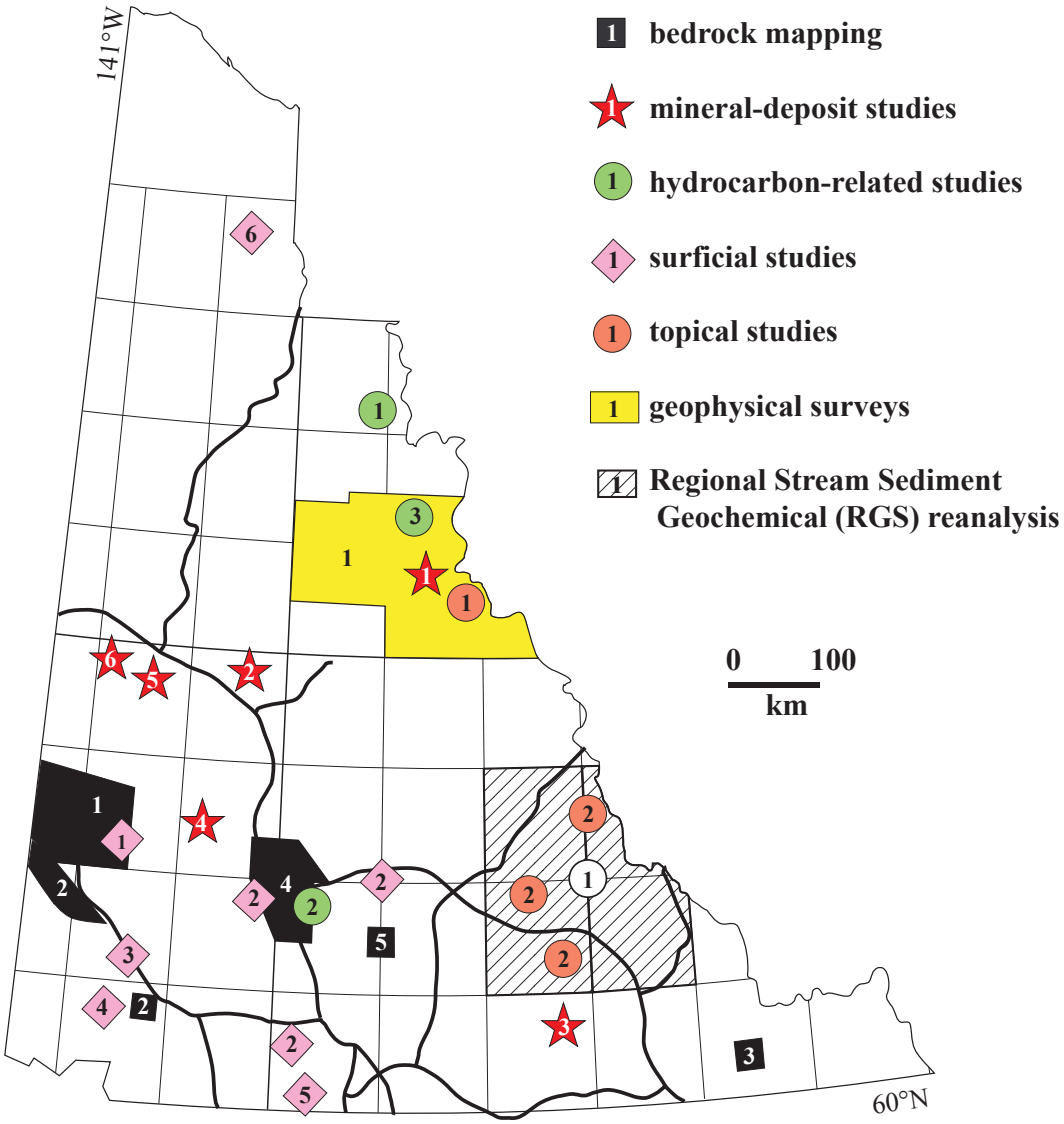

Figure 3. *Field projects carried out or sponsored by the Yukon Geological Survey in 2007.*

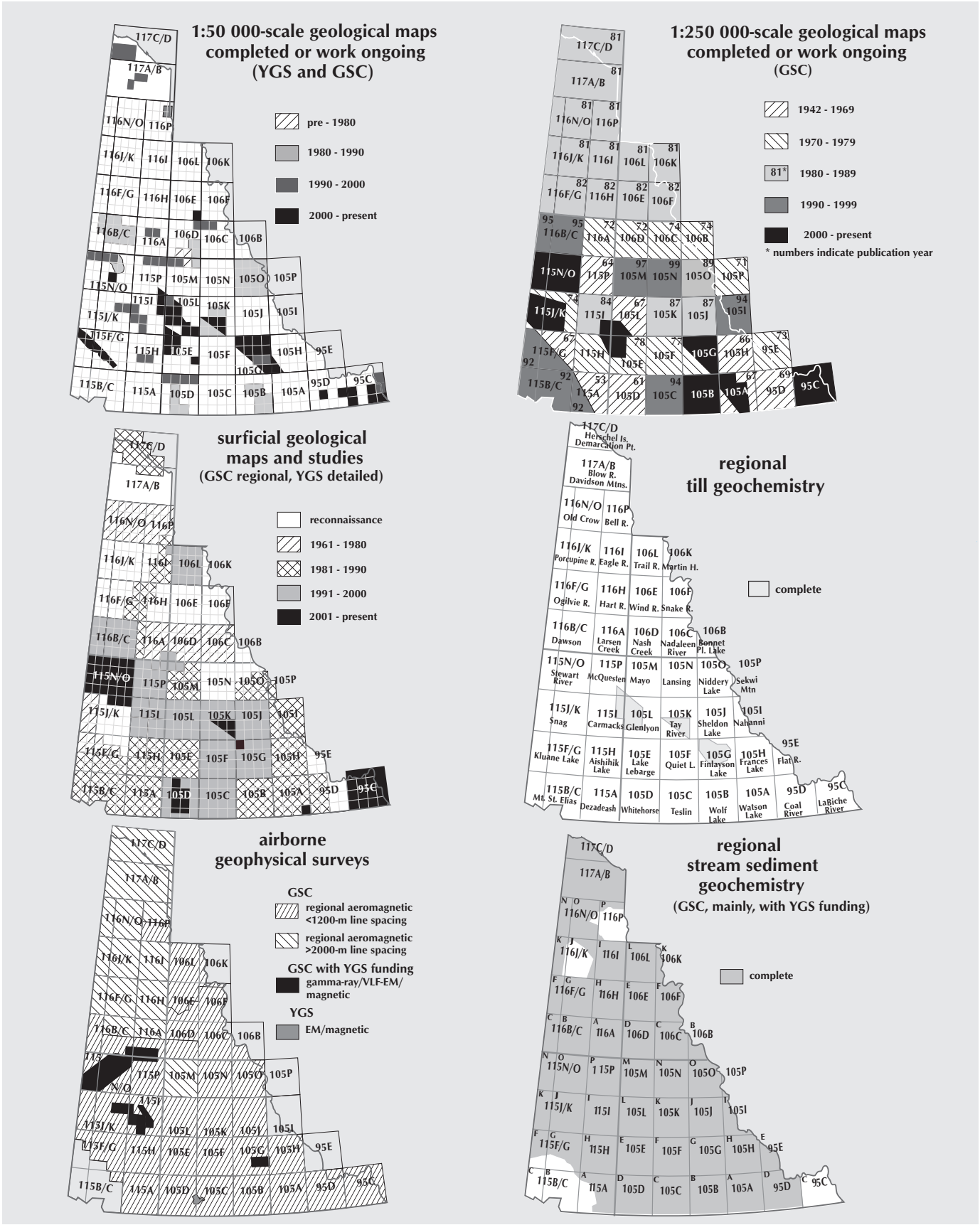

Figure 4. *Summary of available geological maps, and regional geochemical and geophysical surveys in the Yukon.*

3. **Lee Pigage** completed the Otter Creek bedrock geology mapping project in southeast Yukon. This work aims to improve the understanding of the regional geology along the south edge of Selwyn basin. This region contains some of the world's largest zinc/lead deposits including Howards Pass and Faro. The epigenetic Mel barite/lead/zinc deposit is located in the Otter Creek map area. The southeastern portion has significant potential for both sedimentary-exhalative (SEDEX) and epigenetic lead–zinc deposits but remains underexplored because of the lack of outcrop. Lee's work has resulted in significant revisions to the stratigraphic and structural framework of the area that should help to focus future exploration.
4. **Maurice Colpron** partnered with **Grant Lowey**, Don White and Steve Gordey of GSC, and Steve Piercey of Laurentian University to complete a new compilation map and synthesis of the north end of the Whitehorse trough. This work integrates surface mapping with the seismic surveys acquired in 2004. The work demonstrates that the Whitehorse trough is a west-verging fold and thrust belt. This reinterpretation has implications for the hydrocarbon potential of the Whitehorse trough and will form the basis for an assessment of this basin planned for 2008.
5. **Elizabeth Westberg** began a detailed bedrock mapping project in eastern Laberge and western Quiet Lake map areas as part of her M.Sc. thesis supervised by **M. Colpron** and **Dr. H.D. Gibson** through Simon Fraser University. Her study will help constrain the nature and location of the boundary between Yukon-Tanana and Cassiar terranes, and the timing and conditions of deformation and metamorphism in this region. This project will contribute to refining the geoscience database in a region prospective for gold, tungsten and base metals.

MINERAL-DEPOSIT STUDIES

1. **Lara Lewis** continued to gather data on intrusion-related and Wernecke Breccia uranium occurrences for a compilation on uranium exploration in Yukon. New age-dates for uranium mineralization are expected to provide constraints on timing of the mineralizing events.
2. **Jake Hanley** under the supervision of **Dr. E. Spooner** at the University of Toronto is completing a post-doctoral study of the evolution and generation of magmatic fluids in mid-Cretaceous granites in Yukon and their relationship to gold mineralization.
3. **Kirsten Rasmussen** began a PhD thesis under the supervision of **Dr. Jim Mortensen** at University of British Columbia (UBC) which will help wrap up 15 years of research into Cretaceous magmatism in the Yukon and adjacent portions of southwestern Northwest Territories and eastern Alaska by researchers from YGS and the Mineral Deposits Research Unit. During the two-year study, the research data will be brought into the new YGS Igneous Database, and all existing U-Pb age determinations will be finalized and major gaps in both crystallization age and lithogeochemical data will be filled. Comprehensive models will be constructed to explain the evolution of Cretaceous magmatism, and the project will investigate the influence of pre-existing crustal geometry (*i.e.*, 'lower-plate' vs. 'upper plate') during crustal shortening and melting.
4. **Thierry Betsi,** under the supervision of **Dr. David Lentz** at the University of New Brunswick, began Doctoral research on gold occurrences in the southern part of the Dawson Range Mineral Belt. There and elsewhere in the northern Cordillera, there appears to be a close link between Cretaceous magmatism and base- and precious-metal mineralization. They hope to formulate more robust applied exploration criteria for the region by narrowing down the specific timing and regional to local controls on precious metal mineralization.
5. **William LeBarge** continued his partnership with **Professor Vladimir Naumov** and graduate students Ilya Mukhanov, Vitalii Bryukhov and Sergei Gubin from Perm University to study both recent and paleoplacers along the Indian River south of Dawson. Their intention is to investigate the placer gold concentration and fine gold potential of low- to high-level alluvial terraces on the Indian River and to relate this information to a definitive stratigraphic framework. New interpretations of geology and data from this study may help to identify and locate undiscovered bedrock sources of gold, as well as new placer deposits in nearby drainages of unglaciated western Yukon. A complementary study with **Dr. Jim Mortensen** at UBC is using gold geochemistry to investigate the relationship between placer gold and bedrock gold, including possible paleoplacers such as the McKinnon Creek conglomerate.

6. **William LeBarge** and **Dr. Yana Fedortchouk** conducted a pilot program to explore the potential for alluvial diamonds in Yukon. They are visiting selected localities where diamonds have been reported, collecting samples for analyses and consulting with world class diamond experts including Dr. Valentin Afanasiev from the Russian Academy of Sciences in Novosibirsk, Russia. The samples are being processed and studied at the Earth Sciences Department of Dalhousie University for the presence of minerals that accompany diamonds in mature placer deposits.

HYDROCARBON-RELATED STUDIES

1. **Tammy Allen** and **Tiffani Fraser** are in the second year of a four-year project to assess the hydrocarbon potential of the Peel Region in northeastern Yukon. The study involves collaboration with GSC, NTGO (Northwest Territories Geoscience Office), industry and university affiliates. The program includes detailed sedimentological fieldwork, laboratory analyses, and subsurface analysis of existing well-log and seismic-reflection data. Tammy and Tiffani are focusing on the hydrocarbon potential of Upper Paleozoic units including the Canol, Imperial and Tuttle formations, among others. They are looking for source rock and reservoir potential from these units, and will be using these data to update the Government of Yukon's Petroleum Resource Assessment for the region.

2,3. **Grant Lowey** completed fieldwork for his three-year study of the sedimentology, stratigraphy and hydrocarbon potential of the Laberge Group in the Whitehorse trough between Whitehorse and Carmacks. The project will conclude in 2008 with a revised assessment of the hydrocarbon potential of the trough. Grant also undertook a reconnaissance assessment of the Bonnet Plume basin in northern Yukon in anticipation of a longer term study. The basin contains several large thermal coal deposits. This work will provide new information that will help to better assess the coal and gas potential of the basin.

SURFICIAL GEOLOGY MAPPING AND STUDIES

Terrain destabilization related to landslides and permafrost degradation have become a major concern in Yukon in recent years, driven by uncertainty surrounding the distribution and nature of permafrost and the effects of climate change. The influence of climate change on the occurrence of forest fires, glacial retreat and permafrost degradation is of prime importance to terrain stability. YGS is continuing efforts to characterize these issues in order to support impending development, infrastructure maintenance and land-use planning within communities and along infrastructure corridors.

1. **Jeff Bond** and **Panya Lipovsky** began mapping the surficial geology of the last unmapped part of southwest Yukon in Stevenson Ridge and northeast Kluane Lake map areas (NTS 115J and G). The area straddles the all-time limit of Pleistocene glaciation originating from the St. Elias Mountains. Multiple glacial limits are preserved and glacial deposits from early to middle Pleistocene local ice cap complexes are present. The area has excellent potential for the preservation of complex Quaternary stratigraphy and this mapping can significantly increase our understanding of Yukon's recent glacial history. The combination of favourable bedrock geology and large areas of unglaciated terrain make this region prospective for new placer discoveries. It also covers one of the proposed routes for a possible railway, which increases the need for surficial mapping as a base for engineering and feasibility studies.

2. **Panya Lipovsky** has recently studied the distribution, geomorphology and potential impacts of various terrain hazards in southern and central Yukon, using a wide variety of techniques, including detailed field-based geomorphological studies, regional landslide inventories, two-dimensional resistivity geophysical surveys, differential GPS surveys, and Interferometric Synthetic Aperture (InSAR) analysis. Panya is continuing to monitor active permafrost-related failures near Carmacks and Little Salmon Lake. Panya is also assisting Yukon Parks to implement a system for monitoring landslide hazards within the drainage basin located upstream of the Kusawa Lake campground.

3. A large volume of permafrost and surficial geology information (stratigraphy, texture, and ice character and content) exists in borehole logs drilled along the Alaska Highway and the proposed pipeline route over the last 30 years. **Panya Lipovsky** has been compiling this information in a borehole database which so far contains records from over 5000 boreholes drilled along the Alaska Highway between Beaver Creek and Haines Junction. This year, **Megan James,** a M.Sc. student with **Dr. Antoni Lewkowicz** at the University of Ottawa, will continue compiling borehole data from southeastern Yukon in order to analyse recent permafrost changes in the area. This digital GIS-compatible database will be extremely useful for a variety of planning purposes within the corridor, including predicting thaw settlement sensitivity and mapping the distribution of permafrost within the Alaska Highway corridor in greater detail than currently exists.

4. A large rock and ice avalanche occurred on the north face of Mount Steele, southwest Yukon Territory, on July 24, 2007. The ice and rock traveled nearly 6 km, with a vertical descent of over 2150 m, leaving a 3.66 km^2 deposit on the Steele Glacier. This was one of the largest landslides onto glaciers in the Canadian Cordillera since 1899. **Panya Lipovsky** has been working with a team of scientists from across Canada and the US to investigate the landslide using reconnaissance field studies, analysis of seismic records and an airborne Light Detection and Ranging (LIDAR) survey.

5. **Amber Church** began a study in the Wheaton valley southwest of Whitehorse for her M.Sc. thesis under the direction of **Dr. John Clague** at Simon Fraser University. This project sets out to address a series of questions pertaining to late Holocene glacial history and landscape change in the Wheaton River valley. Amber's thesis will primarily focus on the paraglacial-related mass wasting history in the upper reaches of the drainage. This information will help guide future land-use planning in recently deglaciated drainages of southern Yukon and northern British Columbia.

6. **Kristen Kennedy** began a project in the Eagle Plains area of northern Yukon for her M.Sc. thesis at the University of Alberta under the direction of **Dr. Duane Froese**. Regional mapping and stratigraphic and sedimentological studies are being carried out on the surficial materials with the intent to develop a process-based model of flood-channel development for the Eagle meltwater channel. This is a feature related to the late stages of the last continental glaciation (Laurentide); the channel is one of the few places in the area where aggregate resources are known. Aggregate resources are scarce in the area and the studies will help to identify construction materials necessary for part of development of oil and gas resources.

TOPICAL (SPECIALIZED) STUDIES

1. **Francesca Furlanetto** began her M.Sc. thesis research in the Wernecke Mountains at under the direction of **Dr. Derek Thorkelson** at Simon Fraser University. She will examine the age of the detrital minerals of the Wernecke Supergroup and compare the data to published results from other formations of approximately the same age in Canada and other continents. This new information on the Wernecke Supergroup should clarify the geological setting of many mineral occurrences in northern Yukon.

2. **Luke Beranek,** a PhD candidate at the University of British Columbia under the supervison of **Dr. Jim Mortensen**, has been steadily adding to the detrital-zircon age database for Late Paleozoic and Triassic rocks on both sides of the boundary between the North American continental margin sequence and Slide Mountain and Yukon-Tanana terranes. Luke's earlier work has shown that the terranes were already shedding debris onto North America by the Early Triassic, substantially earlier than previously thought. This work is changing our understanding of how and when these terranes formed and collided with one another.

AIRBORNE GEOPHYSICAL SURVEYS

1. **GSC** in collaboration with **YGS** completed an extensive aeromagnetic survey in the Wernecke and Mackenzie mountains that was begun in 2006. Results will be published in early 2008. Funding was provided by DIAND under the SINED program.

REGIONAL STREAM GEOCHEMISTRY

1. Regional stream geochemical coverage of the Yukon is nearing completion, with two areas with low mineral potential remaining outside of parks (Fig. 4). With SINED funding, YGS and GSC are now beginning to reanalyse samples from previous surveys using modern analytical methods. Eventually, data from key areas will be brought to a consistent standard to allow evaluation of data across large areas. Results from NTS map sheets 105G and 105J will be released in early 2008, and from map sheets 105H and 105I later in the year.

LIAISON TO INDUSTRY, FIRST NATIONS AND THE PUBLIC

YGS recognizes the importance of effectively communicating information on the geology and mineral and energy resources of the Yukon to a broad audience that includes industry, resource managers, First Nations and the general public. We are continuing to focus more attention on developing strategies and products that meet these needs.

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. This year, in order to respond to extraordinary levels of exploration, Lara Lewis and Steve Traynor have also contributed to this effort.

Karen Pelletier, Charlie Roots and other YGS staff continue to respond to increasing demands from educators and interest groups for information on the geology and non-renewable resources of the Yukon.

The types of outreach activities include:

Primary and secondary (* post-secondary)

- classroom visits*
- geology field trips*
- career fairs
- summer camps
- mining week activities

General public

- mining week displays and activities
- public talks
- public field trips

Adult activities

- training for teachers and interpretive staff
- group requests for speakers

In response to numerous requests for simplified geological information, particularly from travelers and educators, we have created various products of interest. These include new commodity and mineral potential brochures, upgrades to our websites, and a Yukon Geological Road Guide. The guide is expected to be available in spring 2008.

In 2007, Panya Lipovsky collaborated with **Dr. Kenji Yoshikawa** at the University of Alaska Fairbanks to establish a long-term permafrost health outreach program in the Yukon Territory. Boreholes were drilled at or near six schools (Beaver Creek, Whitehorse, Dawson, Faro, Ross River and Old Crow) to depths ranging between 3 and 15 m. Air and ground temperature data loggers were installed at each site and will be monitored annually by Grade 6 to 12 students who will post the results on a central website. The boreholes form part of a circumpolar network of permafrost monitoring stations that have been installed at schools throughout Alaska, Greenland, Russia, Mongolia and Scandinavia. In addition to actively involving school students, the program will contribute valuable data for scientific research.

PROGRAMS

YUKON MINING INCENTIVES PROGRAM

The Yukon Mining Incentives Program (YMIP) is administered by Steve Traynor. In 2007/08, funding totalling $719 850 was offered to 45 of 56 applicants. Proposals approved for funding included 4 under the Grassroots – Prospecting module, 17 under the Focused Regional module and 24 under the Target Evaluation module.

Projects targeting gold accounted for 22 of the approved projects and included 14 hardrock targets and 8 placer targets. Copper was the targeted commodity for 11 other projects receiving approval for YMIP funding and another 7 of the approved exploration projects focused on zinc-lead. Of the remaining five proposals approved for funding, three targeted silver, one explored for molybdenum and another for uranium.

MINING AND PETROLEUM ENVIRONMENTAL RESEARCH GROUP

Mining and Petroleum Environmental Research Group (MPERG) is a cooperative working group made up of government agencies, environmental, mining and petroleum resource companies, Yukon First Nations and

non-government organizations (NGOs). It was established to promote research into environmental issues for mining and petroleum development in the Yukon. Participants bring together their resources and knowledge to work cooperatively on industry-related environmental issues and projects. MPERG creates a favourable environment to facilitate finding solutions before environmental problems arise. The Group is funded by YGS and chaired by Grant Abbott, with administrative support from Karen Pelletier.

Five studies were approved for funding for 2007/08:

- Yukon Government, Oil & Gas Management Branch: Stage 2 investigation of seismic lines and associated disturbances and the development of a recovery curve for modeling the cumulative footprint of oil and gas development in North Yukon;
- EDI Environmental Dynamics Inc.: Guidelines for Industrial Activity in Bear Country;
- EDI Environmental Dynamics Inc.: Guidelines for Flying in Caribou Country;
- EDI Environmental Dynamics Inc.: Natural Sources of Contaminants in the Yukon (with a focus on selenium and other organophilic elements);
- Amber Church, Simon Fraser University: Contemporary glacial influences on the hydrology and geomorphology of Wheaton River, Yukon.

INFORMATION MANAGEMENT AND DISTRIBUTION

With the increasing volume of information generated by YGS and others, and rapidly evolving digital technology, the Survey continues to put significant resources into making geological information more accessible. Our website and Map Gallery have both undergone substantial revisions that make them easier to use and provide greater online functionality to the MINFILE and publications databases. A large part of our effort has gone into developing and maintaining key databases and making all of our information internet-accessible. Ongoing activities include support for the H.S. Bostock Core Library and the Energy, Mines and Resources (EMR) library (Elijah Smith Building).

DATABASES

Yukon MINFILE is a database containing over 2600 records on Yukon's mineral occurrences. It is maintained by Robert Deklerk and Ken Galambos. The database is now fully searchable online. As a result, the most current CD-ROM release dates back to November 2005, and will likely be the last CD-ROM of the database we release. Online searching of the database allows the user to access the most complete and up-to-date data, as it links to a non-static dataset. This new direction has required conversion of the database from Access to Oracle and the standardization of data and data fields. Now that two geologists are devoted to MINFILE, plans are to progressively streamline and update the database over the next year.

The Yukon Placer Database, compiled by Bill LeBarge, was updated and a new version was released in May 2007, with detailed updated information from placer mining activity between 2003 and 2006. The database is in Microsoft Access 2000 format and is a comprehensive record of the geology and history of Yukon placer mining. The database contains descriptions of 457 streams and rivers, and 1443 associated placer occurrences of which 130 were updated for this version. It also includes location maps in Portable Document Format (PDF). We are currently working towards bringing this database online.

YGS, in partnership with GSC, is planning to update the Yukon Digital Geology compilation, which was last revised in 2003. The revised database will not only incorporate recent maps but will also conform to the North American Data Model. This standard, which is slowly being adopted by geological surveys across North America, allows users to generate a seamless map from more than one source (*i.e.*, two or more jurisdictions). The model will allow the selection of subsets of data to generate maps defined by lithology, age or map unit. It will also be possible to create generalized maps through a hierarchy of attributes (*i.e.*, Group vs. Formation or Paleozoic vs. Devonian). Jeff Bond and Panya Lipovsky began development of a Digital Surficial Geology Map of the Yukon in partnership with GSC and with SINED funding. The map database will have the same functionality as the bedrock database. Release is planned for early 2008.

The Yukon Regional Geochemical Database 2003, compiled by Danièle Héon, contains all of the available digital data for regional stream sediment surveys that have

been gathered in the Yukon under the Geological Survey of Canada's National Geochemical Reconnaissance Program. It can be viewed online through the Map Gallery and is available on CD-ROM in Microsoft Excel 2000 format and in ESRI ArcView Shapefile format.

The YukonAge Database, compiled by Katrin Breitsprecher and Jim Mortensen at the University of British Columbia with funding from YGS, was updated in 2004. It can be viewed on YGS Map Gallery in a version modified by Mike Villeneuve and Linda Richard of GSC. The database now contains 1556 age determinations derived from 1166 rock samples from the Yukon Territory. It is available in both Microsoft Access 2000 format and as a flat file in Microsoft Excel 2000 format so that the data may be viewed without Microsoft Access.

The Yukon Geoscience Publications Database is available online. It is current and contains more than 8000 references to papers on Yukon geology and mineral deposits, including YGS publications.

All open assessment reports (more than 5000) are now in PDF format and accessible over the internet through the EMR library website. In the Yukon, reports remain confidential for five years. In addition, we have acquired exploration records from the various companies that owned the Faro District. This acquisition includes both records of the Faro District as well as other projects. Most of the records are now available for viewing.

H. S. BOSTOCK CORE LIBRARY

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

EMR LIBRARY

The Yukon Energy, Mines and Resources Library is the Yukon's largest scientific library and an invaluable resource. It is located in Room 335 of the Elijah Smith Building and is open to the public. The Library provides access to Yukon Mining Assessment reports, maps (geology, topographic and aeromagnetic), and aerial photographs. It holds many geology journals and a good selection of materials on general geology, Yukon geology, and economic geology. The Library is also the access point for Faro exploration records. In addition to geological information, the Library has books, reports and journals in other areas, such as oil and gas, forestry, agriculture, and energy, as well as a very comprehensive collection of Yukon publications.

INFORMATION DISTRIBUTION

YGS distributes information in three formats: 1) paper maps and reports are sold and distributed through our Geoscience Information and Sales office; 2) many recent publications and databases are available in digital format at much lower prices than for paper copies; and, 3) most of our publications are available as PDF files on our website (*www.geology.gov.yk.ca)* free of charge. A catalogue of assessment reports is also available online (*www.emr.gov.yk.ca/library)*.

We are pleased to make spatial data available through our interactive map server; the MapMaker Online (formerly the Map Gallery) can be accessed through the YGS website. We are continuing to improve MapMaker. Users are encouraged to provide feedback and suggest improvements.

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

Geoscience Information and Sales
c/o Whitehorse Mining Recorder
102-300 Main Street (Elijah Smith Building)
P.O. Box 2703 (K102)
Whitehorse, Yukon Y1A 2C6

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To access the EMR Library:
Website: *www.emr.gov.yk.ca/library*
Ph. (867) 667-3111
E-mail: emrlibrary@gov.yk.ca

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La Commission géologique du Yukon

Grant Abbott[1] et Maurice Colpron[2]
Le Service de géologie du Yukon

Abbott, J.G. et Colpron, M., 2008. La Commission géologique du Yukon. Dans : Yukon Exploration and Geology 2007, D.S. Emond, L.R. Backburn, R.P. Hill et L.H. Weston (réds.), la Commission géologique du Yukon, p. 81-84.

SOMMAIRE D'ACTIVITÉS

La Commision géologique du Yukon (CGY ; figure 1) a rebondie d'une période difficile en 2006 et a vue un nombre d'ajustements au personel en 2007 (figure 2). C'est avec plaisir que l'on acceuil le retour de Robert Deklerk aux Services minéraux après avoir vaincu un cancer. Ken Galambos est aussi de retour après quelques années avec le département du développement économique. Il travaille maintenant sur le MINFILE avec Rob. Steve Traynor remplace Ken au Programme d'encouragement des activités minières du Yukon (PEAMY). Les Services minéraux ont aussi grandemment bénéficier de l'aide temporaire de Lauren Blackburn et Catherine Welsh. Notre bureau de vente des cartes est aussi en transition après la retraite d'Ali Wagner au printemps dernier ; elle est remplaçée à titre temporaire par Kim Murray. Notre capacité en terme de l'Information géospatiale a aussi augmentée avec l'arrivé d'Aubrey Sicotte à titre permanent et de Bailey Staffen pour un an. Il ne fut pas possible de combler les postes vacants de géologues de projet et d'évaluation minérale en 2007, mais on demeure optimiste pour l'an 2008. Finalemment, c'est avec plaisir que l'on acceuil en 2008 la Docteure Carolyn Relf comme nouvelle directrice, remplacant Grant Abbott qui prendra sa retraite au printemps. Carolyn amène avec elle une expérience scientifique et administrative exceptionelle, et c'est avec anticipation qu'on attend sa direction.

Un comité de liaison technique à la CGY examine nos programmes deux fois par année. Nous remerçions le président, Gerry Carlson, et les membres du comité pour leur précieux appui et les conseils constructifs qu'ils nous fournissent.

CARTOGRAPHIE DU SUBSTRATUM ROCHEUX

1. **Don Murphy** est en charge d'une étude multidisciplinaires du terrane de Windy-McKinley dans la région de Stevenson Ridge : une région avec peu d'affleurements, donc peu connue. Ce projet est en collaboration avec la Commision géologique du Canada (CGC) et plus particulièrement Cees van Staal. Le projet inclut aussi une étude des dépôts meubles sous la direction de Jeff Bond. Les résultats préliminaires révèlent un potentiel minéral qui était jusqu'à maintenant inconnu. Un relevé géophysique aéroporté est prévu pour l'année à venir.
2. **Steve Israel** a complété la cartographie de la partie occidentale des monts Kluane, où des indices de minéralisation de nickel-cuivre et éléments du groupe du platine tel que Canalask sont présentemment examinés par l'industrie. Les travaux de Steve ont permis d'éclaircir l'histoire tectonique complexe de Wrangellia. Il est aussi impliqué dans une étude de la déformation récente assoçiée à la faille de Denali en collaboration avec Don Murphy de la CGY et des chercheurs de la Commision géologique des États-Unis (USGS).

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3. **Lee Pigage** a complété la cartographie de la région d'Otter Creek dans le sud-est du Yukon. Ce projet a pour bût d'améliorer nos connaissances de la stratigraphie, la structure, et le potentiel minéral à la limite sud-est du bassin de Selwyn. La région entoure le gisement de barityne-plomb-zinc épigénétique de Mel. Le bassin de Selwyn est bien connu pour ses gisements géants de plomb-zinc tel que Howards Pass et Faro, mais sa partie sud-est demeure peu explorée largement à cause de sa faible densité d'affleurements. Lee propose une nouvelle interprétation stratigraphique et structurale qui devrait être utile à la définition de nouvelles cibles d'exploration.

4. **Maurice Colpron** a collaboré avec **Grant Lowey, Don White** et **Steve Gordey** de la CGC, et **Steve Piercey** de l'université Laurentienne, pour complété une nouvelle compilation géologique de la partie nord de la fausse de Whitehorse. Cette compilation intègre la géologie de surface avec le relevé sismique acquit en 2004 et révèle un style de déformation de plis et chevauchements à transport vers le sud-ouest. Cette nouvelle interprétation sera importante lors de la réévaluation du potentiel pétrolier de la fausse de Whitehorse prévue pour 2008.

5. **Elizabeth Westberg** a entamé une cartographie détaillée à la bordure des régions de Laberge et de Quiet Lake dans le câdre de sa maîtrise à l'université Simon Fraser, sous la direction de **M. Colpron** et du Docteur **H.D. Gibson**. Cette étude tentera de préciser la nature du contact entre les terranes de Yukon-Tanana et de Cassiar, et déterminera l'âge et les conditions de déformation et du métamorphisme dans cette région.

ÉTUDES DE GÎTES MINÉRAUX

1. **Lara Lewis** a continué à recueillir des données sur les indices d'uranium assoçiés aux brèches de Wernecke et reliés aux intrusions, dans le cardre d'une compilation portant sur l'exploration pour l'uranium au Yukon. De nouvelles datations de la minéralisation en uranium devraient établir la chronolgie des événements minéralisateurs.

2. **Jake Hanley** et **Ed Spooner** (université de Toronto) ont complété une étude post-doctorale portant sur l'origine et l'évolution des fluides magmatiques, et leurs relations à la minéralisation aurifère dans les granits du Crétacé moyen au Yukon.

3. **Kirsten Rasmussen** a entammé une thèse de doctorat avec le Docteur **Jim Mortensen** (université de la Colombie-britannique [UBC]) portant sur le magmatisme d'âge Crétacé au Yukon et dans les parties adjacentes des Territoires du Nord-Ouest et de l'Alaska. Cette étude est la culmination de plus de 15 ans de recherches par la CGY et les chercheurs de l'unité de recherche en gîtes minéraux de UBC (MDRU). Cette étude contribuera entre autre à la nouvelle base de données sur les roches ignées de la CGY.

4. **Thierry Betsi** a débuté une étude doctorale des indices aurifères de la partie sud du Dawson Range, sous la supervision du Docteur **David Lentz** de l'université du Nouveau-Brunswick (UNB). La minéralisation en métaux de base et précieux semble être assoçiée aux intrusifs d'âge Crétacé dans la région, mais les facteurs contrôlant sa mise en place ne sont pas bien compris.

5. **William LeBarge** a poursuivit sa collaboration avec le Professeur **Valdimir Naumov** et ses étudiants gradués de l'université de Perm en Russie portant sur l'étude des placers récents et ancients de la région de la rivière Indian au sud de Dawson. Le bût de cette étude est de développer une nouvelle interprétation de la géologie dans l'espoir d'identifier de nouvelles sources d'or filonien, de même que de nouvelles ressources placériennes dans les ruisseaux avoisinants. De plus, le Docteur **Jim Mortensen** (UBC) utilise la composition géochimique de l'or afin d'établir la relation entre les dépôts filoniens et placériens, incluant la probabilité de paléoplacers dans le conglomérat de McKinnon Creek.

6. **William LeBarge** et la Docteure **Yana Fedortchouk** ont conduit une étude portant sur l'évaluation du potentiel pour les diamants alluviaires au Yukon. Ils ont échantilloné plusieurs des localités où l'on a rapporté des rumeurs de diamants. Ces échantillons sont présentemment analysés pour la présence de minéraux indicateurs à l'université Dalhousie. Le Docteur **Valentin Afanasiev** de l'académie des sciences russe de Novosibirsk en Russie agit comme consultant sur ce projet.

ÉTUDES PORTANT SUR LES HYDROCARBURES

1. **Tammy Allen** et **Tiffani Fraser** sont dans leurs deuxième année d'une étude de quatre ans portant sur l'évaluation du potentiel en hydrocarbures de la région de Peel, dans le nord-est yukonnais. Ce projet est une collaboration de la CGY avec la CGC, le centre géoscientifique des Territoires du Nord-Ouest, et des partenaires industriels et universitaires. Leurs études sont centrées sur les unités du Paléozoïque supérieur, notamment les formations de Canol, Imperial et Tuttle, dans le bût de déterminer leurs potentiels en termes de roches sources et de réservoir.

2, 3. **Grant Lowey** a complété ses travaux de terrains dans le cardre de son étude de trois ans de la sédimentologie, stratigraphie, et le potentiel en hydrocarbures du Groupe de Laberge dans la fausse de Whitehorse. Ce projet se concluera en 2008 avec une réévaluation du potentiel pétrolier de la fausse de Whitehorse. Grant a aussi entamé une reconnaissance du bassin de Bonnet Plume dans le nord du Yukon dans le bût d'y poursuivre un projet à long terme. Ce bassin renferme plusieurs gisements de charbon et cette étude résultera en une meilleure évaluation de son potentiel en charbon et en gaz.

ÉTUDES DES DÉPÔTS MEUBLES

1. **Jeff Bond** et **Panya Lipovsky** ont entamé la cartographie des dépôts meubles dans les régions de Stevenson Ridge et de Kluane Lake ; région qui enjambre la limite Pléistocène des glaciers émanants des monts Saint Elias. La région renferme plusieures limites glaciaires et semble préserver une stratigraphie du Quaternaire complexe. Cette étude amènera vraisemblablement une meilleure compréhension des glaciations récentes au Yukon. Un socle rocheux favorable et de grandes étendues de terrains non-glaciaires sont propices à la découverte de nouveaux placers dans la région.

2. **Panya Lipovsky** utilise une vaste gamme de techniques afin de déterminer la distribution, géomorphologie et les impacts de divers accidents de terrains dans le sud et le centre du Yukon. Elle continue la surveillance des glissements de terrain reliés à la fonte du pergélisol et aide le département des parcs du Yukon dans l'établissement d'un système de surveillance en amont du terrain de camping du lac Kusawa.

3. Un grand nombre de données sur le pergélisol et les dépôts meubles sont contenues dans les forages géotechniques qui ont été fait le long de la route de l'Alaska au cours des 30 dernières années.
Panya Lipovsky a compilée cette information dans une base de données qui contient maintenant plus de 5000 forages entre Beaver Creek et Haines Junction.
Megan James continuera cette compilation au cours de l'année à venir dans le cardre de sa maîtrise avec le Docteur **Antoni Lewkowicz** de l'université d'Ottawa.

4. Une avalanche de roches et de glace majeure s'est produite le 24 juillet 2004 sur le côté nord du mont Steele dans le sud-ouest du Yukon. Des débris on voyagés sur plus de 6 kilomètres, avec une chute verticale de plus de 2150 mètres, et déposant près de 3,66 kilomètres carrés des roches et de glace sur le glacier Steele. Ce fût le glissement de terrains le plus important dans la cordillère canadienne depuis 1899. **Panya Lipovsky** étudie ce glissement de terrain avec plusieurs chercheurs canadiens et américains.

5. **Amber Church** a débutée une étude de l'histoire glaciare de l'Holocène tardif dans la vallée de Wheaton au sud de Whitehorse. Cette étude formera la base de sa thèse de maîtrise sous la direction du Docteur **John Clague** à l'université Simon Fraser.

6. **Kristen Kennedy** étudie les dépôts meubles dans la région d'Eagle Plain dans le cardre de sa maîtrise sous la direction du Docteur **Duane Froese** à l'université d'Alberta. Cette région renferme une des rares ressources en graviers du nord du Yukon ; ressource qui sera nécessaire pour la construction de routes pour le développement éventuel des ressources en hydrocarbures de la région.

ÉTUDES DÉTAILLÉES

1. **Francesca Furlanetto** a commencé une étude doctorale des minéraux détritiques dans les roches sédimentaires du Supergroupe de Wernecke sous la direction du Docteur **Derek Thorkelson** de l'université Simon Fraser. Ces données permettront de préciser les corrélations entre le Supergroupe de Wernecke et d'autre séquences sédimentaires au Canada et ailleurs, ainsi que l'environnement géologique de plusieurs indices minéraux du nord du Yukon.

2. **Luke Beranek** continue d'augmenter le nombre d'analyses des zircons détritiques dans les roches Paléozoïques tardives et du Trias de part et d'autre de la limite entre la marge continentale nord-américaine et les terranes de Slide Mountain et Yukon-Tanana. Cette étude forme la base de sa thèse de doctorat à l'université de Colombie-Britannique sous la tutelle du Docteur **Jim Mortensen.** Luke a démontré que des débris provenant des terranes s'accumulaient sur la marge nord-américaine dès le Trias précoce, beaucoup plus tôt que l'on le croyait auparavant.

RELEVÉS AÉROMAGNÉTIQUES

1. La CGC, en collaboration avec la CGY, a compléter un programme majeur de relevés aéromagnétiques des monts Wernecke et Mackenzie qui fût commencé en 2006. Les résultats seront disponibles en début 2008.

GÉOCHIMIE

1. La géochimie des ruisseaux est pratiquemment complètée au Yukon. On entame maintenant la modernisation des analyses dans le bût de standardiser ces données à l'échelle régionale. Les résultats de réanalyse des feuillets cartographiques 105G et 105J seront publiés en début 2008, alors que ceux des feuillets 105H et 105I paraîtrons plus tard dans l'année.

DIFFUSION DE L'INFORMATION

La Commission géologique du Yukon diffuse de l'information en trois formats : 1) les cartes et rapports sur papier sont vendus par le Bureau d'information et des ventes en géoscience ; 2) la plupart de nos publications et bases de données récentes sont disponibles en format numérique à prix réduit ; et 3) plusieurs de nos publications sont disponibles sans frais sous format PDF sur notre site internet (www.geology.gov.yk.ca). La liste des rapports d'évaluation de propriétés minières disponibles en format numérique est maintenant aussi offerte par internet (www.emr.gov.yk.ca/library).

Nous sommes fier de diffuser de l'information géospatialle par l'entremise de notre service de carte interactive 'MapMaker' (l'ancien Map Gallery), que l'on accède par le site internet de la CGY. Ce site de carte interactive est continuellement le sujet d'améliorations ; nous apprécions les commentaires des usagers.

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

Bureau d'information et des ventes en géosciences
a/s Conservateur des registres miniers
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Robert E. Leckie Award for Outstanding Reclamation Practices

Judy St. Amand[1]
Mining Lands, Energy Mines and Resources

St. Amand, J., 2008. Robert E. Leckie Awards for Outstanding Reclamation Practices. *In:* Yukon Exploration and Geology 2007, D.S. Emond, L.R. Blackburn, R.P. Hill and L.H. Weston (eds.), Yukon Geological Survey, p. 85-88.

QUARTZ RECLAMATION

YUKON NEVADA GOLD CORPORATION

Yukon Nevada Gold Corporation is the recipient of the 2007 Robert E. Leckie Award for Outstanding Quartz Reclamation Practices. They are conducting a large drill program in the Ketza River area near Ross River.

The company has worked hard to design a vigorous cleanup program for this previously abandoned site. Their reclamation efforts include removing waste petroleum, contaminants and chemicals from the site; disposing of 600 empty barrels, removing 100 truckloads of trash, and eliminating scrap metal from waste sites (Fig. 1).

In addition to this waste-removal program, Yukon Nevada Gold has resloped and seeded three waste dump areas, as well as cleaned up the mill, and removed several old buildings. An incinerator now replaces the landfill, and the company has taken an assertive stance with their operators to ensure that sumps are in place for every drill site.

This award recognizes Yukon Nevada Gold's progressive policies and unwavering efforts to reclaim this mine site.

Figure 1. *Overview of the Yukon Nevada Gold Corp. site at Ketza River after removal of tonnes of debris and much reclamation.*

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HONOURABLE MENTION: Selwyn Resources Ltd. has received an honourable mention for the their project at Howard's Pass which straddles the border of Yukon and Northwest Territories. The company carried out an aggressive exploration drilling program in this area to aid in their feasibility study. The majority of the work was done in the Yukon.

This award recognizes this company's commitment to integrate progressive environmental and socio-economic practices into its operations.

Selwyn Resources used very modern equipment and sampling techniques to collect high-quality data for 18 environmental baseline studies, and they also have involved the Kaska Tribal Council in their 'hands-on' environmental fieldwork (Fig. 2). Selwyn Resources has also made significant contributions to Dechen la Camp in order to develop environmental awareness for over 20 young people within the Territory. The company's well rounded programs and 'best practices' are undoubtedly an asset to the mining industry.

Figure 2. *Selwyn Resources Ltd.'s site has been bio-engineered using willows collected from the property. This is one of several areas where these methods have been used for site stability.*

PLACER RECLAMATION

NO NAME RESOURCES INC.

No Name Resources Inc. is the 2007 recipient of the 2007 Robert E. Leckie Award for Outstanding Placer Reclamation Practices. The company has been placer mining at Ten Mile and Thirteen Mile creeks in the Dawson mining district since 2003.

Brent and Rosemary Pasareno took over several properties, which had been mined by previous operators since the 1970s, when no legislation existed to encourage reclamation practices.

They have cleaned both areas, and removed abandoned equipment, tanks and debris to a single storage yard for each site. They have sloped and contoured old mining works and camp areas, rehabilitating the two sites so they can now revegetate naturally (Fig. 3). They are considered exemplary operators.

Figure 3. *This is one of the sites where No Name Resources Inc. has removed the abandoned debris remaining from many years of placer operations. The site has been resloped and contoured in preparation for natural revegetation.*

HONOURABLE MENTION: Ross Mining Ltd. received an honourable mention for the work they are doing on Dominion Creek near Dawson City. Jon Rudolph has continued this company's tradition of responsible and exemplary reclamation works since becoming president.

At this site, stripping, mining and reclamation occur concurrently. The disturbed area is carefully contoured and topsoil is spread to encourage rapid revegetation (Fig. 4). There are extensive areas that are reclaimed with healthy regrowth. Reclaimed areas are aesthetically pleasing and complement the natural valley landscape.

In a pilot project with other private sector partners, Ross Mining is working to establish and market Yukon placer gold as a 'green' product; gold that is mined and produced using the highest environmental and human rights standards. This additional incentive could effect change in the placer industry as a whole and demonstrates the exemplary practices of Ross Mining Ltd.

Figure 4. *Ross Mining Ltd. have dumped topsoil for spreading on this sloped and contoured previously mined site.*

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Hydrocarbon potential of Upper Paleozoic strata, eastern Richardson Mountains, northern Mackenzie Mountains and Peel Plateau, Yukon

Tammy L. Allen[1] and Tiffani A. Fraser[2]
Yukon Geological Survey

Allen, T.L. and Fraser, T.A., 2008. Hydrocarbon potential of Upper Paleozoic strata, eastern Richardson Mountains, northern Mackenzie Mountains and Peel Plateau, Yukon. *In:* Yukon Exploration and Geology 2007, D.S. Emond, L.R. Blackburn, R.P. Hill and L.H. Weston (eds.), Yukon Geological Survey, p. 91-114.

ABSTRACT

Upper Paleozoic strata in the eastern Richardson Mountains, northern Mackenzie Mountains and Peel Plateau of the Yukon consist of basinal sediments overlain by a siliciclastic sedimentary wedge derived from the Late Devonian Ellesmerian orogeny. Unconformably overlying Paleozoic strata in the Peel Plateau are Cretaceous sedimentary rocks that were deposited in the foreland basin of the Cretaceous Cordilleran orogeny.

This study, as part of the interdisciplinary "Regional Geoscience Studies and Petroleum Potential, Peel Plateau and Plain" project, examines the sedimentology, stratigraphy and hydrocarbon potential of Upper Paleozoic strata in the Peel region and adjacent Richardson and Mackenzie mountains. Units investigated as part of this study include the Canol (Upper Devonian), Imperial (Upper Devonian) and Tuttle (Upper Devonian-Lower Carboniferous) formations, 'Cf' map unit (?Upper Devonian-Lower Carboniferous), and 'Mo' map unit (?Upper Devonian-Lower Carboniferous). Preliminary analyses suggest the Canol, Imperial, Tuttle, 'Cf' and 'Mo' are potential hydrocarbon source rocks for the region. The Tuttle Formation is the best prospective reservoir rock of the Upper Paleozoic strata.

RÉSUMÉ

Les couches du Paléozoïque supérieur dans la partie orientale des monts Richardson, au nord des monts Mackenzie, consistent en sédiments de bassin recouverts d'un biseau siliciclastique dérivé de l'orogenèse ellesmérienne du Dévonien tardif. Des sédiments du Crétacé déposés dans le bassin d'avant-pays de l'orogène de la Cordillère reposent en discordance sur les strates du Paléozoïque.

Cette étude, menée dans le cadre du projet interdisciplinaire d'Études géoscientifiques régionales et d'évaluation des ressources pétrolières du plateau et de la plaine de Peel, examine la sédimentologie, la stratigraphie et le potentiel pour les hydrocarbures des couches du Paléozoïque supérieur dans la région de Peel et des monts Richardson et Mackenzie adjacents. Les unités examinées dans le cadre de cette étude comprennent les formations de Canol (Dévonien supérieur), d'Imperial (Dévonien supérieur) et de Tuttle (Dévonien supérieur – Carbonifère inférieur), l'unité cartographique «Cf» (?Dévonien supérieur – Carbonifère inférieur) et l'unité cartographique «Mo» (?Dévonien supérieur – Carbonifère inférieur). Les analyses préliminaires suggèrent que les formations de Canol, d'Imperial et de Tuttle ainsi que les unités cartographiques «Cf» et «Mo» constituent des sources potentielles de roche mère pour les hydrocarbures dans cette région. Le Formation de Tuttle constitue la meilleure roche réservoir d'intérêt dans les couches du Paléozoïque supérieur.

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INTRODUCTION

The study is part of the "Regional Geoscience Studies and Petroleum Potential, Peel Plateau and Plain" research project. It is a working partnership that involves the efforts of the Geological Survey of Canada, Northwest Territories Geoscience Office, Yukon Geological Survey, and university and industry affiliates. It is a four-year project that will conclude in 2009.

The aim of the project is to study the regional geology of the Peel Plateau and Plain, including the stratigraphy, sedimentology and depositional history, as well as hydrocarbon potential. As part of this study, we focused on Upper Paleozoic strata that occur in the Yukon portion of the Peel region. These strata were analysed for their petroleum potential including source rock potential, and where applicable, reservoir rock potential.

FIELD INVESTIGATIONS

During summer 2007, fieldwork was conducted on NTS map sheets 106E (Wind River), 106F (Snake River) and 106L (Trail River), between latitude 65° and 67°N and longitude 133° and 136°W (Fig. 1). Four weeks were spent in the region encompassing the Peel Plateau, adjacent eastern Richardson Mountains and northern flank of the Mackenzie Mountains, conducting field investigations of Upper Paleozoic and Cretaceous strata. Upper Paleozoic outcrop is limited to the flanks of the Richardson Mountains and the northern front of the Mackenzie Mountains, while Cretaceous strata are exposed in river cuts in the Peel Plateau. This study is a continuation of fieldwork conducted in 2006 on the eastern flank of the Richardson Mountains (Fraser and Allen, 2007). This paper focuses on investigations of the Upper Paleozoic strata.

Sample collection focused on obtaining representative examples of shale to determine source rock potential and thermal maturation using Rock-Eval pyrolysis and total organic carbon (TOC) analysis, as well as age determination from palynomorphs. Sandstone and conglomerate were collected to examine lithology and to measure reservoir parameters such as porosity and permeability. Other investigations included measuring detailed stratigraphic sections to collect data on stratigraphic thicknesses, determining the nature of contacts between units and interpreting depositional environments.

REGIONAL STRATIGRAPHY

The Peel Plateau and Plain in the Yukon is underlain by a westerly thickening wedge of Phanerozoic sedimentary rock (up to 4.5 km thick) that unconformably overlies a poorly understood Proterozoic succession (Osadetz *et al.*, 2005). Phanerozoic strata in the region are divided into three main depositional systems: 1) Cambrian to Upper Devonian carbonate and shale of the Mackenzie Peel shelf and Richardson trough (Morrow, 1999); 2) an Upper Devonian to Carboniferous clastic wedge that was deposited in a foreland basin of the Yukon and Ellesmerian fold belts associated with the Frasnian to Tournaisian Ellesmerian orogeny (Richards *et al.*, 1997); and 3) Cretaceous marine shelf deposits that were deposited in the foreland basin of the Cordilleran orogen (Dixon, 1992).

Upper Paleozoic strata (specifically Upper Devonian to Lower Carboniferous) for the Richardson Mountains are correlative with the Peel Plateau (Figs. 2 and 3), and consist of the Canol, Imperial and Tuttle formations, with the overlying Ford Lake Shale in the western Richardson Mountains and the 'Cf' map unit in the Peel Plateau. In the northern Mackenzie Mountains, the stratigraphy is structurally complicated, resulting in units being repeated or removed over the length of an exposure. Norris (1982a) amalgamated the Hare Indian, Canol and Imperial formations when mapping NTS area 106F, demonstrating the complexity of their distribution. It is important to note that the Canol and Imperial formations in the northern Mackenzie Mountains are the only units that are correlative with strata on the eastern flank of the Richardson Mountains (Fig. 2). Stratigraphically above this level the relationship between the strata is not clear, though it is likely that the 'Mo' map unit of the Mackenzie Mountains is the stratigraphic equivalent to the Tuttle Formation. The 'Cf' map unit is found both in the northern Mackenzie Mountains and in the Peel Plateau.

Upper Paleozoic strata in the Peel and adjacent regions that were investigated as part of this study will be described in the following sections and include the Canol, Imperial and Tuttle Formations, and 'Cf' and 'Mo' map units.

CANOL FORMATION

The Canol Formation has been documented in the Mackenzie Delta, Kandik Basin, Eagle Plain, Richardson Mountains, Bonnet Plume Basin and Peel Plateau of the Yukon (Morrow *et al.*, 2006; Pigage, 2007). On the Trail

River map sheet, the Canol Formation disconformably overlies the Road River Group and is conformably overlain by the Imperial Formation (Morrow, 1999). On Trail River proper (east Richardson Mountains), the Canol Formation attains a thickness of 225 m, although in the subsurface of Peel Plateau and Plain it is generally much thinner (< 100 m) (Fraser and Hogue, 2007; Pyle *et al.*, 2006). In the Snake River map area (northern Mackenzie Mountains), the distribution and thickness of the Canol Formation is uncertain, as it was amalgamated with the Hare Indian and Imperial formations for the purpose of mapping (Norris, 1982a).

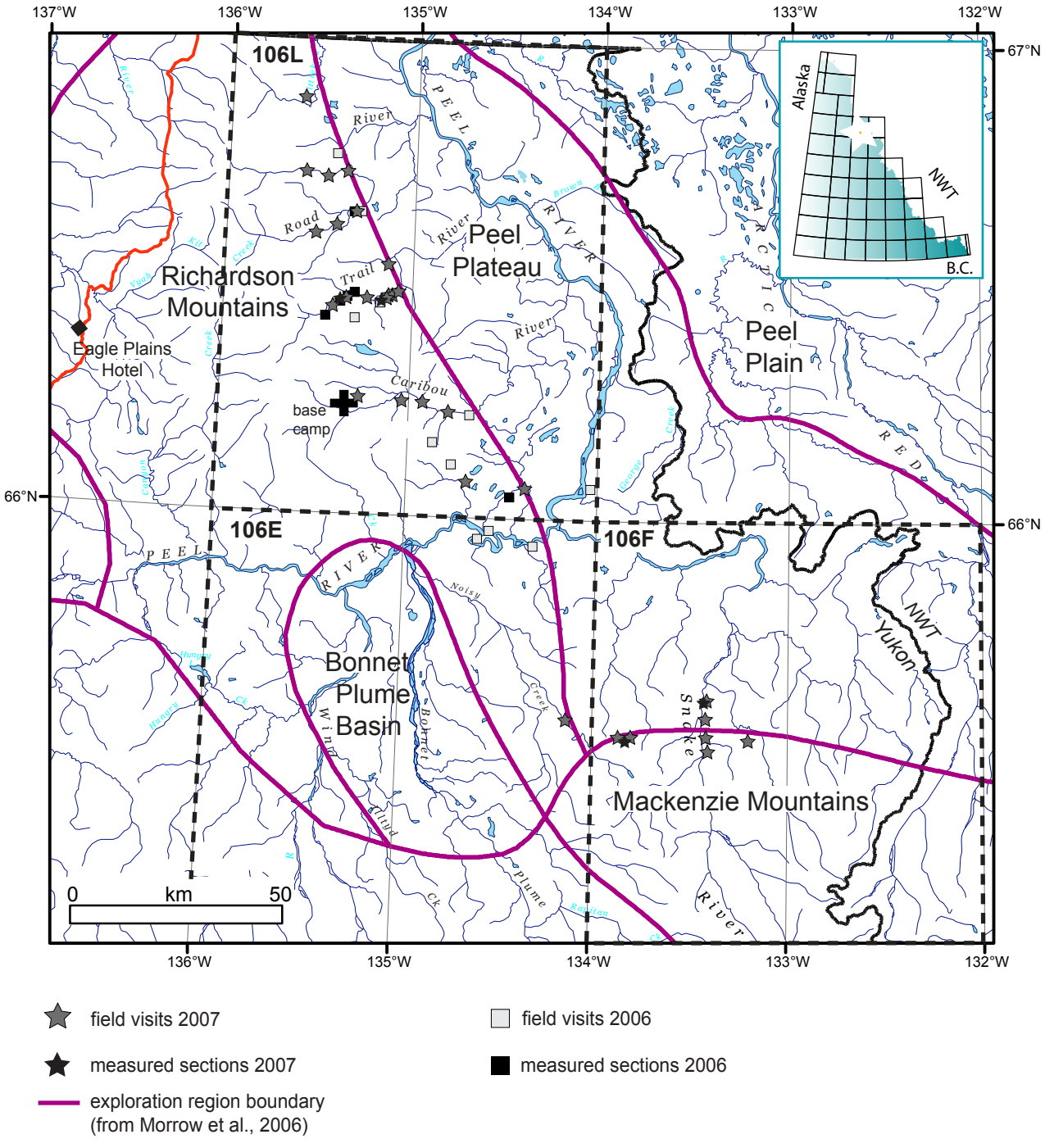

Figure 1. *Location map and general geography of study area.*

The resistant Canol Formation forms canyons on the Trail and Road rivers. In the study area, the Canol Formation consists of dark grey to black, noncalcareous shale and chert coated with a distinctive bright yellow and apple green patina, possibly the mineral jarosite (Aitken *et al.*, 1982). The chert occurs as thin to very thin, even parallel planar beds that are commonly rusty weathered. The chert is separated by thinly to thickly laminated shale that is sooty to very well indurated (Figs. 4a and 4b). The Canol Formation has large elongate carbonate(?) concretions measuring metres across; it also contains small pyrite concretions which are 1 to 2 cm across, but

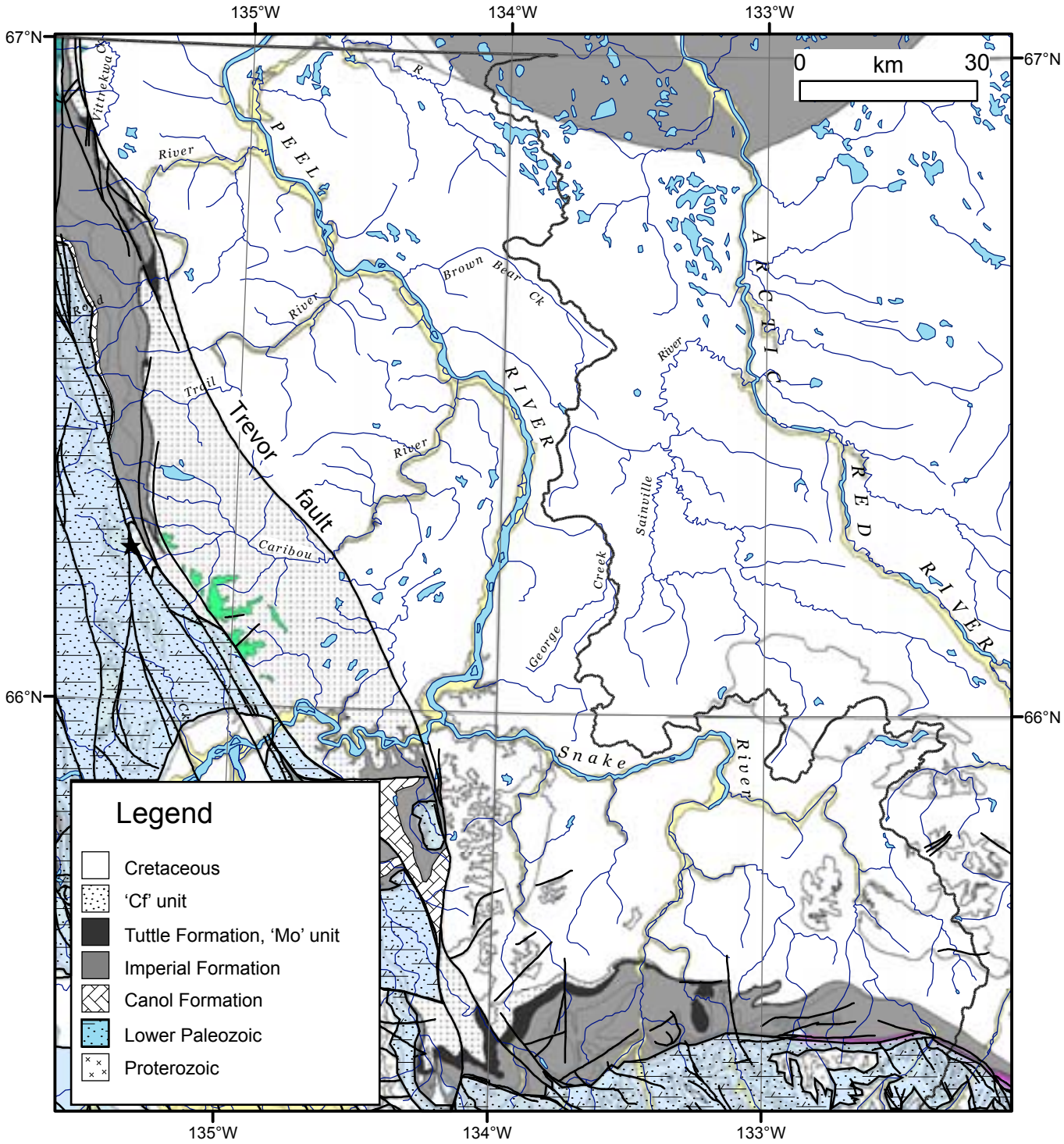

Figure 2. *Geological map of study area. Geology modified from Norris (1981; 1982a,b; Gordey and Makepeace, 2001).*

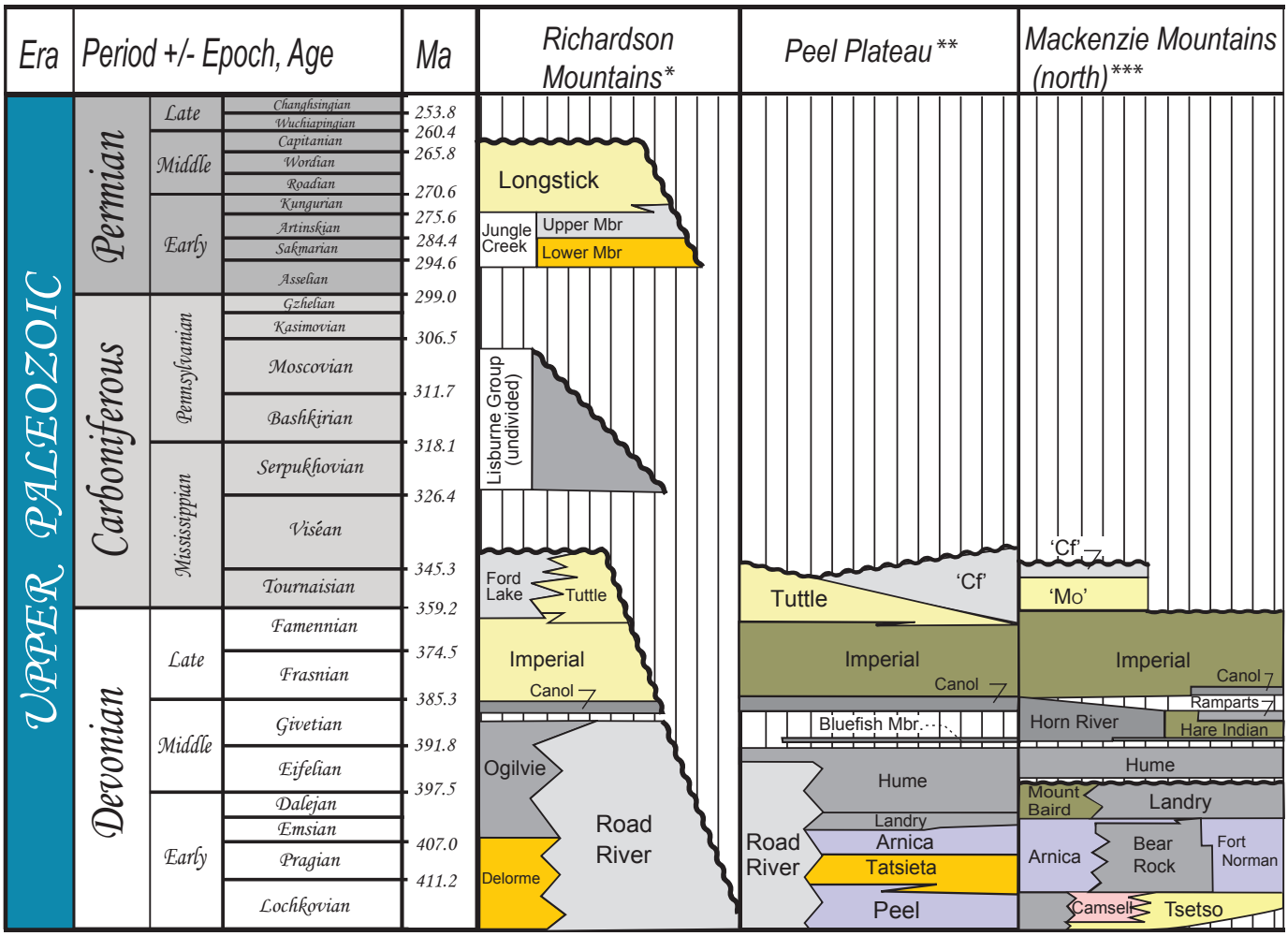

Figure 3. *Stratigraphic column of Upper Paleozoic strata for the three physiographic regions where fieldwork was conducted: the Richardson Mountains, Peel Plateau and Mackenzie Mountains. Ma = million years.*

**from Morrow et al. (2006); **modified from Pigage (2007); ***modified from Morrow et al. (2006)*

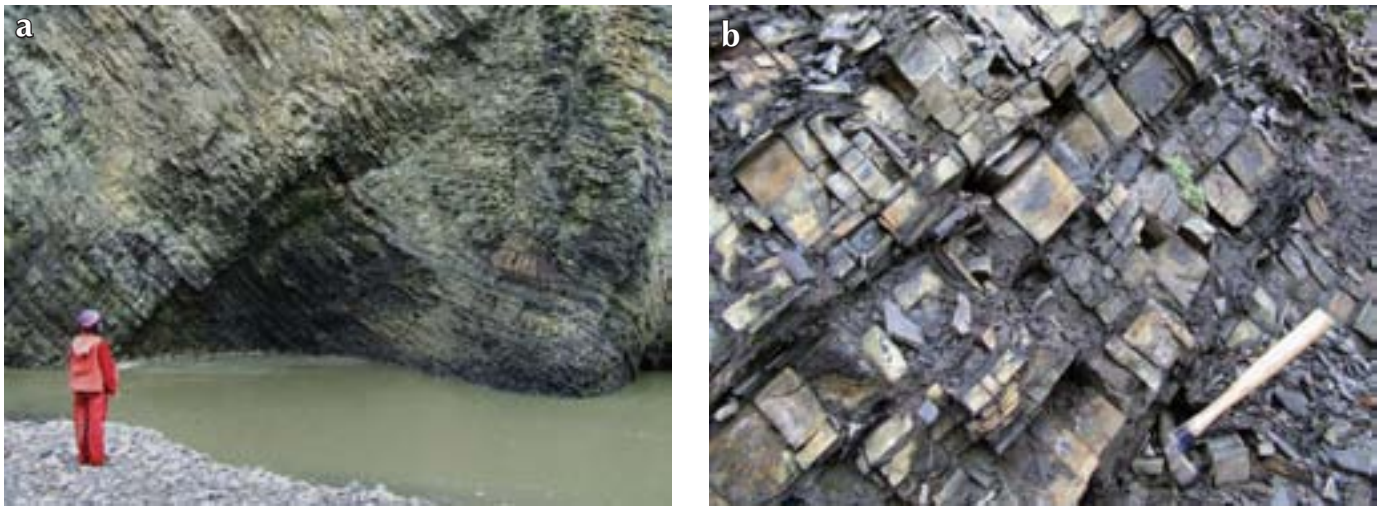

Figure 4. ***(a)*** *Typical outcrop of the Canol Formation, Trail River. Note planar, even beds of chert and shale. Large carbonate concretions observed in the far right of the outcrop.* ***(b)*** *Close up of the Canol Formation, Trail River, showing planar-bedded shale and chert (thicker beds). Rock hammer for scale is 30 cm long.*

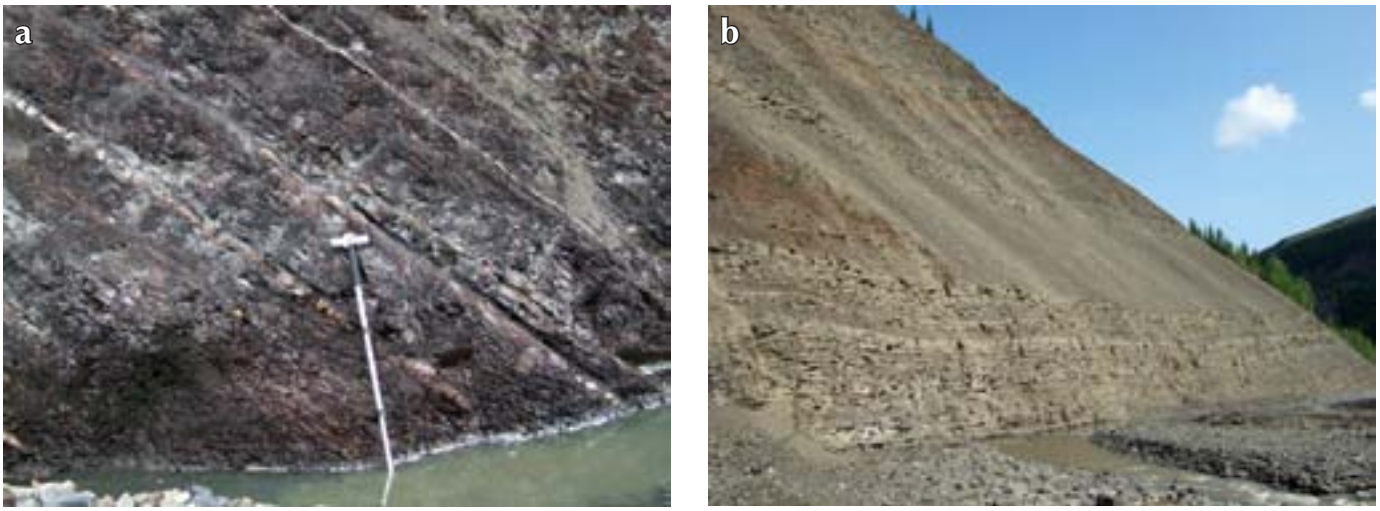

Figure 5. ***(a)*** *'Lower Imperial' Formation, Trail River. This lower member is characterized by thick intervals of mudstone punctuated by continuous resistant siderite bands, as shown here. Length of pogo for scale is approximately 1.3 m.* ***(b)*** *'Upper Imperial' Formation, Tetlit Creek. The upper member consists of interbedded sandstone, mudstone and lesser shale. Sandstone volume increases towards the top of the formation.*

locally up to tens of centimetres. On Road River, the Canol outcrop has a strong sulphurous smell.

The Canol Formation has been dated as late Givetian, but a more likely date is early Frasnian based on palynomorphs from Trail River identified by D.C. McGregor (Norris, 1985). Al-Aasm *et al.* (1996) suggest the Canol was deposited in a deeper marine anoxic to dysoxic setting based on degrees of pyritization (DOP).

IMPERIAL FORMATION

The Imperial Formation extends across northern Yukon from Eagle Plain in the west to the Mackenzie Delta in the east, including the Richardson Mountains, Bonnet Plume and Peel region (Morrow *et al.*, 2006; Pigage, 2007). In the east Richardson Mountains, the Imperial conformably overlies the Canol Formation and is conformably overlain by the Tuttle Formation. In the northern Mackenzie Mountains, the Imperial is mapped together with the Canol and its relation is thus uncertain. Here, it is overlain conformably by the 'Mo' map unit, particularly in the west, and unconformably by the Cretaceous Arctic Red Formation, particularly in the east. The Imperial is 716 m thick at its type section on Imperial River (N.W.T.) (Tassonyi, 1969) and 1461 m of strata were measured on Trail River (Norris, 1968). A maximum thickness of 1909 m is recorded in the Union Amoco McPherson B-25 well, in the southern part of the northern Richardson Mountains (Pugh, 1983).

In the east Richardson Mountains, the Imperial consists of two lithologically different units: a lower mudstone dominated unit and an upper interbedded shale/mudstone and sandstone unit informally referred to in this paper as the 'lower Imperial' and the 'upper Imperial', respectively. The 'lower Imperial' Formation is predominantly medium-grey mudstone with a small percentage of medium-grey thin sandstone beds and siderite bands (Fig. 5a). The mudstone is uniform, structureless and blocky-weathered with rusty fractured surfaces that give the unit an overall reddish hue. The siderite occurs as continuous bands (10 to 15 cm thick) and as nodules within discrete layers. Some nodules contain pyrite and/or calcite(?) septaria.

Sandstone beds increase gradually in abundance and thickness upward in the Imperial Formation, resulting in a more resistant 'upper Imperial' (Fig. 5b). Sandstone within the Imperial Formation is very fine to fine-grained, quartz-rich and well cemented. Thin section investigations of the Imperial reveal quartz and minor chert, with dark, grungy-looking material between the grains which may be calcite and/or siderite. Sedimentary structures include flute marks and load casts at the base of sandstone beds, locally with iron carbonate nodules. The finer grained sedimentary rocks of the 'upper Imperial' include blocky, structureless, grey mudstone and lesser grey shale.

Palynological studies of samples collected on the Trail River suggest that the 'upper Imperial' Formation is

Frasnian to early Famennian? (Late Devonian)[1]. Samples submitted from the 'lower Imperial' on the Trail River contain spores that are very poorly preserved and did not yield a date[1], however in an earlier study, spores identified by D.C. McGregor (reported in Norris, 1985) from the base of the Imperial Formation on Trail River were dated as late Givetian or early Frasnian (Middle-Late Devonian).

Several authors have noted turbidite features in the Imperial Formation (*e.g.,* Norris, 1997; Glaister and Hopkins, 1974; and Glennie, 1963). Paleoflow direction of these sediments is noted as generally from a north, northwest, and lesser west (Hills and Braman, 1978) and southeast source (Pugh, 1983). In the subsurface, clinoforms observed on seismic lines demonstrate an easterly derived sediment source for the Imperial Formation, particularly in the N.W.T. portion of the Peel region, east of Flyaway Creek (Y. Lemieux; W. Zantvoort, pers. comm. 2007).

TUTTLE FORMATION

The Tuttle Formation is described in Fraser and Allen (2007). It is suggested the reader consult this paper for a more comprehensive description of the Tuttle Formation.

The Tuttle Formation has been documented in Eagle Plain, the southern Richardson Mountains, Peel Plateau and the western part of the Peel Plain (Morrow *et al.*, 2006; Pigage, 2007). Some authors suggest the basal contact of the Tuttle with the Imperial Formation is conformable (Pugh 1983), whereas others report that on the Trail River, and possibly elsewhere, it is unconformable (Norris 1985; Braman, 1981). D.K. Norris' (1981) geology map of the Trail River map sheet suggests that the Tuttle is conformably overlain by the 'Cf' map unit. Subsurface studies (*e.g.,* Pugh, 1983; Lutchman, 1977) report the Tuttle as being overlain unconformably by Cretaceous strata. The Tuttle is 874 m thick at the type section in the Peel Y.T. F-37 well (Pugh, 1983). The thickest Tuttle section recorded in the Peel region is 1198 m in the Trail River Y.T. H-37 well.

The Tuttle Formation consists of alternating packages of coarse-grained and finer grained strata (Fraser and Allen, 2007). Coarse-grained intervals are resistant in nature and comprise sandstone with minor conglomerate (Fig. 6a). Sandstone consists predominantly of chert and quartz. Locally the chert is weathered to a porous, chalky white material referred to as 'tripolitic' chert (Shell Canada Ltd., 1964). 'Tripolitic' refers to a light coloured, porous, friable siliceous sedimentary rock which results from the weathering of chert (after Neuendorf *et al.*, 2005). Chert is also observed as variable-coloured clasts (*e.g.,* grey, black, yellow and green). Between the sandstone grains, a white chalky material can locally be observed, which may be a kaolinite pore-filling cement described by Pugh (1983). A very minor amount of mica has also been observed between sandstone grains. Sandstone textures range from

[1]*J. Utting, 2007. Palynological investigations of 25 outcrop samples and 8 core samples from the Upper Paleozoic, Western District of Mackenzie, submitted by T. Allen and T. Fraser, Yukon Geological Survey (NTS 106E/15, 16 and NTS 106L 1,4,6,8,9,10,11). GSC unpublished report 02-JU-2007, 14 p.*

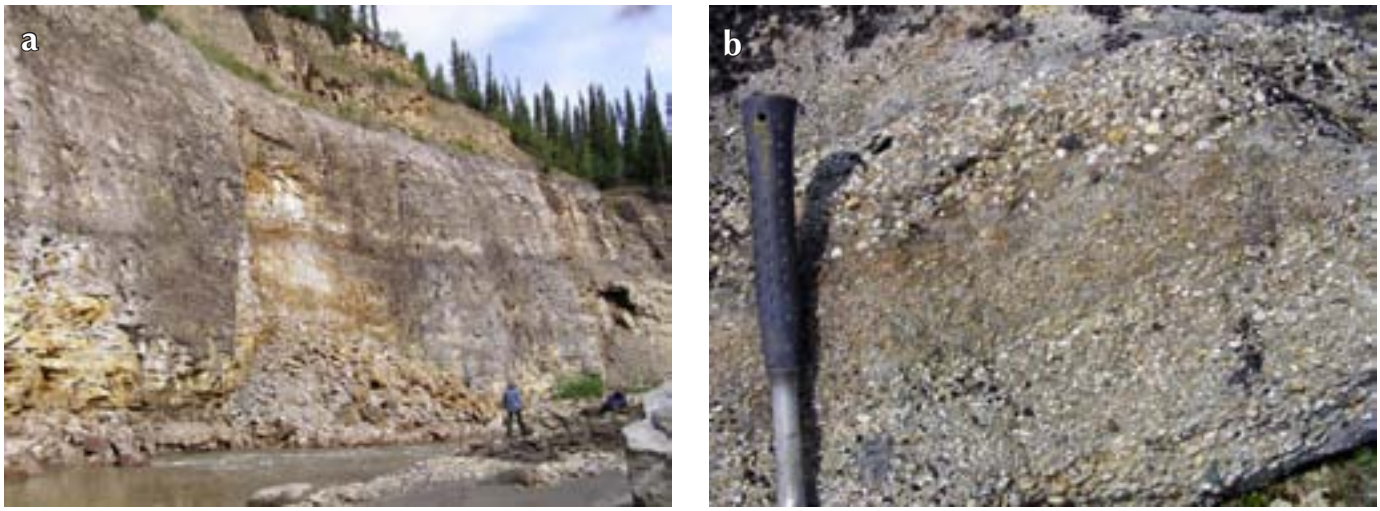

Figure 6. ***(a)*** *Outcrop of the Tuttle Formation sandstone, near the Trevor fault on Trail River. Note strata are flat-lying. This is the locality where oil-stained samples were collected. Person for scale in bottom right.* ***(b)*** *Close up of the Tuttle Formation, exposed on a ridge north of Road River. In the northern part of the study area, the Tuttle Formation is coarser grained, commonly consisting of granule to pebble conglomerate, as displayed here. Rock hammer handle for scale is 19 cm.*

fine to very coarse grained, with sorting mainly poor to moderate. Sedimentary structures were difficult to discern from weathered outcrop exposures.

Conglomerate is not common in the Tuttle Formation, however it does occur as discrete beds up to 60 cm thick within sandstone-dominant intervals, and is more common in the northern part of the Trail River map sheet (Fig. 6b). Fine-grained intervals of the Tuttle Formation, up to 150 m thick, are composed of interbedded shale, siltstone and very fine grained sandstone, giving the strata a 'striped' appearance. The sandstone in these intervals is very thinly bedded, quartz-rich and well indurated, and displays ripples and load casts.

Recent palynological investigations of samples collected from the Trail River map sheet (NTS 106L) suggest the Tuttle Formation is latest Frasnian to late Famennian (Strunian; Late Devonian) in age[1].

Lutchman (1977) suggested the Tuttle Formation (referred to as the 'Mississippian clastic wedge') was of fluvio-deltaic origin based on study of drill core, well logs and drill cuttings. Hills and Braman (1978) have suggested a turbidite setting for the Tuttle Formation on the Trail River. Current field investigations support the interpretation of Hills and Braman (1978): that the Tuttle Formation was deposited within a turbidite setting that began during deposition with the Imperial Formation. Supporting evidence includes: the presence of repeated fining-upward sequences (partial Bouma sequences, with divisions A through DE); load casts, flutes and tool marks on bases of beds; and soft sediment deformation (*i.e.*, intraformational slump folds). Partial Bouma sequences commonly consist of massive to cross-bedded granular conglomerate at the base, grading upwards to cross or parallel-bedded, medium-grained sandstone, with fine to very fine grained sandstone and locally shale or rippled siltstone at the top.

Our fieldwork found that strata on the Trail River mapped by Norris (1981) as map unit 'Cf' is likely the Tuttle Formation, based on lithologic characteristics and age. Portions of map unit 'Cf' on the Caribou and Road rivers also display similarities to the Tuttle Formation, suggesting that detailed mapping of these areas would enhance the geological understanding of Upper Paleozoic strata in this region.

[1]*J. Utting, 2007. Palynological investigations.*

'MO' MAP UNIT

Lower Carboniferous(?) sandstone and shale outcrops along the northern front of the Mackenzie Mountains in the Wind River and Snake River map areas (NTS 106E and 106F). Norris (1981; 1982a,b) mapped these clastic sediments as unit 'Mo'. The 'Mo' map unit unconformably overlies the Imperial Formation and is overlain conformably by a shale-rich unit mapped as 'Cf' by Norris (1982a; see description of 'Cf' in section below), or unconformably by Cretaceous strata. The total thickness of the 'Mo' map unit is difficult to determine due to its discontinuous exposures and folding and faulting in the region.

No published description exists for the 'Mo' map unit, except for the description in the map legends of NTS sheets 106E and 106F (Norris, 1982a,b) which describes it as "sandstone, light grey, medium-grained; shale, dark grey; nonmarine?". More recently, authors have included the 'Mo' map unit with the Tuttle Formation (Gordey and Makepeace, 2001). Figure 18 of Pugh (1983) and Figure 8.11 in Richards *et al.* (1997) suggest that Carboniferous strata, mapped as 'Mo' along the northern front of the Mackenzie Mountains in the vicinity of Snake River, is fine-grained sandstone of the Tuttle Formation.

On the Snake River, the 'Mo' map unit crops out as resistant, very fine to fine-grained sandstone (Fig. 7a) forming a narrowing of the river channel. The sandstone is quartz-rich and very dense. It consists of alternating intervals of rippled, lenticular, thinly bedded sandstone; cross-bedded, thickly bedded sandstone; and minor shale (Fig. 7b). Horizontal and vertical burrows are commonly observed in the rippled sandstone. Other features include coalified plant debris and stylolites draped with black organic(?) material. The section on Snake River has an increase in the percentage of fine-grained siliciclastic rocks upsection.

Thin-section analysis reveals that the sandstone of the 'Mo' map unit is quartz-rich with minor typically non-porous chert. The quartz grains are commonly fused together and where a matrix is present it may consist of carbonate with small amounts of mica and chlorite. Based on this study, the 'Mo' map unit exhibits features that are unique to the Tuttle Formation, including high quartz to chert ratios; substantial quartz cementation; low porosity and permeability values (see hydrocarbon potential discussion below); the presence of carbonate cement; overall small grain size; presence of bioturbation; and well preserved sedimentary structures.

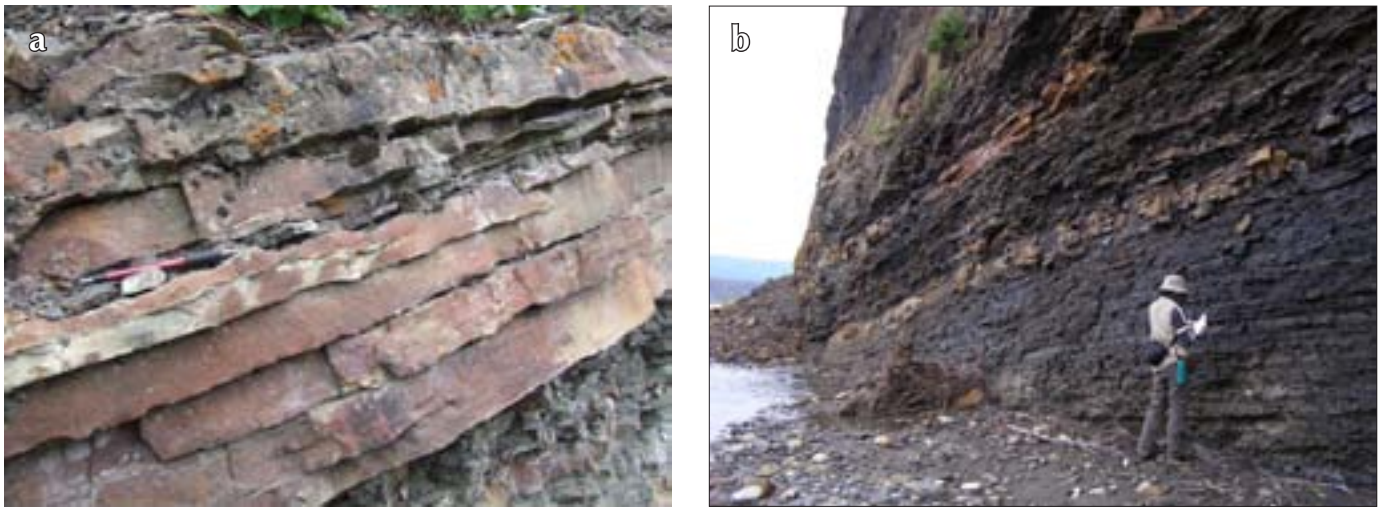

Figure 7. ***(a)*** *Close up of fine-grained sandstone beds typical of the 'Mo' map unit, Snake River. Pencil for scale is 15 cm long.* ***(b)*** *Outcrop of 'Mo' map unit, Snake River demonstrating alternating very fine grained rippled sandstone beds (dark grey) and more resistant, fine-grained rippled and cross-bedded sandstone beds (light grey).*

'CF' MAP UNIT

On the Trail River, Snake River and Wind River map sheets a unit overlying and time equivalent to the Tuttle Formation was mapped as 'Cf' by Norris (1981; 1982a,b). 'Cf' is described as "shale, dark grey, silty, concretionary; marine and nonmarine" (Norris, 1981; 1982a,b). Norris (1984) later suggested that this unit is correlative with the Ford Lake Shale.

It is important to note that the 'Cf' map unit is not reported from the Peel subsurface. In subsurface Yukon Peel wells, strata immediately underlying Cretaceous sediments have been assigned to the Tuttle Formation.

Our field investigations show that the lithology of the area mapped as 'Cf' is diverse. On the Trail River, the unit mapped as 'Cf' is Tuttle Formation sandstone and shale. On Caribou River, the mapped 'Cf' unit crops out in different locations as two distinctive packages: a resistant black shale that appears similar to the Canol Formation (Fig. 8a); and interbedded grey shale and fine-grained sandstone (Fig. 8b). The resistant black shale variety of 'Cf' fits nicely with Brabb's (1969a, p. 12) description of the Ford Lake Shale as consisting "predominantly of grayish-black siliceous shale and laminated grayish-black chert that splits with a slabby parting". This lithology was also seen on other tributaries of the Peel River, where it occurs as siliceous, dark grey to black shale coated with a white, yellow or orange patina. Generally, the beds consist of rusty-weathered, alternating shale (<1 cm thick) and chert (<10 cm thick). Due to the resistant nature of this lithology, the outcrop forms cliffs that weather light grey to tan and from a distance look like sandstone. In addition to having a distinctive sulphurous smell, gypsum crystals and pyrite nodules are common. In a number of localities, the outer surface of the shale has been burnt to moderate reddish-brown, presumably from forest fire activity. To date, dating of this shale has been hampered by the lack of pollen or spores found in samples.

The interbedded grey shale and sandstone of the 'Cf' map unit was observed on Caribou River, Noisy Creek (northern Mackenzie Mountains), and possibly the Road and Trail rivers, and is probably the same unit that Richards *et al.* (1997, p. 221) described as "cyclic, marine and nonmarine (deltaic) shale, siltstone, sandstone and coal". Palynological investigations of shale collected above the black shale on Caribou River suggest a late Famennian (Strunian) age (Utting, 2007), which is time equivalent to the Tuttle Formation. The sandstone is commonly fine to medium grained. In places it resembles the lithology of the Tuttle Formation (chert and quartz-rich), but in other areas appears more like the 'Mo' map unit (quartz with lesser chert and carbonate cement). On the Caribou River, sandstone beds are up to 1 m in thickness, and have sharp bases with load casts and flutes. Each sandstone package grades upwards from horizontally bedded fine to medium-grained sandstone, to rippled fine to very fine grained sandstone and siltstone. It is unclear how this interbedded shale and sandstone unit relates to the resistant black shale unit as no contacts between them were observed.

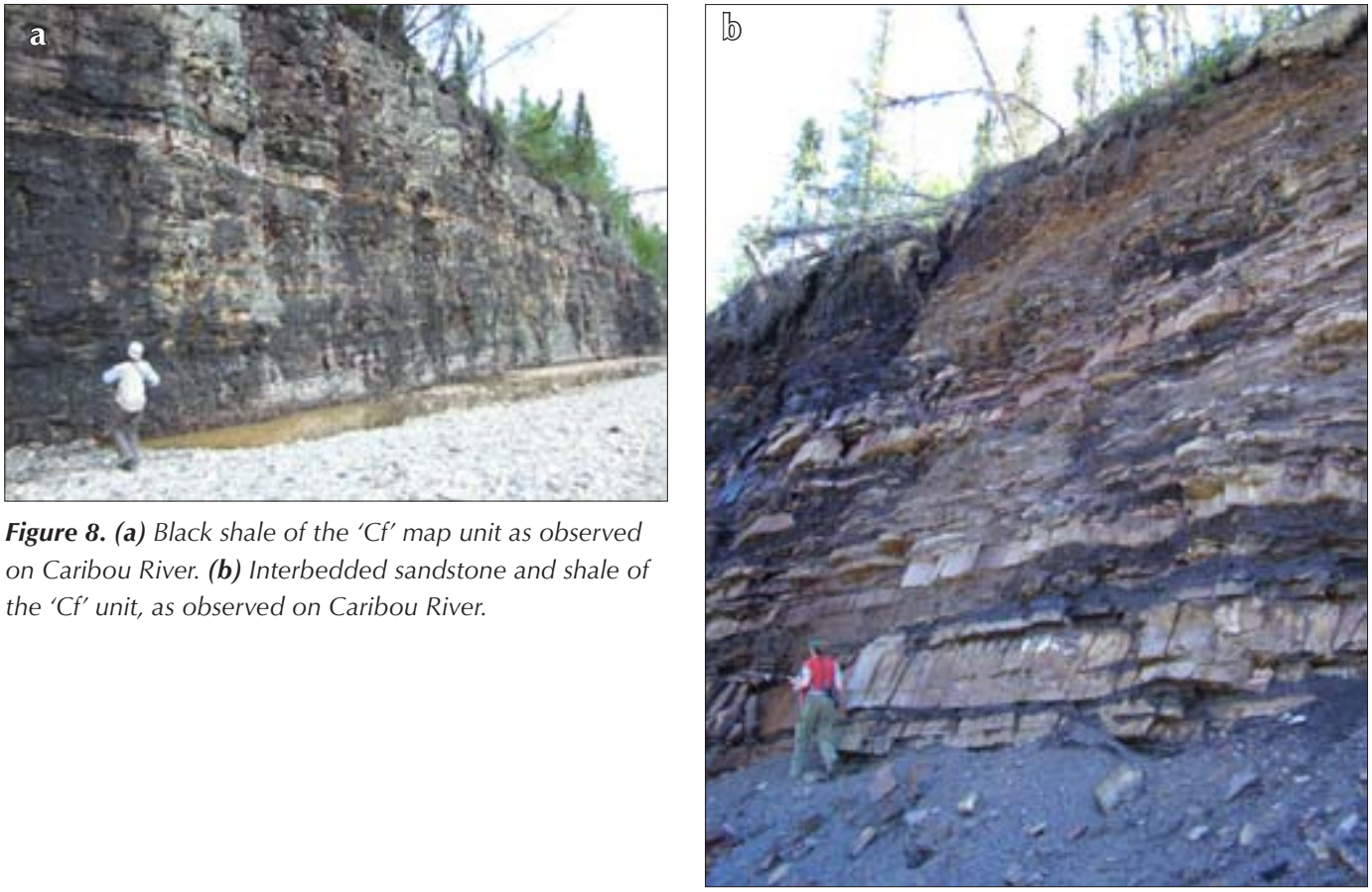

Figure 8. (a) *Black shale of the 'Cf' map unit as observed on Caribou River.* ***(b)*** *Interbedded sandstone and shale of the 'Cf' unit, as observed on Caribou River.*

HYDROCARBON POTENTIAL

As part of this study, shale of the Canol, Imperial and Tuttle formations as well as the 'Cf' and 'Mo' map units were analysed for source rock potential. The coarse-grained fractions of the Imperial and Tuttle formations and the 'Mo' map unit were examined for reservoir rock potential. Included in the results are sample values from both 2006 and 2007. Source rock potential results from 2006 were previously reported in Gal *et al.* (2007) as part of a compilation of data from the Peel region, including results from Yukon and Northwest Territories studies of strata ranging from Proterozoic to Cretaceous.

SOURCE ROCK GEOCHEMISTRY

Source rock potential is based on 124 outcrop samples collected from Upper Paleozoic stratigraphy in the eastern Richardson Mountains, western Peel Plateau, and northern Mackenzie Mountains. The Canol, Imperial and Tuttle formations as well as the 'Mo' and 'Cf' map units were sampled. Rock samples were pyrolyzed using Rock-Eval/TOC to evaluate the type of kerogen, amount of organic carbon and thermal maturity.

Analyses were conducted at the Organic Geochemistry Labs of the Geological Survey of Canada (GSC) Calgary on a Delsi Rock-Eval 6 unit equipped with a TOC analysis module. Results are displayed in Appendix I and Figure 9. The quantity of organic carbon is expressed as weight percent of rock of total organic carbon (TOC). Measured parameters derived from Rock-Eval pyrolysis reported below include S1, which represents milligrams of hydrocarbons that can be thermally distilled from 1 g of rock (mg HC/g rock); S2, which represents milligrams of hydrocarbons generated by pyrolytic degradation of the kerogen in 1 g of rock (mg HC/g rock); and T_{max} (°C) which corresponds to the oven temperature at which the maximum amount of S2 hydrocarbons is generated (Peters, 1986). Other parameters including hydrogen index (HI; S2/TOC x 100) and oxygen index (OI; S3/TOC x 100) are calculated from the measured values. For guidelines on interpreting Rock-Eval and TOC data, refer to Table I.

Table 1. *Rock-Eval interpretative guidelines (modified from Peters et al., 2005).*

Source rock generative potential			
Quality	**TOC (wt.%)**	**S1 (mg HC/g rock)**	**S2 (mg HC/g rock)**
poor	<0.5	<0.5	<0.25
fair	0.5-1	0.5-1	2.5-5
good	1-2	1-2	5-10
very good	2-4	2-4	10-20
excellent	>4	>4	>20
Type of hydrocarbon generated			
Kerogen	**HI (mg HC/g TOC)**	**S2/S3**	**Main product at peak maturity**
I	>600	>15	oil
II	300-600	10-15	oil
II/III	200-300	5-10	oil/gas
III	50-200	1-5	gas
IV	<50	<1	none
Level of thermal maturation			
Maturation	**T_{max} (°C)**	**Ro(%)**	
immature	<435	0.20-0.60	
top of oil window	~435-445*	0.60-0.65	
bottom of oil window	~470	1.35	
postmature	>470	>1.35	
	*varies with type of organic matter		

QUANTITY AND TYPE OF ORGANIC MATTER

Canol Formation

Total organic carbon (TOC) values for Canol Formation strata range from 2.41 to 6.92 wt.% with the exception of one sample that was 0.20 (average 4.21 wt.%; Fig. 9a), with hydrogen index (HI) values from 1 to 15 mg HC/g TOC and oxygen index (OI) values from 4 to 80 mg CO_2/g TOC. The type of organic matter for the Canol Formation could not be determined using the modified van Krevelen (HI versus OI) diagram (Fig. 10a) because values plot too low on this diagram to be meaningful (*i.e.*, indicating thermal maturation is too high; Peters, 1986). Vitrinite reflectance[1] of two samples indicates that Canol strata contain highly weathered amorphous kerogen. Canol Formation strata have a good to very good source rock potential.

[1]*Organic Geochemistry and Organic Petrology Labratory (OGOPet Lab), pers. comm., 2007. Coal Maceral and Vitrinite Reflectance Database (J. Reyes, analyst), Geoscience Data Repository, Earth Sciences Sector, Natural Resources Canada, Government of Canada.*

Imperial Formation

The Imperial Formation is less promising in terms of a source rock, with TOC values of 0.33 to 7.03 wt.% (average 2.18 wt.% (weight percent)) with almost 60% of the Imperial samples less than 1 wt.% (Fig. 9b). The Imperial Formation comprises type III, gas-prone kerogen, with HI values of 1 to 147 mg HC/g TOC and OI values of 3 to 145 mg CO_2/g TOC (Fig. 10b). Imperial Formation strata on Trail River contain reworked vitrinite particles[1]. The amount and type of TOC suggest that the Imperial Formation has fair to good source rock potential.

Tuttle Formation

TOC values for Tuttle Formation strata range from 0.28 to 40.25 wt.% , although typically the TOC ranges from 1 to 3 wt.% (Fig. 9c). The Tuttle Formation contains type II, oil- and gas-prone and type III, gas-prone kerogen, with HI values of 31 to 458 mg HC/g TOC, and OI values of 4 to 107 mg CO_2/g TOC (Appendix I and Fig. 10c). Tuttle strata on Road River are liptinite-rich with high amounts of sporinite and evidence of hydrocarbon fluid inclusions in

some quartz fractures[1], which supports a type II kerogen type. Bitumen, exudatinite and resinite are also present as well as reworked inertinite and pyrobitumen[1]. The unit has good to very good source rock potential for oil and gas. Oil-stained sandstone samples collected on Trail River have S1 values up to 6.8 mg/g rock.

'Mo' map unit

The 'Mo' map unit has TOC values ranging from 2.10 to 11.31 wt.% (average 4.17 wt.%), suggesting the strata are favourable in terms of source rock potential (Fig. 9d). The organic matter is type III, or gas-prone, based on the HI values (40 to 130 mg HC/g TOC) and OI values (7 to 34 mg CO_2/g TOC) (see Appendix I and Figure 10d.)

[1]*OGOPet Lab, 2007. Coal Maceral and Vitrinite Reflectance.*

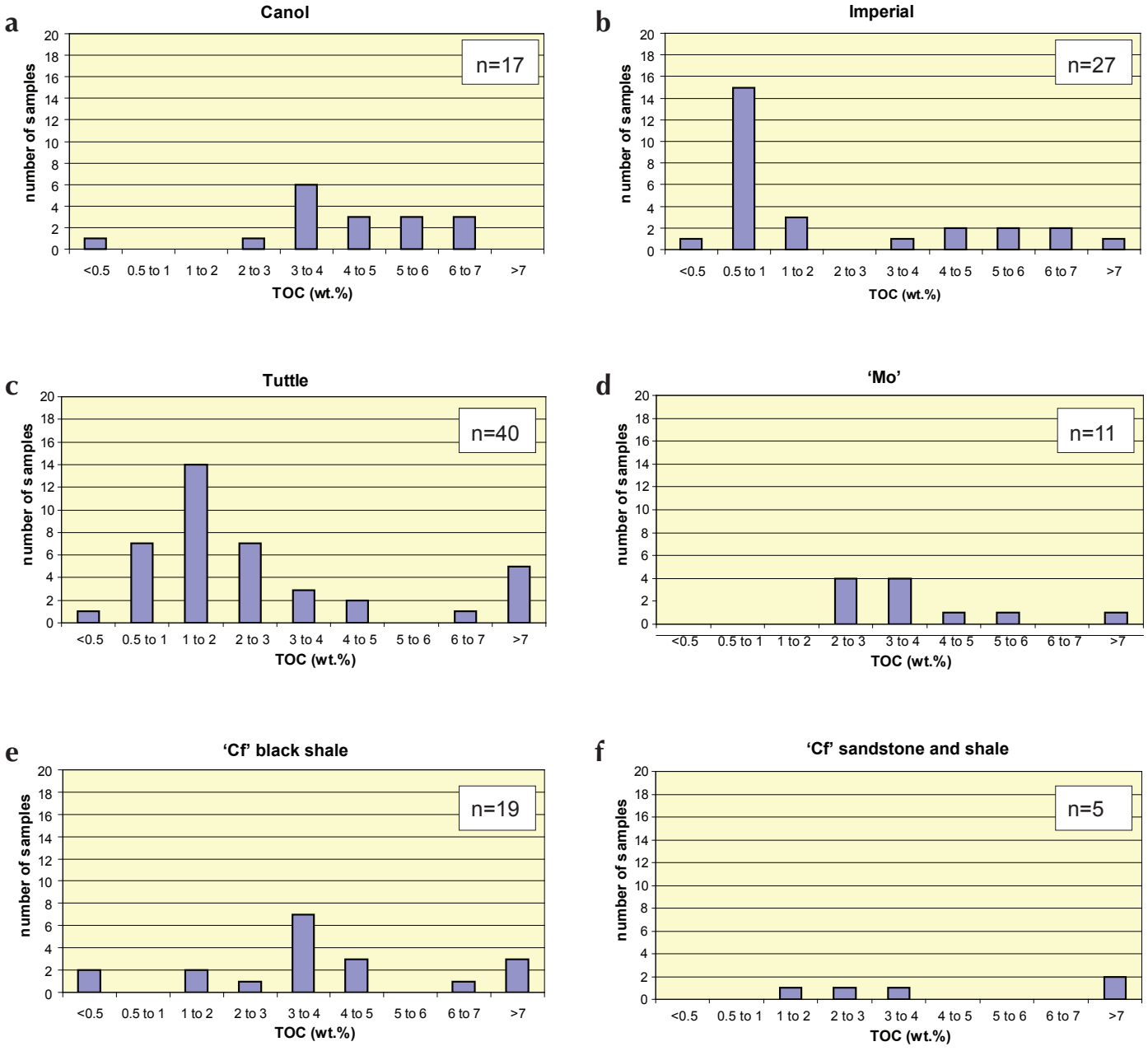

Figure 9 (a-f). *Total Organic Carbon content (TOC) by geological unit. See Table 1 for interpretative guidelines.*

'Cf' map unit

The 'Cf' map unit black shale contains high TOC values, ranging from 1.46 to 12.17 wt.% (average 4.15 wt.%; Fig. 9e). Organic matter within the 'Cf' black shale comprises type II, oil- and gas-prone kerogen, and type III, gas-prone kerogen, with HI values ranging from 26 to 326 mg HC/g TOC and OI values ranging from 3 to 500 mg CO_2/g TOC (Fig. 10e). Only two samples yielded OI values over 57. The 'Cf' black shale has good to very good source rock potential for oil and gas. S1 values for nine of the 'Cf' black shale samples are over 1 mg/g rock, also suggesting a good to excellent generative potential (Peters, 1986). TOC values for the 'Cf' interbedded sandstone and shale unit range from 1.19 to 12.43 wt.% (Fig. 9f), with HI values of 61 to 273 mg HC/g TOC and OI values of 3 to 31 mg CO_2/g TOC (see Appendix I and Fig.10f).

THERMAL MATURATION

T_{max} values can be used to estimate the level of thermal maturity of sedimentary sequences, however caution should be used with samples that have S2 values below 0.2 mg HC/g rock as they are unreliable due to the broad nature of their S2 peak (Peters, 1986). Thermal Alteration Index (T.A.I.) and vitrinite reflectance are also useful thermal maturity indicators. T.A.I. corresponds to maturity-induced colour changes in organic matter (miospores) under the microscope in transmitted light (Staplin, 1969). Vitrinite reflectance (R_o) was conducted by the Organic Geochemistry and Organic Petrology Laboratory at the GSC Calgary.

The overall maturity trend on the Trail River map sheet shows that the thermal maturity of geologic units increases from east to west towards the Richardson Mountains.

The Canol Formation along the eastern Richardson and northern Mackenzie mountains, the oldest strata examined in the study area, is within the dry gas zone in terms of hydrocarbon generation at surface. T_{max} values for the Canol Formation are largely unreliable as the S2 values are all below 0.2 mg HC/g rock (Peters, 1986). However, vitrinite reflectance results for Canol Formation strata (on Trail River) from the same section are 1.81%R_o, and indicate Canol strata are in the dry gas zone.

For the same region, the overlying Imperial Formation strata also lie within the dry gas zone. Here, T.A.I. values for all Imperial Formation samples submitted are consistently 3+/4- = R_o% 1.85[1] (dry gas zone) and a single vitrinite reflectance sample measured 1.58%R_o[2]. Spores identified by D.C. McGregor from the Imperial Formation on Trail River were black, indicating that they had undergone severe thermal alteration (Norris, 1997).

At surface, there appears to be a shift in the thermal maturity of the Tuttle Formation and 'Cf' strata compared to the underlying units, from the dry gas zone to the oil window. This may be a reflection of older strata (Canol and Imperial) having been subjected to greater burial depths, variations in the type of organic matter, or the shift may be related to the proximity to deformation along the mountains. Organic material in the Imperial and Tuttle formations includes common exinous, woody and coaly fragments[1], suggesting that the type of organic matter is not the reason for the abrupt change in thermal maturation values between the Imperial and Tuttle formations. The proximity to deformation along the Richardson Mountains is likely the explanation, as further to the south on the Peel River, as well as in subsurface to the east, Imperial strata are less thermally altered and are within the oil window.

Tuttle Formation strata range from thermally immature with respect to hydrocarbon generation to within the oil window. T.A.I. values for the Tuttle are all 2= R_o% 0.55[1] (oil window). These values are consistent with T_{max} values (403 to 460°C) and vitrinite reflectance results (0.61 to 0.65%R_o[2]. During our field investigations we collected a number of oil-stained sandstone samples from Trail River. Tuttle Formation strata consist of type II/III, oil- to gas-prone source rocks that at surface are just entering the oil window.

With the exception of samples from Peel River which are anomalous, the overlying and possibly time equivalent(?) 'Cf' map unit either ranks within the oil window or is just entering the oil window (*i.e.*, T_{max} values range from 432 to 444° and 431 to 438°C). These values are consistent with T.A.I results that are all 2= R_o% 0.55[1] (oil window) (Utting, 2007) and vitrinite reflectance values that are 0.65 to 0.78%R_o[2].

[1]*J. Utting, 2007. Palynological investigations.*

[2]*OGOPet Lab, 2007. Coal Maceral and Vitrinite Reflectance.*

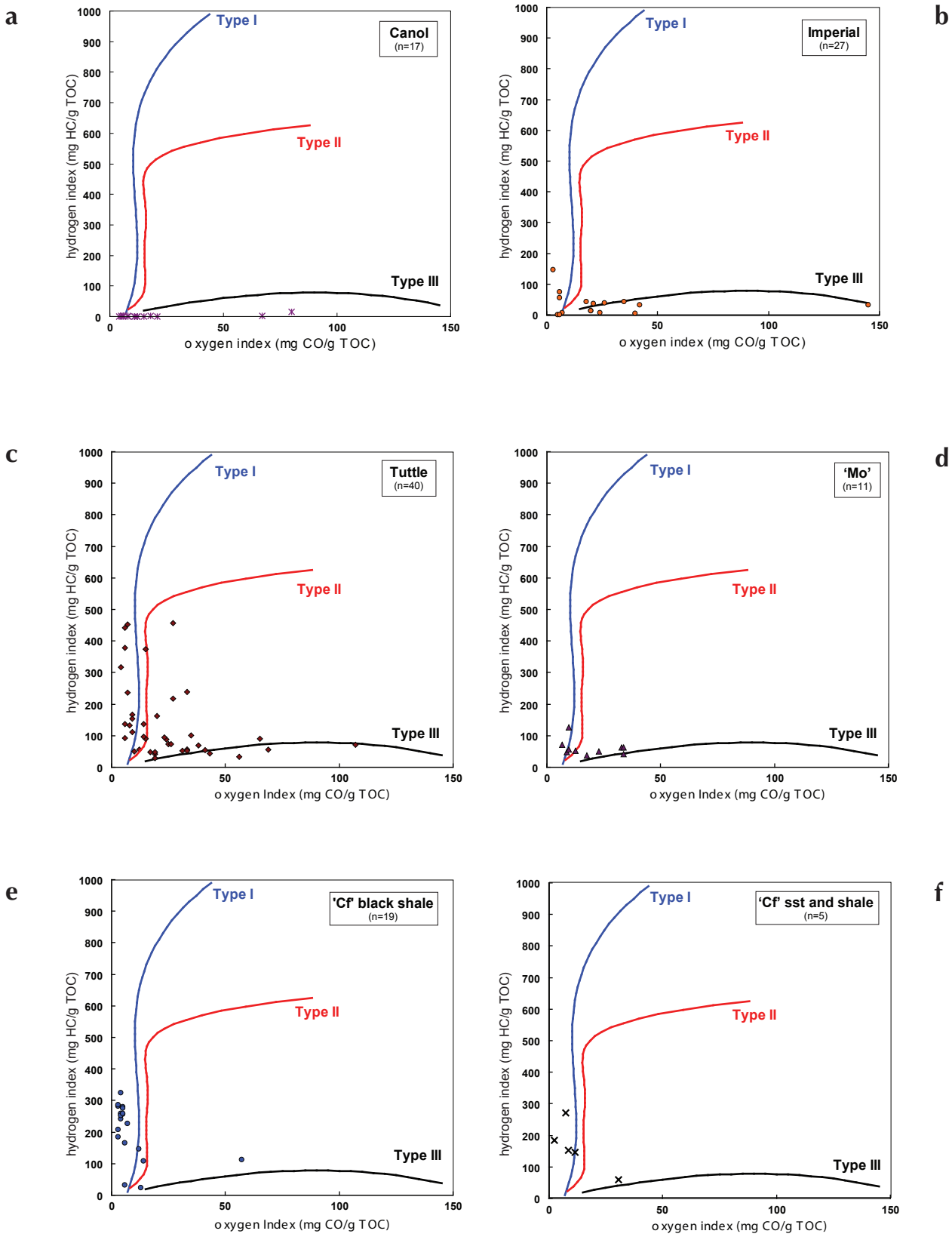

Figure 10 (a-f). *Hydrogen index (HI) versus oxygen index (OI) cross plots for each geologic unit examined. See Table 1 for interpretative guidelines.*

RESERVOIR ROCK POTENTIAL

Reservoir rock potential is based on coarse-grained outcrop samples of Imperial Formation, Tuttle Formation and the 'Mo' map unit analysed for determination of porosity and permeablility. Samples were submitted to AGAT Laboratories, Core Services Division in Calgary using standard procedures of AGAT Laboratories. All results are reported in AGAT Laboratories (2006; 2007)[1]. Thin sections, impregnated with blue epoxy to highlight porosity, were also examined for their detailed reservoir characteristics.

In addition to outcrop samples, eight subsurface samples from drill core were also examined for their reservoir rock potential. These samples were taken from the coarse-grained fraction of the Tuttle Formation. Six of these samples were taken from the Peel River Y.T. L-01 well, and one each from the Peel River Y.T. K-09 and Peel River Y.T. J-21 wells. Cored intervals in Peel wells are rare and these samples represent all available cored intervals from Upper Paleozoic formations in Yukon Peel region wells. These samples were made into thin sections, impregnated with blue epoxy, in order to examine lithology and porosity characteristics.

Imperial Formation

Imperial Formation sandstone observed in the eastern Richardson Mountains is very fine to fine-grained, and is characterized by quartz with minor chert lithology. Lab analysis of three outcrop samples show that the Imperial Formation has negligible porosity and permeability values (Fig. 11a). Thin-section analyses from five samples confirm the 'tight' nature of these sandstones. Depending upon the sample, porosity in Imperial Formation sandstone is restricted by a combination of the following: fused quartz grain boundaries with overgrowths; infill with silt and clay grains, as well as clay minerals; and calcite cement.

[1]*AGAT Laboratories, 2006. Final core analysis report: Outcrop samples miscellaneous locations. Prepared for the Yukon Geological Survey, File RC12795, 6 p.*
AGAT Laboratories, 2007. Final core analysis report: Whitehorse Yukon misc outcrop samples. Prepared for the Yukon Geological Survey, File RC30014, 6 p.

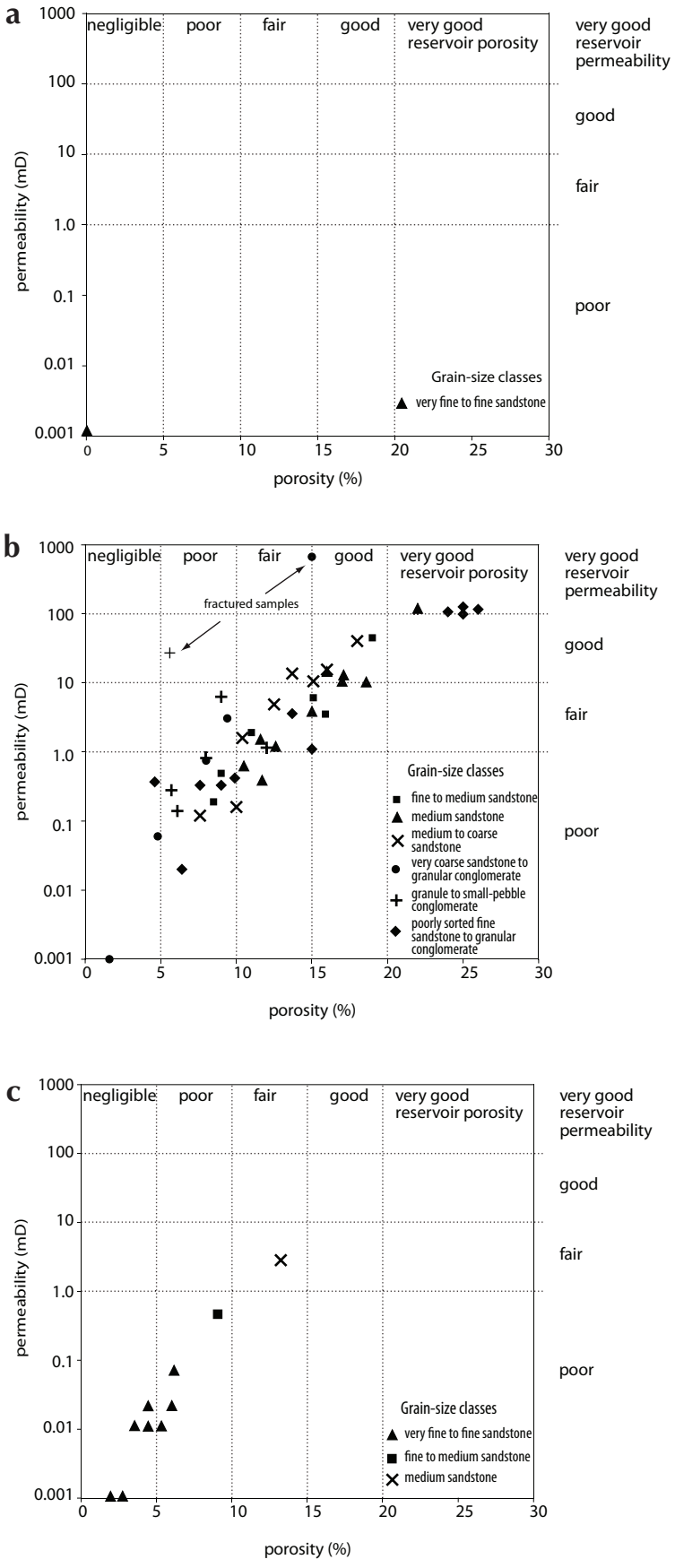

Figure 11. *Reservoir potential cross plots.* ***(a)*** *Imperial Formation,* ***(b)*** *Tuttle Formation, and* ***(c)*** *'Mo' map unit. Reservoir classes after Levson (2001).*

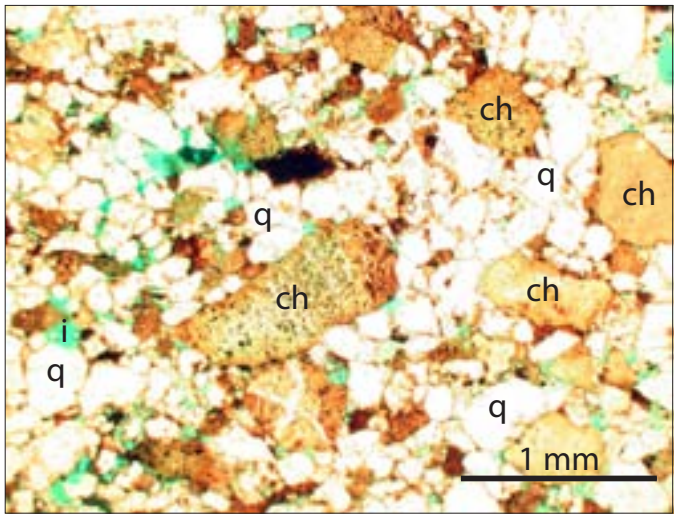

Figure 12. *Thin-section sample from the Tuttle Formation on Trail River. Chert (ch) in this sample is porous and is stained with hydrocarbons, in contrast to quartz (q) which is impermeable. There is also intergranular porosity in this sample (i).*

Tuttle Formation

The coarse fraction of the Tuttle Formation has a wide range of grain sizes ranging from fine-grained sandstone to small pebble conglomerate. Forty-six field samples, divided into six grain-size classes, were analysed for porosity and permeability with results plotted on Figure 11b. Porosity ranges from 2 to 26%, with permeability ranging between 0 and 127 mD. For the Tuttle Formation, reservoir potential based on porosity and permeability varies from negligible to very good using reservoir classes by Levorson (2001). From this cross-plot, it is apparent that grain size does not significantly influence porosity and permeability values. Thin-section analysis of Tuttle sandstones from outcrop show the presence of intergranular porosity as well as intragranular porosity within weathered chert grains (see discussion below). Oil-stained chert grains and what are likely small oil accumulations can be found in the pores of some Tuttle samples (Fig. 12). In samples with lower porosity, the quartz to chert ratio is higher, and primary porosity is commonly restricted by quartz overgrowths and infill by what appear to be clay minerals.

The eight Tuttle sandstone core samples were analysed using imaging software to determine an area percent of the thin section that is porous (*i.e.*, highlighted as blue when impregnated with epoxy). Eight photographs were made from each thin section, and an average porosity was determined for each sample. Results from this study are shown in Figures 13a, b and c.

Six sandstone samples were analysed from the Peel River Y.T. L-01 well between depths of 4455.8' and 4483.2' (1358.1 to 1366.5 m; Fig. 13a). Average porosity ranged from 11.1% to 24.0%. Average grain size over this interval is fine- to medium-grained sand. In samples with lower porosity, primary porosity appears to be restricted by quartz overgrowths, calcite cement, and fused grain boundaries. Fused grain boundaries are more abundant between quartz grains, rather than between chert grains. Where chert grains are fused with one another, the contact does not appear to be as tight as between a quartz-quartz contact, sometimes allowing a thin vein of porosity. In these zones of lower porosity, some stylolites can be observed. In areas of higher porosity, secondary porosity plays an important role, particularly due to the weathering of chert grains (Fig. 14). Chert grains weather both around their margins, as well as within their boundaries. The dissolution of these grains, combined with any primary porosity, appears to provide a well connected pore distribution thereby enhancing permeability.

Sandstone from the Peel River Y.T. K-09 well was sampled at a depth of 4391.5′ (1338.5 m) from a fine-grained sandstone (Fig. 13b). Average porosity was 7.9%. Porosity from this sample is mainly secondary from the dissolution of chert grains and includes both porosity within and between chert grains. In some cases, entire chert grains have been weathered, resulting in large pore spaces. This sample is generally well compacted with boundaries between quartz grains well fused. A small amount of porosity in this sample has been reduced by calcite cement.

One fine-grained sandstone sample was analysed from the Peel River Y.T. J-21 well at a depth of 2020.7′ (615.9 m; Fig. 13c). Average porosity from this sandstone was <3%. This sandstone was very well compacted with an abundance of fused grain boundaries both between chert and between quartz grains. The small amount of porosity that is observed is associated with the weathering of chert grains. This secondary porosity appears to be greatly reduced due to both calcite and siderite cement, found both within and between chert grains. This sample has a higher quartz to chert ratio than the other subsurface samples, and quartz overgrowths also play a role in porosity reduction.

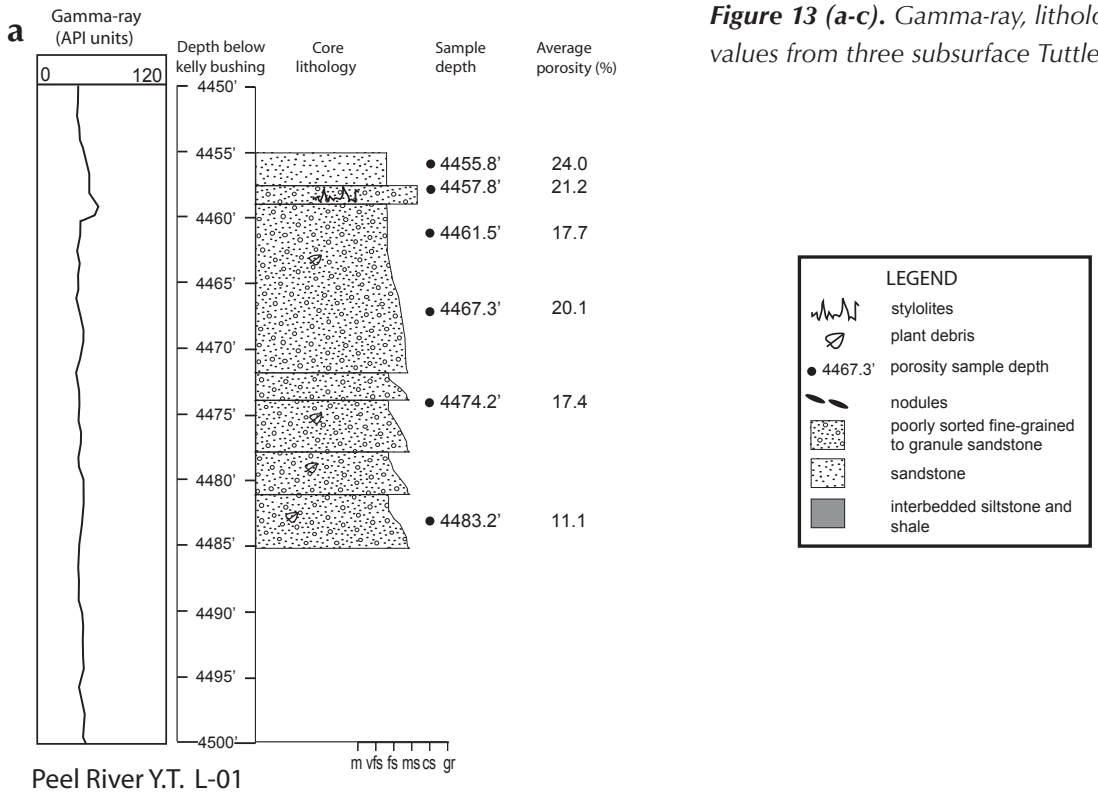

Figure 13 (a-c). *Gamma-ray, lithology log and porosity values from three subsurface Tuttle cores.*

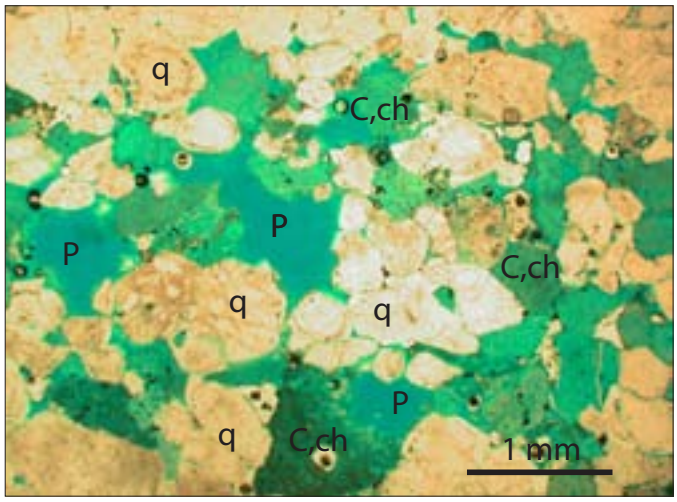

Figure 14. *Thin section of the Tuttle Formation demonstrating both intergranular (P) and intragranular (C) porosity. Tuttle sandstone typically consists of quartz (q) and chert (ch). The chert grains tend to be porous and locally contain hydrocarbons.*

From observation of both outcrop and subsurface samples, porosity within the Tuttle Formation is both intragranular and intergranular, both greatly influenced by the presence of weathered chert. The higher the percentage of chert, the greater the rock's ability to reduce the effects of quartz cementation, and to provide secondary porosity from weathering. As previously stated, weathered chert within the Tuttle Formation has been referred to as 'tripolitic' (Shell Canada Ltd., 1964). Our investigation shows that the presence of 'tripilotic chert' in the Tuttle Formation greatly enhances its reservoir capabilities.

'Mo' map unit

The 'Mo' map unit, is typically very fine to fine-grained in texture. Ten field samples were analysed for porosity and permeability with samples ranging from very fine to medium-grained sandstone. From the analyses conducted, reservoir characteristics of the 'Mo' are generally negligible to poor, with only one sample rating as fair (Fig. 11c). Porosity values ranged from 2 to 13%, with permeability ranging from 0 to 2.6 mD. On this cross-plot, grain size appears to influence reservoir characteristics with medium sandstone units having better reservoir prospects. Thin-section analysis of 'Mo' sandstone displays generally a well compacted quartz-rich sandstone with fused grain boundaries and minor porosity. Primary porosity, where present, is commonly reduced by quartz overgrowths, clay minerals, and/or calcite cement.

OIL STAINS AND HYDROCARBON SEEPS

Oil staining was noted in porous sandstone of the Tuttle Formation on Trail River, near the Trevor fault. These samples were not in outcrop, instead were scattered along the river bed below an active rock fall.

Oil-stained sandstone samples were stained dark brownish grey, very porous (16+%) and smelled strongly petroliferous (Fig. 15). Grain size of the samples ranged from fine to coarse, with sorting normally poor to moderate. These samples have been submitted to the Organic Geochemistry Laboratory at the GSC Calgary for analysis to determine the type of hydrocarbon present, the source rock for the hydrocarbons from the identification of biomarkers, and the thermal maturity.

In the vicinity of the Trevor fault zone on Trail River, there is a very strong sulphur smell in the air over several kilometres that can be detected from a helicopter. Figure 16a shows the surface expression of what appears to be Late Devonian to Early Mississippian Tuttle Formation sandstone thrust over possible Cretaceous shale (palynological dating from the shale is in progress). In the area, the Tuttle Formation sandstone is locally coated with a yellowish orange and white popcorn-like coating, particularly along fractures and joints (Fig. 16b). In addition, the rocks in the river are locally coated in a whitish-grey residue. This evidence suggests that there is a gas leak from the Trevor fault on Trail River. Continuing research into this phenomenon will be conducted in summer 2008.

Figure 15. *Tuttle Formation sandstone from Trail River exhibiting hydrocarbon staining. Unstained sandstone is on the far right of sample.*

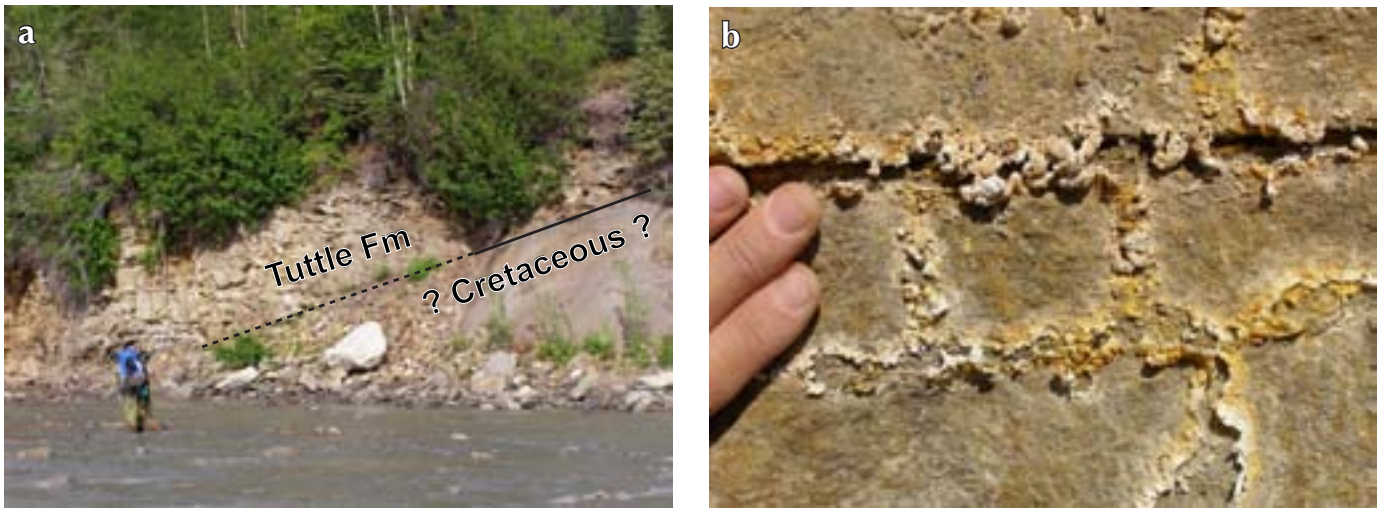

Figure 16. ***(a)*** *Surface expression of what may be the Trevor fault on Trail River. This view of the north side of the river shows Tuttle Formation sandstone thrust eastwards over probable Cretaceous shale.* ***(b)*** *Chemical and/or biological precipitate on Tuttle Formation outcrop in the Trevor fault zone, Trail River, indicating a possible gas leak.*

SUMMARY

The aim of the "Regional Geoscience Studies and Petroleum Potential, Peel Plateau and Plain" research project is to study the geology and hydrocarbon potential of the inter-territorial Peel region. This specific project is investigating the Upper Paleozoic geology and hydrocarbon potential in the Yukon portion of the study area. Other projects involved with this study are currently underway and can be viewed on the NWT Geoscience office website[1].

Upper Paleozoic geology in the Yukon Peel region consists of the Canol, Imperial and Tuttle formations, and 'Cf' and 'Mo' map units. These strata span the Late Devonian to Early Mississippian time interval. The Canol Formation is a basinal shale that is overlain by a siliciclastic sedimentary wedge derived from the Late Devonian Ellesmerian orogeny. Sediments of the clastic wedge include the Imperial and Tuttle formations, and overlying 'Cf' map unit in the eastern Richardson Mountains, Peel Plateau and northern Mackenzie Mountains. The 'Mo' map unit is also observed in the northern Mackenzie Mountains and may be the southern extension of the Tuttle Formation.

Shale from the Canol, Imperial and Tuttle formations, and 'Cf' and 'Mo' map units were analysed for source rock potential. All of these formations have good TOC values and thus have the ability of producing hydrocarbons under proper conditions. Thermal maturation analyses from outcrop indicate that the Canol and Imperial formations are post-mature to within the gas window, while the Tuttle Formation and 'Cf' unit are immature to within the oil window.

Sandstone from the Imperial and Tuttle formations, and 'Mo' map unit were analysed for reservoir rock potential including porosity and permeability. Conglomerate of the Tuttle Formation was also included in this analysis. Based on this study, the Tuttle Formation has the best reservoir potential, especially when it contains a substantial proportion of tripolitic (porous) chert. Reservoir potential of Tuttle surface samples ranged from negligible to very good, with values in some samples exceeding 25% porosity and 100 mD for permeability. Subsurface porosity values from the Peel River Y.T. L-01 well range from 11 to 24% from Tuttle Formation core. From the northern Mackenzie Mountains, the 'Mo' map unit has fair reservoir potential at best, with better prospects in medium-grained sandstone as opposed to fine or very fine. The Imperial Formation has no reportable reservoir properties from samples obtained in the east Richardson Mountains and Yukon portion of the northern Mackenzie Mountains.

Further studies in the Peel region are recommended, including detailed bedrock mapping and structure analysis. A number of questions remained unanswered concerning the distribution and variability of the 'Cf' map

[1]*www.nwtgeoscience.ca/petroleum/PeelPlateau.html*

unit, and the relationship of the 'Mo' map unit to the Tuttle Formation. The strata along the northern Mackenzie Mountains appear to be much more complex than mapped during Operation Porcupine (Norris, 1982a,b). Further fieldwork is warranted in order to sort out the stratigraphy and distribution of units in this area.

ACKNOWLEDGEMENTS

We would like to thank International KRL Resources Corporation and Cash Minerals for helicopter and camp support during the 2007 field season. We are extremely thankful for their generosity. We also received helicopter support in the northern Mackenzie Mountains from the Polar Continental Shelf Project. We would also like to acknowledge Prism Helicopters, as well the scientists at GSC Calgary for their expertise and help with many aspects of this project.

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APPENDIX 1: Rock-Eval/TOC data

													NAD83, Zone 8	
Sample	Formation	T_{max} (°C)	VR	TAI	S1	S2	S3	PI	S2/S3	TOC	HI	OI	UTME	UTMN
06TNT-TR-001A	Canol	610			0.02	0.04	0.42	0.31	0.10	5.33	1	8	478123	7366448
06TNT-TR-002	Canol	609			0.01	0.06	0.50	0.21	0.12	4.06	1	12	478147	7366501
06TNT-TR-003	Canol	424	1.8		0.02	0.02	0.78	0.40	0.03	3.75	1	21	478153	7366536
06TNT-TR-004	Canol	488			0.01	0.06	0.65	0.17	0.09	4.39	1	15	478147	7366501
06TNT-TR-024B	Canol	610			0.01	0.05	0.42	0.17	0.12	3.70	1	11	477802	7366192
06TNT-TR-024C	Canol	610			0.02	0.08	0.28	0.20	0.29	5.05	2	6	477802	7366192
06TNT-TR-024E	Canol	609			0.01	0.12	0.31	0.09	0.39	5.63	2	6	477887	7366189
06TNT-TR-024G	Canol	609			0.01	0.03	0.39	0.26	0.08	3.34	1	12	477989	7366393
06TNT-TR-024I	Canol	609			0.01	0.16	1.13	0.06	0.14	6.19	3	18	478054	7366379
06TNT-TR-024K	Canol	610	1.81		0.03	0.10	0.33	0.26	0.30	6.25	2	5	478119	7366453
07TNT-RR-14A	Canol	422			0.01	0.03	0.16	0.24	0.19	0.20	15	80	475322	7385986
07TNT-RR-14B	Canol	607			0.02	0.06	1.62	0.24	0.04	2.41	2	67	475322	7385986
07TNT-SR-40A	Canol	608			0.01	0.06	0.53	0.19	0.11	4.94	1	11	551078	7270060
07TNT-SR-40B	Canol	607			0.02	0.09	0.25	0.20	0.36	6.92	1	4	572154	7267463
07TNT-SR-41A	Canol	607			0.02	0.05	0.18	0.23	0.28	3.08	2	6	571692	7270748
07TNT-SR-41B	Canol	607			0.01	0.03	0.19	0.23	0.16	3.16	1	6	571679	7270744
07TNT-SR-41C	Canol	607			0.02	0.05	0.24	0.24	0.21	3.18	2	8	571679	7270744
07TNT-SR-41D	Canol/ Imperial?	607			0.01	0.04	0.13	0.13	0.31	1.39	3	9	571634	7270745
07TNT-SR-41F	Canol/ Imperial?	607			0.01	0.04	0.15	0.16	0.27	1.87	2	8	571634	7270745
06TNT-TR-007	Imperial	594			0.01	0.07	0.35	0.07	0.20	0.76	9	46	478543	7366649
06TNT-TR-008	Imperial	324			0.13	0.18	1.58	0.43	0.11	6.41	3	25	478489	7366667
06TNT-TR-009	Imperial	606			0.01	0.06	0.27	0.11	0.22	1.11	5	24	478545	7366689
06TNT-TR-010	Imperial	602			0.00	0.05	0.17	0.03	0.29	0.73	7	23	478605	7366713
06TNT-TR-011	Imperial	428		3+/4-	0.02	0.04	0.88	0.37	0.05	6.98	1	13	478711	7366788
06TNT-TR-012A	Imperial	607		3+/4-	0.02	0.44	0.46	0.04	0.96	7.03	6	7	481330	7370081
06TNT-TR-012D	Imperial	546			0.00	0.11	0.20	0.04	0.55	0.62	18	32	481404	7370113
06TNT-TR-012F	Imperial	555		3+/4-	0.00	0.12	0.78	0.03	0.15	0.77	16	101	481439	7370117
06TNT-TR-013A	Imperial	540		3+/4-	0.01	0.16	0.35	0.07	0.46	0.80	20	44	481618	7370239
06TNT-TR-013B	Imperial	554	1.58		0.01	0.14	0.49	0.04	0.29	0.73	19	67	481469	7370231
06TNT-TR-013E	Imperial	540			0.01	0.13	0.17	0.05	0.76	0.64	20	27	481778	7370230
06TNT-TR-013F	Imperial	539		3+/4-	0.00	0.06	0.08	0.06	0.75	0.33	18	24	481790	7370212
06TNT-PR-032A	Imperial	480			0.05	0.31	1.44	0.15	0.22	0.99	31	145	515914	7315451
06TNT-PR-032B	Imperial	431	0.7		2.48	2.93	0.23	0.46	12.74	3.94	74	6	515914	7315451
06TNT-PR-032C	Imperial	438			1.06	2.82	0.30	0.27	9.40	5.07	56	6	515914	7315451
06TNT-PR-035A	Imperial	443		2	1.78	6.20	0.14	0.22	44.29	4.22	147	3	518634	7317560
07TNT-TR-01C	Imperial	494			0.03	0.39	0.27	0.07	1.44	1.03	38	26	482781	7370653
07TNT-TR-01D	Imperial	496			0.02	0.44	0.26	0.04	1.69	1.22	36	21	482807	7370647
07TNT-TR-01E	Imperial	485			0.02	0.24	0.20	0.07	1.20	0.57	42	35	482922	7370654
07TNT-TR-02B	Imperial	602			0.01	0.07	0.24	0.09	0.29	0.99	7	24	479871	7368934
07TNT-RR-15A	Imperial	577			0.00	0.09	0.15	0.04	0.60	0.75	12	20	480166	7387921
07TNT-TET-22A	Imperial	581			0.01	0.10	0.17	0.06	0.59	0.86	12	20	477777	7399240
07TNT-TET-23A	Imperial	605			0.00	0.02	0.23	0.12	0.09	0.57	4	40	472740	7400219
07TNT-TR-33A	Imperial	484			0.01	0.33	0.14	0.04	2.36	0.77	43	18	492785	7379035
07TNT-TR-33C	Imperial	483			0.01	0.22	0.30	0.04	0.73	0.72	31	42	483012	7370833

Appendix 1 continued

													NAD83, Zone 8	
Sample	Formation	T_{max} (°C)	VR	TAI	S1	S2	S3	PI	S2/S3	TOC	HI	OI	UTME	UTMN
07TNT-SRT-42A	Imperial	608			0.01	0.06	0.24	0.16	0.25	4.86	1	5	571448	7275031
07TNT-SRT-42B	Imperial	607			0.01	0.06	0.35	0.12	0.17	5.47	1	6	571441	7275024
06TNT-TR-014A	Tuttle	451		2	0.05	0.36	0.43	0.13	0.84	0.62	58	69	483250	7371104
06TNT-TR-014C	Tuttle	447			0.02	0.30	0.13	0.06	2.31	0.67	45	19	483250	7371104
06TNT-TR-014G	Tuttle	451		2	0.19	4.84	0.36	0.04	13.44	4.22	115	9	483250	7371104
06TNT-TR-015J	Tuttle	457			0.02	0.56	0.31	0.03	1.81	1.00	56	31	483445	7371302
06TNT-TR-015K	Tuttle	451			0.01	0.21	0.30	0.02	0.70	0.28	75	107	483479	7371292
06TNT-TR-016A	Tuttle	435		2	0.45	20.57	0.26	0.02	79.12	6.42	320	4	483552	7371310
06TNT-TR-016C	Tuttle	437			0.07	3.51	0.21	0.02	16.71	2.59	136	8	483552	7371310
06TNT-TR-016-2	Tuttle	434	0.61		0.05	2.05	0.55	0.02	3.73	2.29	90	24	483570	7371318
06TNT-TR-017A	Tuttle	437		2	0.10	1.93	0.45	0.05	4.29	1.98	97	23	484937	7372301
06TNT-TR-017C	Tuttle	432			0.07	2.52	0.26	0.03	9.69	1.80	140	14	484937	7372301
06TNT-TR-019E	Tuttle	430	0.61	2	0.10	10.71	3.62	0.01	2.96	10.37	103	35	483971	7391104
06TNT-RR-191	Tuttle	451			0.04	0.89	0.53	0.05	1.68	2.86	31	19	483971	7391104
06TNT-RR-019K	Tuttle	434		2	0.01	1.57	0.50	0.01	3.14	2.03	77	25	483995	7391125
06TNT-RR-020A	Tuttle	430		2	0.04	2.22	0.15	0.02	14.80	2.33	95	6	484113	7391184
06TNT-RR-020B	Tuttle	424			0.09	1.45	0.49	0.06	2.96	2.92	50	17	484090	73911172
06TNT-RR-020C	Tuttle	423		2	0.06	1.00	0.19	0.06	5.26	1.94	52	10	484090	73911172
06TNT-RR-020F	Tuttle	430			0.04	2.14	0.10	0.02	21.40	1.54	139	6	484066	7391159
06TNT-RR-020H	Tuttle	425		2	0.91	64.15	7.92	0.01	8.10	29.30	219	27	484059	7391144
06TNT-RR-020H	Tuttle	424		2	0.73	66.60	7.85	0.01	8.48	40.25	165	20	484059	7391144
06TNT-RR-020M	Tuttle	427			0.11	1.21	1.86	0.09	0.65	3.35	36	56	484061	7391137
06TNT-RR-020O	Tuttle	426			0.28	24.07	16.90	0.01	1.42	26.18	92	65	484061	7391137
06TNT-RR-020O	Tuttle	429	0.65		0.27	26.49	14.05	0.01	1.89	37.40	71	38	484061	7391137
06TNT-RR-020S	Tuttle	437			0.08	0.73	0.28	0.10	2.61	1.46	50	19	484055	7391159
06TNT-RR-020V	Tuttle	428		2	0.02	1.45	0.49	0.02	2.96	1.92	76	26	484041	7391150
06TNT-RR-028A	Tuttle?	440		2	0.02	0.49	0.25	0.03	1.96	0.77	64	32	485951	7391245
06TNT-TR-029A	Tuttle	425	0.51		0.05	0.81	0.16	0.06	5.06	1.37	59	12	490861	7369955
06TNT-TR-029C	Tuttle	425		2	0.17	8.55	0.24	0.02	35.63	3.60	238	7	490861	7369955
06TNT-TR-030A	Tuttle	409			4.03	3.57	0.14	0.53	25.50	0.95	376	15	494000	7372110
07TNT-TR-01H	Tuttle	449			0.10	0.32	0.18	0.23	1.78	0.54	59	33	483303	7370860
07TNT-TR-01I	Tuttle	451			0.08	0.35	0.32	0.20	1.09	0.74	47	43	483303	7370860
07TNT-TR-03A	Tuttle	403			6.73	5.63	0.09	0.54	62.56	1.48	380	6	492479	7371153
07TNT-TR-03E	Tuttle	437			0.02	0.92	0.56	0.02	1.64	1.71	54	33	492374	7371087
07TNT-TR-03F	Tuttle	434			0.01	0.52	0.37	0.02	1.41	0.90	58	41	492374	7371087
07TNT-TR-05D	Tuttle	412			6.39	6.38	0.09	0.50	70.89	1.44	443	6	494063	7372007
07TNT-TR-05F	Tuttle	419			1.88	2.84	0.17	0.40	16.71	0.62	458	27	494049	7371914
07TNT-TR-05H	Tuttle	427			0.08	6.91	0.36	0.01	19.19	4.09	169	9	493706	7371672
07TNT-TR-05J	Tuttle	410			6.80	7.06	0.11	0.49	64.18	1.55	455	7	493706	7371672
07TNT-TR-06C	Tuttle/ Cretaceous?	433			0.05	1.78	0.33	0.02	5.39	1.28	139	26	494382	7372458
07TNT-RR-16A	Tuttle? Cf?	426			0.12	2.06	0.11	0.06	18.73	2.26	91	5	484649	7391140
07TNT-NTR-20A	Tuttle	427			0.03	2.09	0.12	0.02	17.42	1.34	156	9	479769	7404483
07TNT-NTR-20B	Tuttle	428			0.15	5.05	0.70	0.03	7.21	2.09	242	33	479713	7404507
07TNT-TET-21A	Tuttle	437			0.06	1.21	0.20	0.05	6.05	1.31	92	15	482352	7400500

Appendix 1 continued

Sample	Formation	T_{max} (°C)	VR	TAI	S1	S2	S3	PI	S2/S3	TOC	HI	OI	NAD83, Zone 8 UTME	NAD83, Zone 8 UTMN
07TNT-TET-21B	Tuttle	447			0.04	1.29	0.18	0.03	7.17	1.29	100	14	482286	7400408
07TNT-MOR-39A	Mo	443			0.14	2.84	0.15	0.05	18.93	2.10	135	7	546139	7350603
07TNT-SR-43A	Mo	468			0.08	2.13	0.39	0.04	5.46	4.21	51	9	571857	7279283
07TNT-SR-43B	Mo	470			0.10	1.43	0.24	0.06	5.96	2.38	60	10	571852	7279389
07TNT-MOR-46C	Mo	451			0.11	1.89	0.95	0.06	1.99	2.86	66	33	553978	7270171
07TNT-MOR-46F	Mo	454			0.36	2.61	1.32	0.12	1.98	3.93	66	34	554160	7270376
07TNT-SR-47E	Mo	470			0.15	3.79	0.34	0.04	11.15	5.22	73	7	571857	7279365
07TNT-SR-47H	Mo	469			0.10	1.49	0.36	0.06	4.14	2.69	55	13	571852	7279389
07TNT-SR-47I	Mo	464			0.16	14.72	1.11	0.01	13.26	11.31	130	10	571855	7279532
07TNT-SR-47L	Mo	473			0.24	1.78	1.34	0.12	1.33	3.93	45	34	571840	7279585
07TNT-SR-47M	Mo	476			0.26	1.75	0.76	0.13	2.30	3.36	52	23	571843	7279614
07TNT-MO-50A	Mo	480			0.10	1.54	0.71	0.06	2.17	3.89	40	18	581624	7270239
06TNT-CC-026B	Cf	443			0.48	5.30	0.08	0.08	66.25	2.54	209	3	523198	7325395
06TNT-CC-026C	Cf	444			2.37	11.37	0.19	0.17	59.84	4.04	281	5	523163	7325414
06TNT-CC-026D	Cf	441			2.18	9.87	0.12	0.18	82.25	3.47	284	3	523163	7325414
06TNT-CC-026E	Cf	441			2.27	8.08	0.13	0.22	62.15	3.10	261	4	523225	7325515
06TNT-CC-026G	Cf	436			1.42	31.45	0.64	0.04	49.14	12.17	258	5	523295	7325620
06TNT-CC-026I	Cf	437			0.01	0.05	0.24	0.17	0.21	0.07	71	343	523167	7325671
06TNT-CC-026J	Cf	440	0.65		1.47	21.18	0.64	0.06	33.09	9.24	229	7	523167	7325671
06TNT-CC-026K	Cf	443		2	1.59	21.03	0.36	0.07	58.42	8.64	243	4	523167	7325671
06TNT-PR-033A	Cf	497		2	0.27	1.56	0.28	0.15	5.57	4.54	34	6	529110	7314150
06TNT-PR-033B	Cf	574	0.78		0.10	1.03	0.50	0.09	2.06	3.89	26	13	529110	7314150
06TNT-PR-033C	Cf	354			0.01	0.05	0.15	0.18	0.33	0.03	167	500	529110	7314150
07TNT-TR-04A	Cf	432			0.05	1.60	0.20	0.03	8.00	1.46	110	14	487862	7371005
07TNT-CR-12A	Cf	439			0.79	8.87	0.13	0.08	68.23	3.51	253	4	507992	7344887
07TNT-CC-27A	Cf	438			0.46	10.27	0.36	0.04	28.53	6.10	168	6	526761	7327329
07TNT-TT-32A	Cf	432			0.10	1.69	0.85	0.06	1.99	1.48	114	57	492785	7379035
07TNT-ACH-34A	Cf	441			2.51	12.79	0.12	0.16	106.58	4.46	287	3	512804	7328585
07TNT-ACH-34B	Cf	438			3.89	10.38	0.17	0.27	61.06	3.73	278	5	512907	7328592
07TNT-ACH-34B	Cf	444			5.07	10.74	0.13	0.32	82.62	3.29	326	4	512907	7328592
07TNT-ACH-34C	Cf	437			1.12	8.13	0.14	0.12	58.07	3.11	261	5	512907	7328592
06TNT-CR-031A	unnamed shale	431		2	0.10	4.52	0.37	0.02	12.22	3.07	147	12	512994	7344407
06TNT-CR-031C	unnamed shale	433	0.67		0.65	16.21	0.29	0.04	55.90	8.69	187	3	512994	7344407
07TNT-TR-10A	unnamed shale	438			0.06	0.72	0.37	0.08	1.95	1.19	61	31	496967	7347199
07TNT-CR-11A	unnamed shale	436			0.09	3.30	0.20	0.03	16.50	2.13	155	9	501997	7347100
07TNT-CR-11B	unnamed shale	431			0.98	33.99	0.97	0.03	35.04	12.43	273	8	501997	7347100

New stratigraphic and provenance studies of Triassic sedimentary rocks in Yukon and northern British Columbia

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ABSTRACT

New fieldwork investigating the provenance and stratigraphic setting of Triassic sedimentary rocks in the northern Cordillera focused on previously documented, but largely unstudied, exposures overlying the Yukon-Tanana, Slide Mountain and Cassiar terranes. We report on the lithologies observed and samples collected from the Sheldon Lake, Quiet Lake and Glenlyon map areas of Yukon, and McDame map area of northern British Columbia. Our research goal is to characterize sediment source regions in the Triassic and constrain early Mesozoic basin development in the northern Cordillera. We interpret the Triassic sedimentary evolution in Yukon and northern British Columbia to be intimately tied to collision of the Yukon-Tanana terrane with the ancient Pacific margin by closing of the Slide Mountain ocean. Our new samples collected from Middle to Late Triassic strata will further constrain that collisional event and add to the database that consists mainly of Early to Middle Triassic miogeoclinal rocks.

RÉSUMÉ

De nouvelles études ont été menées sur le terrain pour connaître l'origine et le cadre stratigraphique des roches sédimentaires triasiques du nord de la Cordillère. Elles étaient axées sur des affleurements reposant sur les terranes de Yukon-Tanana, de Slide Mountain et de Cassiar, affleurements qui ont été précédemment répertoriés mais peu étudiés. Le présent rapport a pour objet les lithologies observées et les échantillons prélevés dans les zones cartographiques du lac Sheldon, du lac Quiet et de Glenlyon, au Yukon, ainsi que dans celle de McDame, dans le nord de la Colombie-Britannique. Nos travaux de recherche visent à caractériser les régions d'origine des sédiments triasiques et à délimiter la formation de bassin pendant le Mésozoïque précoce, dans le nord de la Cordillère. Notre interprétation suppose que l'évolution sédimentaire triasique au Yukon et dans le nord de la Colombie-Britannique est intimement liée à la collision survenue entre le terrane de Yukon Tanana et l'ancienne marge du Pacifique pendant la fermeture de l'océan de Slide Mountain. Les nouveaux échantillons que nous avons prélevés dans des strates datant du Trias moyen à tardif permettront de mieux délimiter cette collision et d'alimenter la base de données portant surtout sur des roches miogéoclinales datant du Trias précoce à moyen.

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INTRODUCTION

In Yukon, Triassic sedimentary rocks occur both as miogeoclinal strata in depositional contact with the North American autochthon (and parautochthonous Cassiar terrane) and as disparate sections in depositional, structural, or ambiguous contact with rocks of the Yukon-Tanana (YTT) and Slide Mountain (SMT) terranes (*e.g.,* Gordey and Anderson, 1993; Roots *et al.*, 2002; Colpron *et al.*, 2005, 2006a). Traditionally, Triassic rocks assigned to the Yukon miogeocline are interpreted to be part of the Western Canada Sedimentary Basin, a westward-thickening package of mixed siliciclastic-carbonate strata that bridge late Paleozoic passive margin sedimentation and Jurassic collisional tectonism in the northern Cordillera (Davies, 1997; Monger and Price, 2002). However, field studies and provenance analyses on Triassic sedimentary rocks since summer 2005 suggest that these strata have a partial source from the YTT and SMT, which lie to the west of the Selwyn basin (Beranek and Mortensen, 2006, 2007). In these earlier reports, we interpreted YTT-derived detritus in the Selwyn basin to indicate mid- to Late Permian partial or full closure of the Slide Mountain ocean, a backarc basin that separated the YTT from the western margin of North America (Colpron *et al.*, 2006a). Subsequently, Permo-Triassic collision between the YTT and Cordilleran margin and emplacement of the YTT onto North America loaded the margin, providing accommodation space in the form of a peripheral foreland basin. This collisional basin was probably active until Middle Triassic time, when it transitioned into an overlap assemblage, blanketing the YTT, SMT and North American margin.

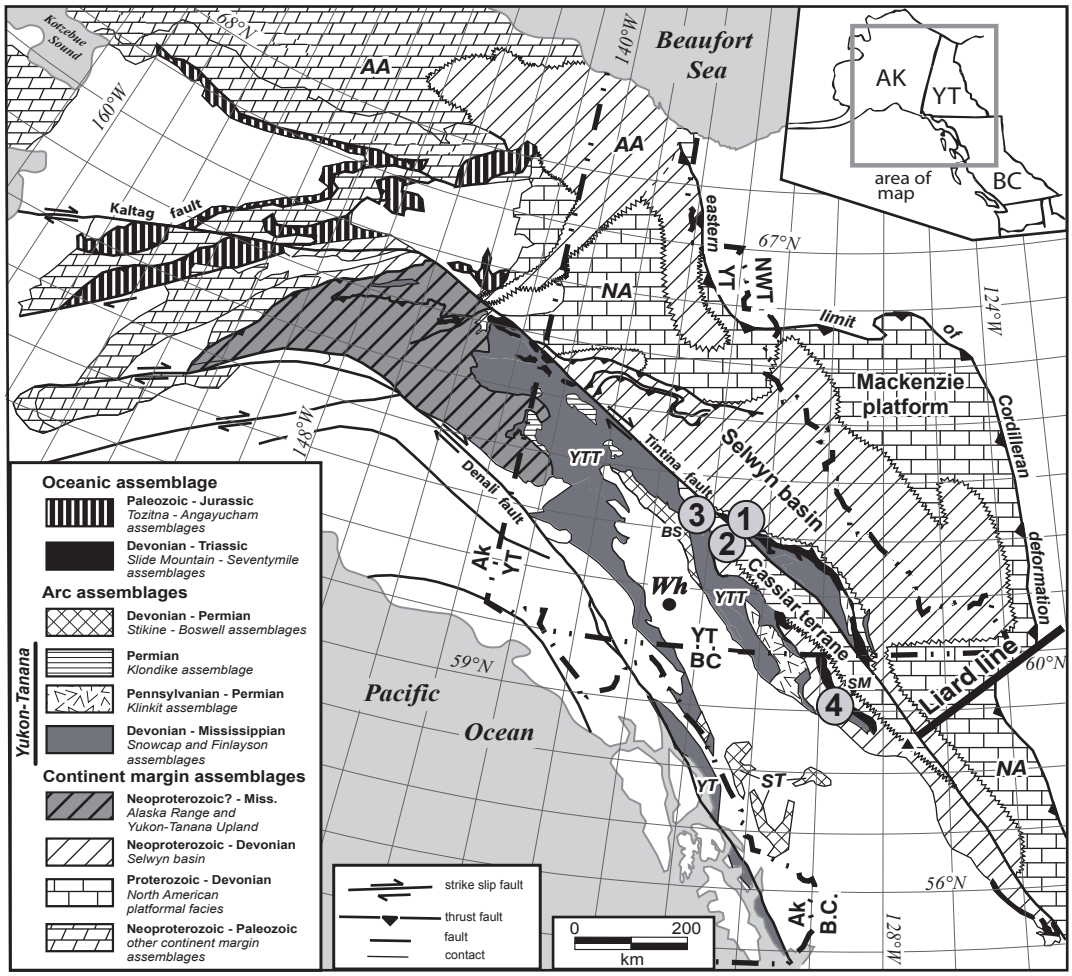

Figure 1. *Early Paleozoic to early Mesozoic tectonic assemblages of the northern Canadian and Alaskan Cordillera. YT = Yukon Territory; BC = British Columbia; NWT = Northwest Territories; Ak. = Alaska; Wh. = Whitehorse; YTT = Yukon-Tanana terrane; SM = Slide Mountain terrane; BS = Boswell assemblage; ST = Stikine assemblage; NA = North American miogeocline; AA = Arctic Alaska. Modified from Colpron et al. (2006a).*

In this report, we document new stratigraphic observations and provenance sampling studies conducted in summer 2007, the final stage of our three-year project investigating Triassic sedimentary rocks of the northern Cordillera. Our new collections add to a suite of Triassic samples from the Selwyn basin and Cassiar terrane (Beranek and Mortensen, 2006, 2007). Research in summer 2007 focused on Late Triassic exposures of the YTT, SMT and Cassiar terrane, complementing our database from 2005 and 2006 that mainly sampled Early to Middle Triassic strata.

TRIASSIC SAMPLE LOCALITIES

SHELDON LAKE MAP AREA

In the southwestern Sheldon Lake (NTS 105J) map area, northeast of the Tintina fault, Triassic sedimentary rocks lie in fault contact with the Cretaceous South Fork volcanics and the early Paleozoic Road River and Earn groups (Gordey and Irwin, 1987). We visited one locality approximately 50 km northeast of Ross River and 10 km south of Tay Lake (location 1 on Fig. 1; Fig. 2). Exposure of Triassic and older strata in this area is limited due to vegetation, and restricted to the south side of a east-trending drainage south of the Connolly caldera (Fig. 3a).

Triassic rocks at this location are predominantly light grey-weathering, grey, thickly bedded, parallel to wavy- to ripple cross-laminated, silty to sandy to bioclastic limestone (Figs. 3b and c). Minor recessive shale and siltstone can also be observed from subcrop. Conodont collections from these limestones are Late Triassic (Carnian-Norian; Orchard, 2006; compilation by S. Gordey, pers. comm.).

Two samples were collected from outcrops of Late Triassic sandy limestone for detrital zircon geochronology. To aid in our understanding of sedimentary provenance in this region, a detrital zircon sample from a coarse-grained, poorly sorted, chert lithic sandstone of the underlying Devono-Mississippian Prevost Formation, which comprises the upper part of the Earn Group in eastern Yukon, was also collected.

QUIET LAKE MAP AREA

In the Quiet Lake (NTS 105F) map area, two sections of Triassic sedimentary rocks of the parautochthonous Cassiar terrane, south of the Tintina fault, were examined. First, rocks of the Triassic Hoole Formation in the core of the Ketza syncline, occurring within the upper plate of an unnamed thrust fault, were sampled (Tempelman-Kluit, 1977). These strata are well exposed immediately north of Mount Green, approximately 25 km due south of Ross River (location 2 on Fig. 1; Figs. 4 and 5a) and underlain by Devonian-Mississippian chert and shale. Orchard (2006) reported Late Triassic conodont ages from rocks of this area. Generally, these strata are light grey to tan-

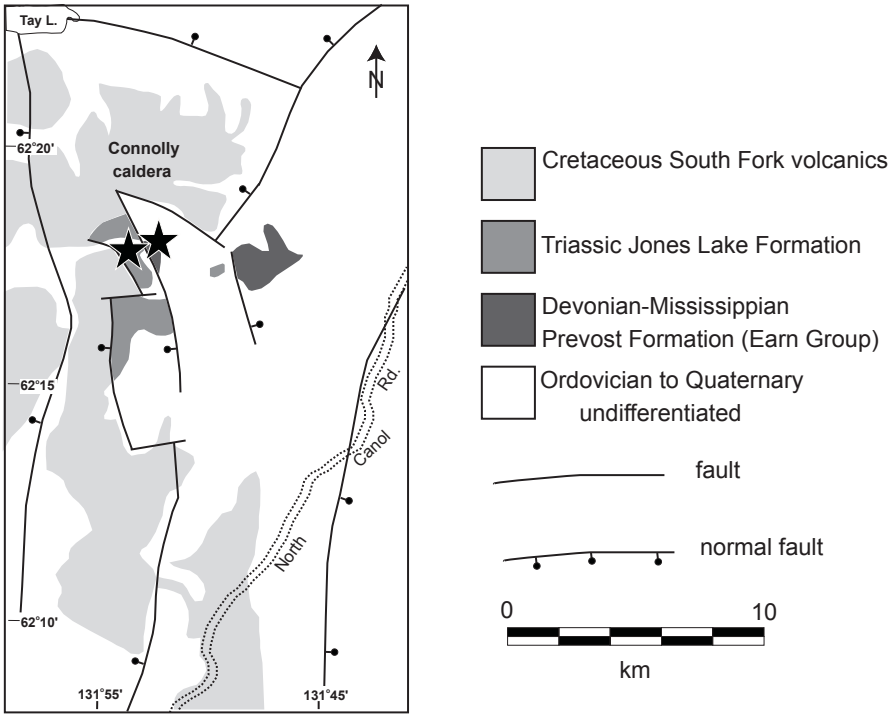

Figure 2. *Simplified geologic map of the Connolly caldera region, Sheldon Lake map area, modified from Gordey and Irwin (1987). Black stars indicate sample locations.*

weathering, grey to dark grey, thin to thickly bedded, parallel to wavy-laminated, silty limestone and limy siltstone to medium- to coarse-grained (quartz) sandy limestone (Fig. 5b). To constrain the provenance of siliciclastic input into this carbonate section, two samples of sandy limestone were collected for detrital zircon analyses.

The second location visited in the Quiet Lake map area was just west of the South Canol road and Lapie River, on the southeast side of Mount Ross, approximately 20 km southwest of Ross River (Fig. 4). As with the previously described section, these Triassic rocks are assigned to the Hoole Formation, occurring structurally above the St. Cyr thrust fault, and are constrained as Late Triassic in age by conodonts (Tempelman-Kluit, 1977; Orchard, 2006).

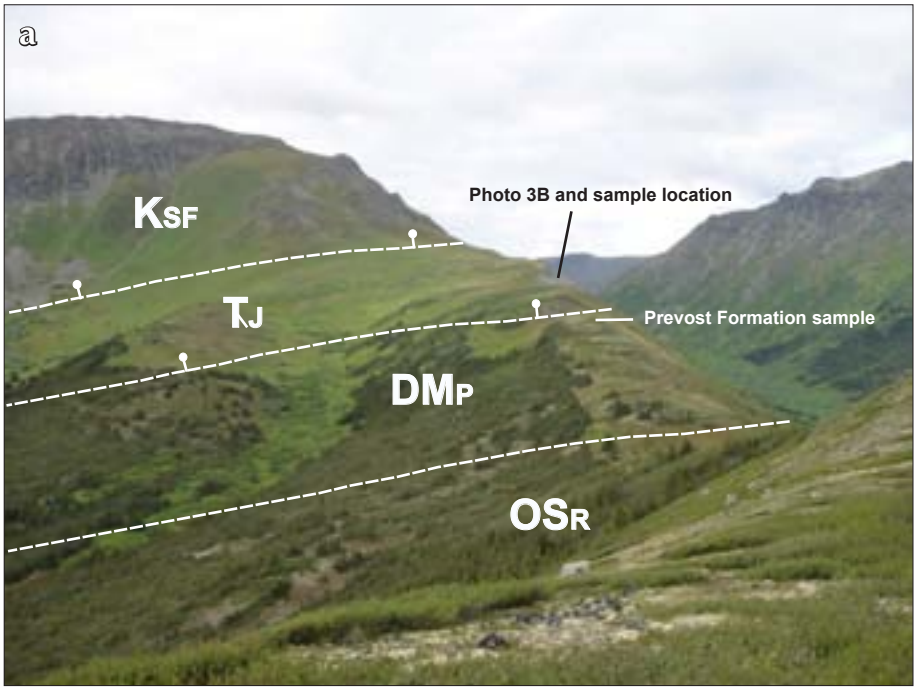

Figure 3. *Field photos of Triassic strata in the Connolly caldera region, north of Ross River, Sheldon Lake map area.* ***(a)*** *View to west of Triassic Jones Lake Formation (TJ) and older sedimentary section (DMP, OSR) in fault contact with Cretaceous South Fork volcanics (KSF). DMP = Devonian-Mississippian Prevost Formation (upper Earn Group); OSR = Ordovician to Silurian Road River Group.* ***(b)*** *Outcrop view of thickly bedded, silty to sandy limestone; hammer for scale.* ***(c)*** *Typical view of wavy- and ripple cross-laminated silty to sandy limestone; hammer handle at right for scale.*

These strata are tan- to buff-weathering, light to medium grey, thin- to medium-bedded, parallel (thin to thickly) to wavy-laminated, calcareous in part, muscovite-bearing in part, siltstone to fine-grained sandstone (Figs. 6a and b). Two samples from these strata were collected for detrital zircon geochronology.

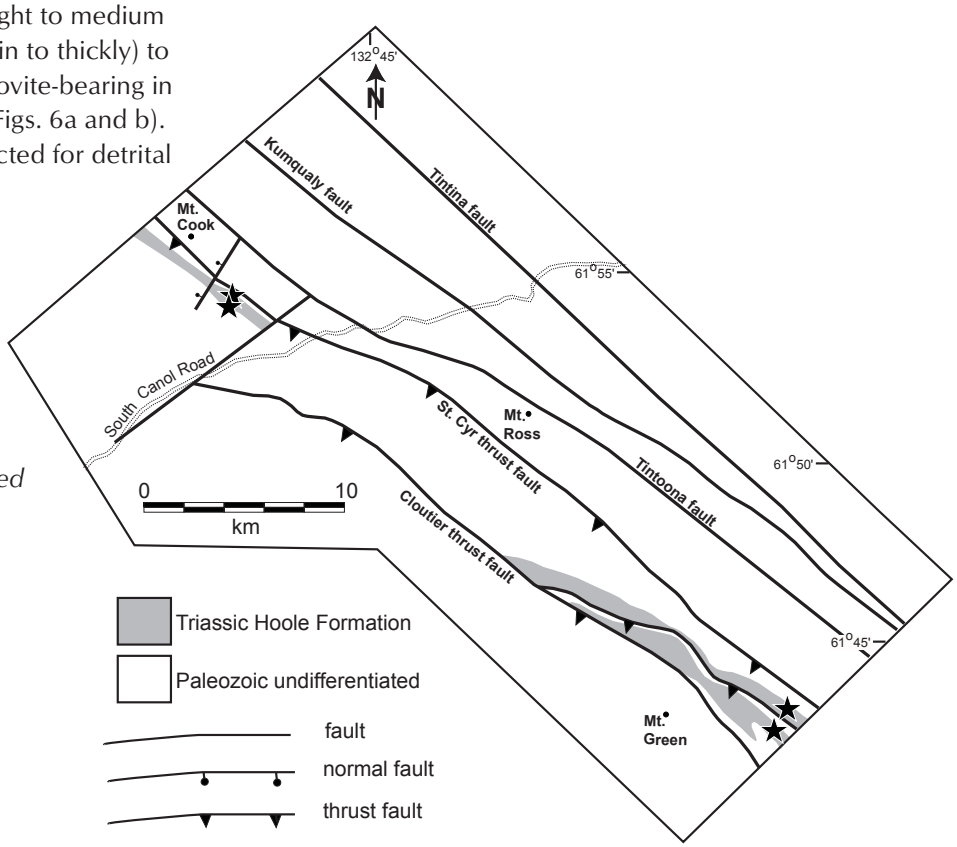

Figure 4. *Simplified geologic map of the northeastern Quiet Lake map area, modified from Templeman-Kluit (1977). Black stars indicate sample locations.*

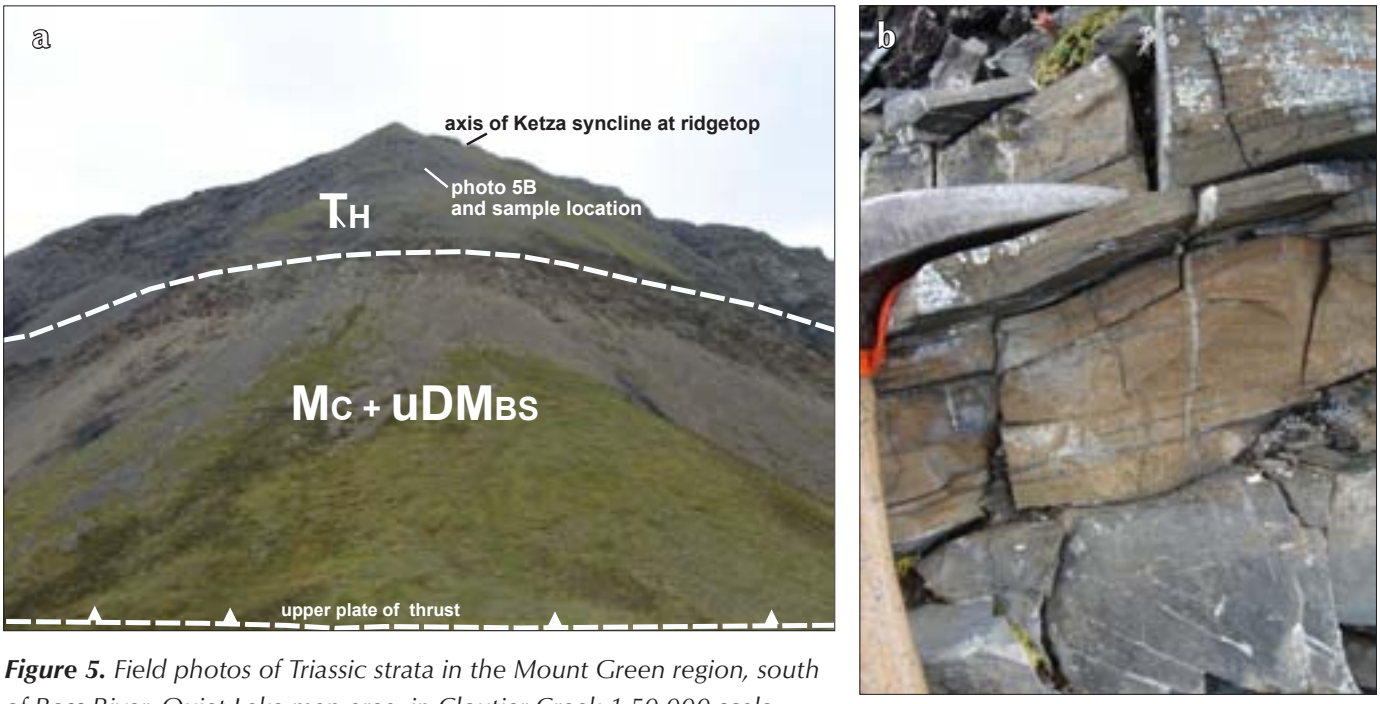

Figure 5. *Field photos of Triassic strata in the Mount Green region, south of Ross River, Quiet Lake map area, in Cloutier Creek 1:50 000-scale sheet.* ***(a)*** *View to south of Triassic (TH) and older sedimentary section (MC +uDMBS) within upper plate of St. Cyr thrust.* ***(b)*** *Typical outcrop view of parallel to wavy-laminated calcareous siltstone to sandy limestone; hammer at left for scale. TH = Triassic Hoole Formation; MC = Mississippian Chert Tuff Formation; uDMBS = Upper Devonian and Mississippian Black Slate Formation.*

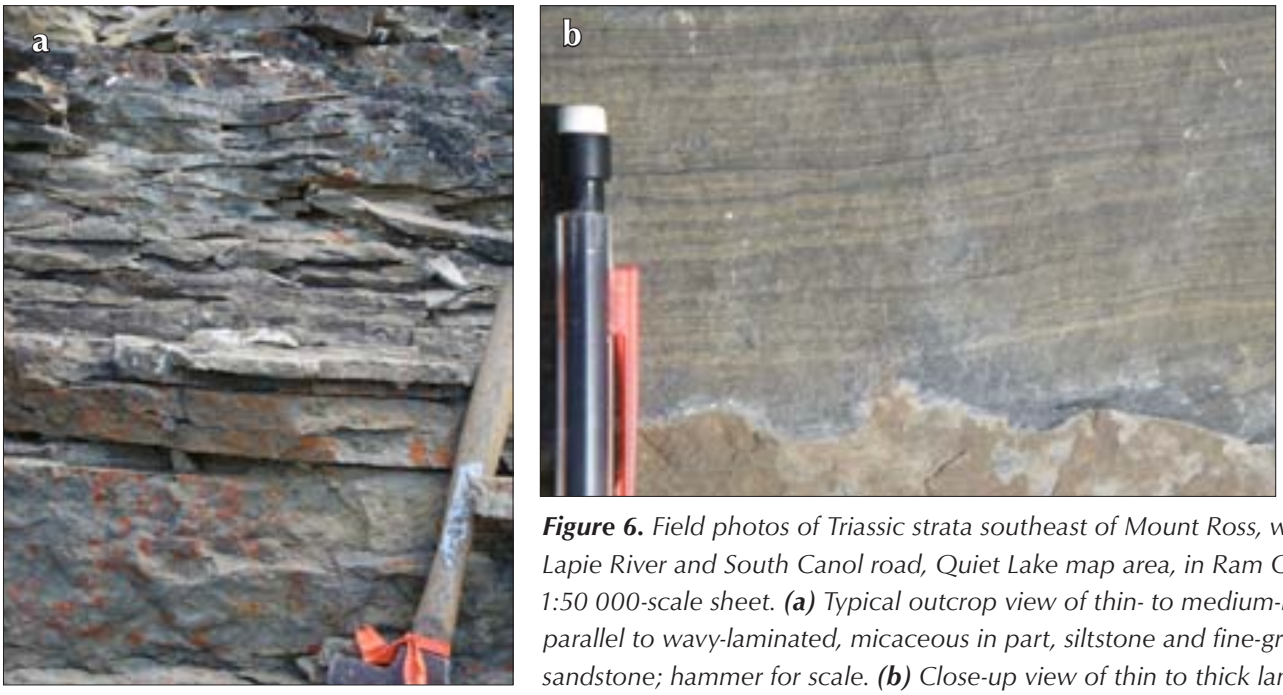

Figure 6. *Field photos of Triassic strata southeast of Mount Ross, west of the Lapie River and South Canol road, Quiet Lake map area, in Ram Creek 1:50 000-scale sheet.* ***(a)*** *Typical outcrop view of thin- to medium-bedded, parallel to wavy-laminated, micaceous in part, siltstone and fine-grained sandstone; hammer for scale.* ***(b)*** *Close-up view of thin to thick laminations (parallel to wavy) within fine-grained sandstone; pencil for scale.*

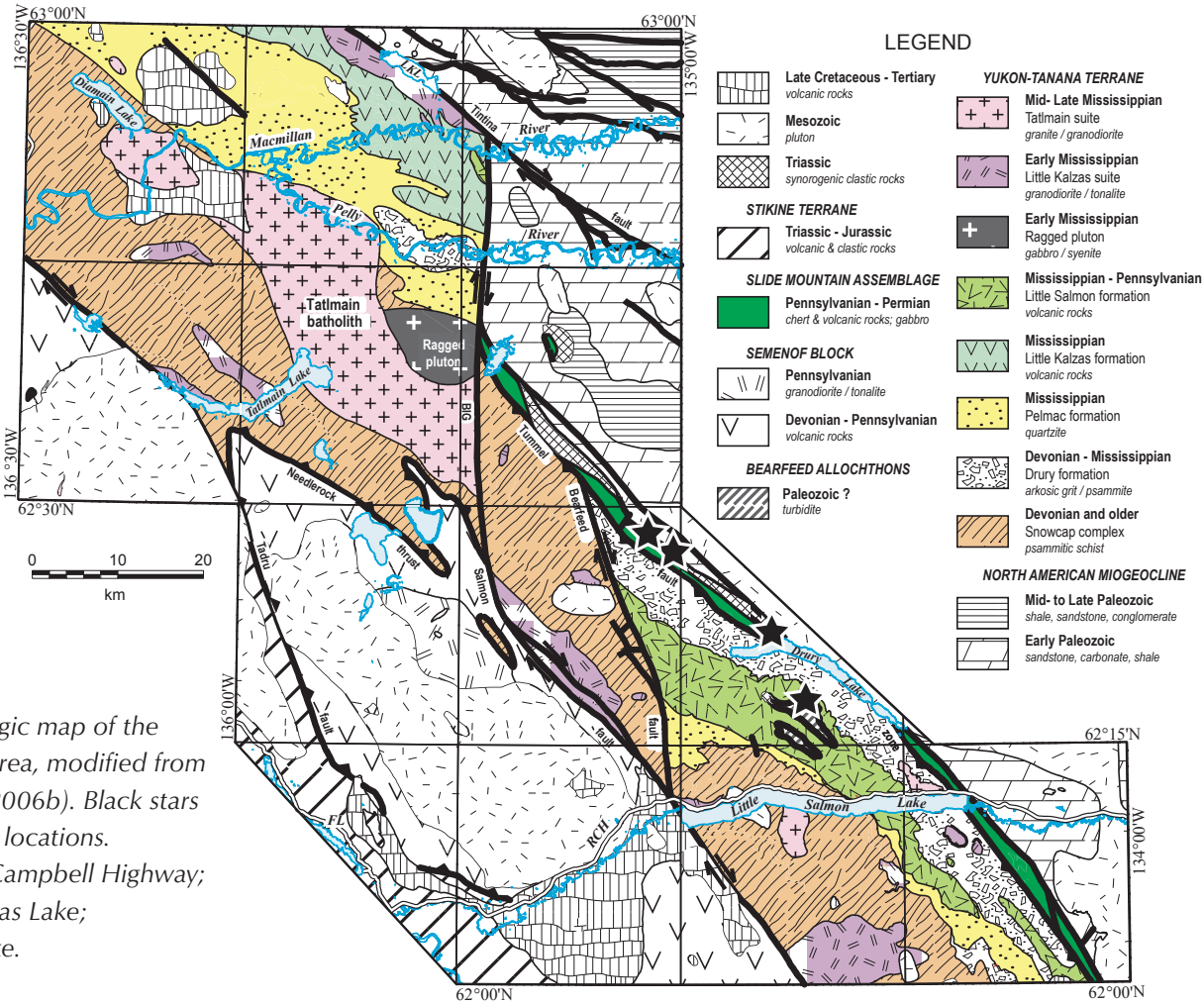

Figure 7. *Geologic map of the Glenlyon map area, modified from Colpron et al. (2006b). Black stars indicate sample locations.*
RCH = Robert Campbell Highway;
LKL = Little Kalzas Lake;
FL = Frances Lake.

GLENLYON MAP AREA

Approximately 30 km north of Little Salmon Lake, east of the Big Salmon fault, Triassic sedimentary rocks in the Glenlyon map area (NTS 105L) occur in the Tummel fault zone, a structural zone that juxtaposes Yukon-Tanana and Slide Mountain rocks with the parautochthonous Cassiar terrane (location 3 on Fig. 1; Fig. 7; Colpron *et al.*, 2005, 2006). In this region, we sampled variably deformed, monomictic to polymictic (chert, shale, felsic volcanic?), muscovite-bearing, pebble conglomerate (Figs. 8a and b) and micaceous feldspathic sandstone for detrital zircon and detrital muscovite geochronology. These strata are similar to, and in one locality include, rocks of the Bearfeed klippe, immediately north of Little Salmon Lake (Fig. 7). Colpron *et al.* (2005) analysed detrital zircons from conglomerate of the Bearfeed klippe, and interpreted Paleozoic ages therein to indicate recycling of the Semenof block (see location on Fig. 7) and Yukon-Tanana terrane.

One section of Triassic strata containing Middle Triassic conodonts (Orchard, 2006) overlying Pennsylvanian-Permian chert of the Slide Mountain terrane was examined (Figs. 8c and d). These strata are well exposed near the northwest end of Drury Lake and comprise brown- to tan-weathering, brown-tan, thin- to medium-bedded, fine- to medium-grained, thickly laminated,

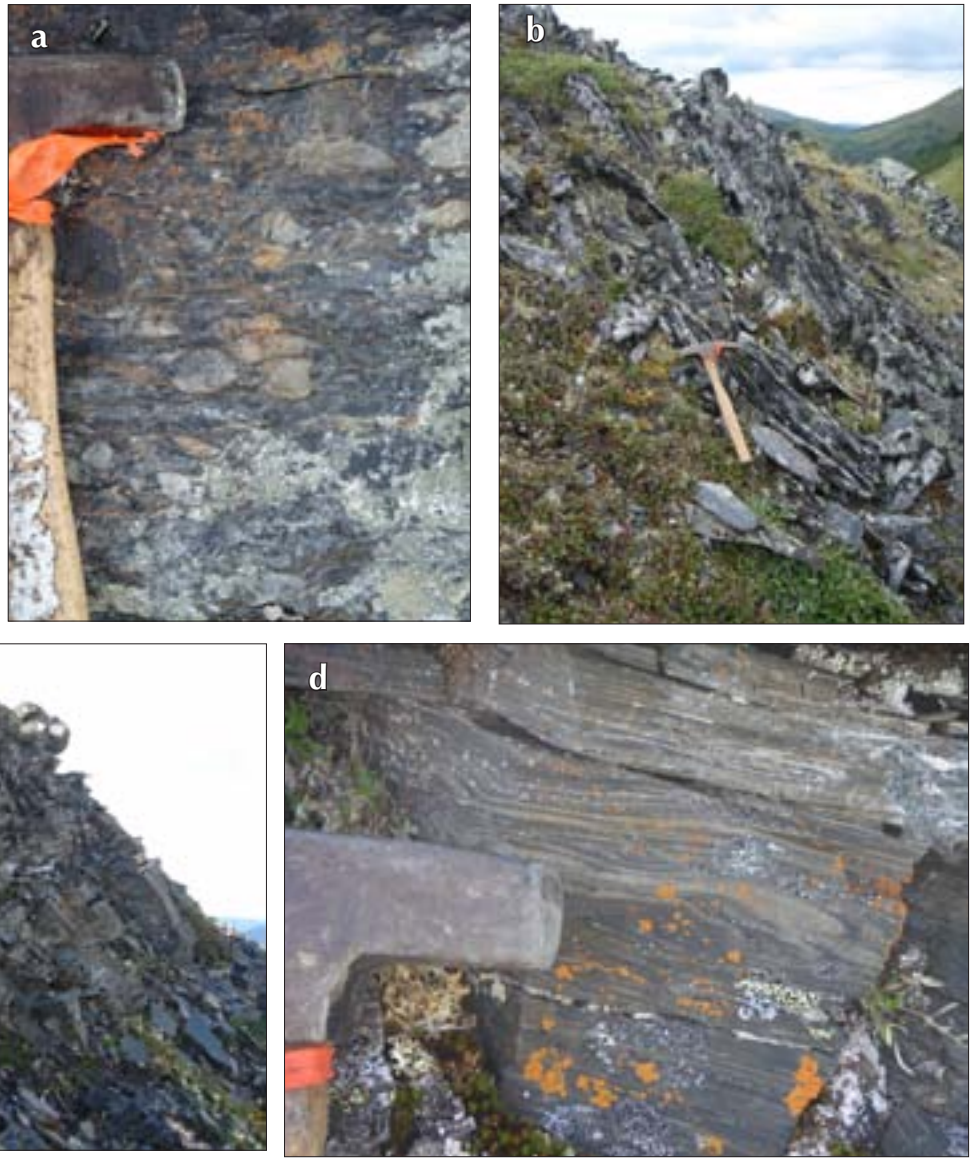

Figure 8. *Field photos from the Glenlyon map area, north of Little Salmon Lake.* ***(a)*** *Close-up view of sheared polymictic conglomerate; hammer for scale.* ***(b)*** *Typical outcrop view of sheared conglomerate and lithic and feldspathic sandstone; hammer for scale.* ***(c)*** *Outcrop view of thin- to medium-bedded siltstone and sandstone that overlies chert of Slide Mountain terrane; backpack for scale.* ***(d)*** *Close-up view of thickly laminated siltstone, showing soft sediment deformation; hammer for scale.*

calcareous shale and sandstone. Samples from this locality were collected for detrital zircon and detrital muscovite geochronology.

MCDAME MAP AREA, NORTHERN BRITISH COLUMBIA

Triassic sedimentary rocks of the Table Mountain Formation within the Sylvester allochthon, at the Cusac gold property (104P 070, BC MINFILE, 2007), near Cassiar, British Columbia, were also examined (location 4 on Fig. 1; Fig. 9). Middle to Late Triassic strata of the Sylvester allochthon were assigned to Division II (Slide Mountain assemblage) by Nelson (1993), and resemble the basal Takla and Slocan groups of Quesnellia in southern British Columbia and Triassic rocks of the Cassiar terrane in Yukon. Triassic strata, exposed in disparate, structurally imbricated sections at Table Mountain, occur as grey- to tan-weathering, grey, fine-grained, siltstone to sandstone and grey- and orange-weathering, dark grey, argillite and phyllite (Fig. 10a), with abundant muscovite along bedding planes. Sedimentary structures such as ripple marks and wavy-laminations are ubiquitous (Fig. 10b). A total of five detrital zircon and two detrital mica samples from Table Mountain were collected. At the Plaza pit (Fig. 10c), we observed pinkish-grey micaceous sandstone that resembles a sandstone unit we sampled in the McNeil klippe area of the Cassiar terrane in southeastern Yukon (Beranek and Mortensen, 2007).

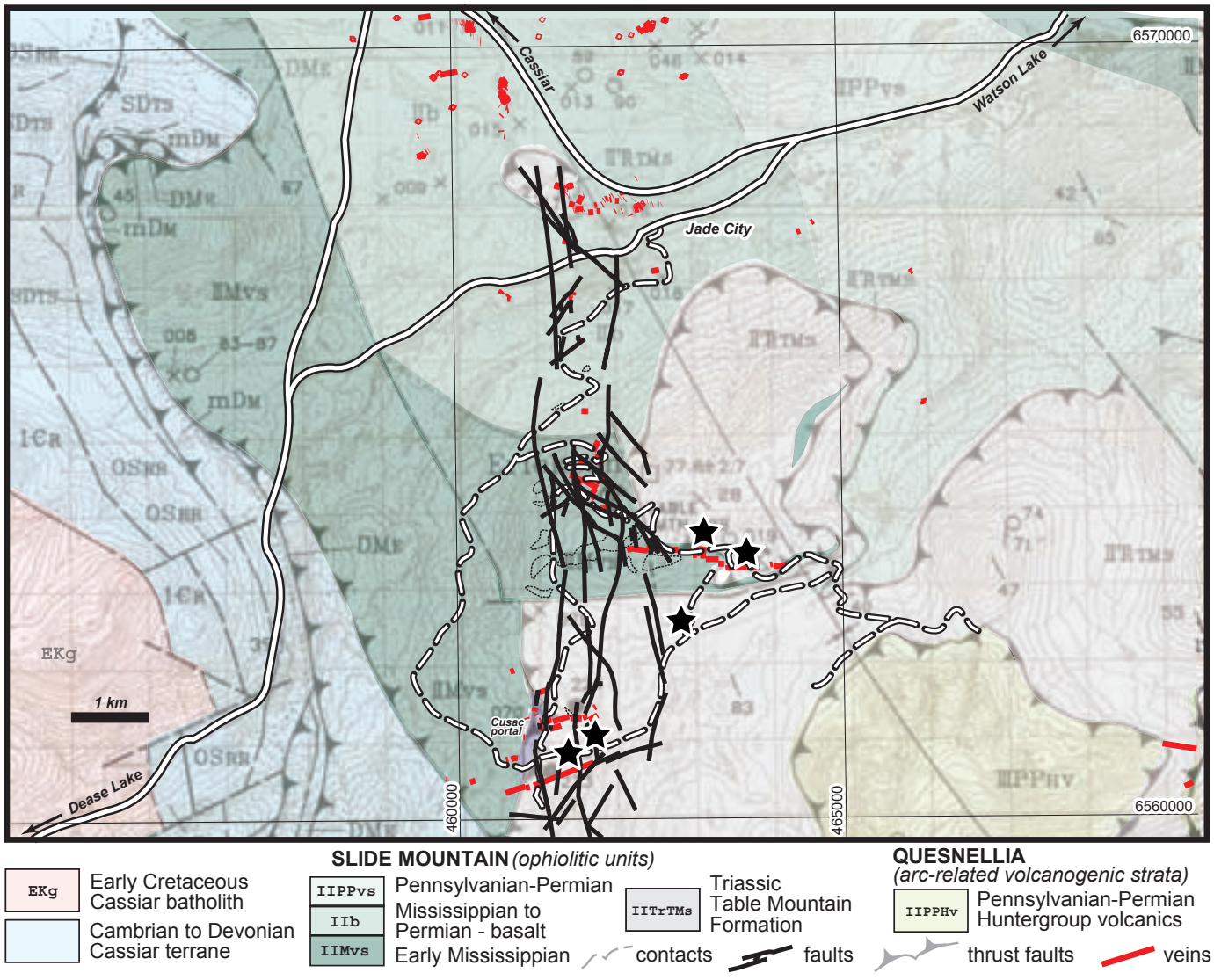

Figure 9. *Geologic map of the Table Mountain area, modified from Colpron et al. (2007). Black stars indicate sample locations.*

Figure 10. *Field photos from Sylvester allochthon at Table Mountain, Cusac gold property, near Cassiar, BC, McDame map area.* ***(a)*** *Typical outcrop view of grey- and orange-weathering argillite to phyllite at the Plaza pit; hammer for scale.* ***(b)*** *View to south of the Plaza pit at Table Mountain; area to the right is outcrop of pinkish-grey micaceous quartzite, back left is argillite and phyllite, portions of which are an overlying thrust plate.* ***(c)*** *Close-up view of ripple marks in tan-weathering micaceous siltstone; hammer for scale.*

SUMMARY

Triassic sedimentary rocks with ages constrained by conodonts were collected for provenance analysis. These new collections will complement an existing database that provides evidence for latest Permian closure of the Slide Mountain ocean and emplacement of the YTT onto the Cordilleran margin. Fieldwork from summer 2007 focused on previously documented, but largely unstudied, exposures of Triassic strata in east-central Yukon. Along with fieldwork carried out in 2005 and 2006, we have now examined and sampled most Triassic outcrop belts within the Selwyn basin, Yukon-Tanana, Slide Mountain and Cassiar terranes. Stratigraphic and provenance analyses from these strata will further constrain the age signatures of detrital mineral populations that have been observed in Triassic miogeoclinal rocks and yield insights into early Mesozoic basin evolution in the northern Cordillera.

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We thank Maurice Colpron and JoAnne Nelson for their time and good nature in the Glenlyon and McDame map areas. Special thanks to Lesley Hunt for her hospitality at the Cusac gold property. Charlie Roots provided unpublished 1:50 000-scale geologic maps from mapping by D. Tempelman-Kluit in the Quiet Lake map area. We thank Steve Gordey for providing a geologic map of the Connolly caldera area, compilation of fossil collections therein, and discussions about Selwyn basin geology. Field logistics and helicopter support for this research were funded by the Yukon Geological Survey. We thank Brian Parsons of Trans North for excellent helicopter support. We appreciate Maurice Colpron for his comments on this manuscript and the use of geologic maps in the Glenlyon and McDame map areas.

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Surficial geology investigations in Wellesley basin and Nisling Range, southwest Yukon

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Bond, J.D., Lipovsky, P.S. and von Gaza, P., 2008. Surficial geology investigations in Wellesley basin and Nisling Range, southwest Yukon. *In:* Yukon Exploration and Geology 2007, D.S. Emond, L.R. Blackburn, R.P. Hill and L.H. Weston (eds.), Yukon Geological Survey, p. 125-138.

ABSTRACT

Results of surficial geology investigations in Wellesley basin and the Nisling Range can be summarized into four main highlights, which have implications for exploration, development and infrastructure in the region: 1) in contrast to previous glacial-limit mapping for the St. Elias Mountains lobe, no evidence for the late Pliocene/early Pleistocene pre-Reid glacial limits was found in the study area; 2) placer potential was identified along the Reid glacial limit where a significant drainage diversion occurred for Grayling Creek; 3) widespread permafrost was encountered in the study area including near-continuous veneers of sheet-wash; and 4) a monitoring program was initiated at a recently active landslide which has potential to develop into a catastrophic failure that could damage the White River bridge on the Alaska Highway.

RÉSUMÉ

Les résultats d'études géologiques des formations superficielles dans le bassin de Wellesley et la chaîne Nisling peuvent être résumés en quatre principaux faits saillants qui ont des répercussions pour l'exploration, la mise en valeur et l'infrastructure de la région. 1) Contrairement à la cartographie antérieure de la limite du lobe des monts St. Elias, aucune indication de limites glaciaires pré-Reid du Pliocène tardif/Pléistocène précoce n'a été trouvée dans la région d'étude. 2) Un potentiel pour les gîtes placériens a été identifié le long de la limite glaciaire de Reid où il y a eu une importante dérivation du drainage pour le ruisseau Grayling. 3) Du pergélisol répandu a été constaté dans la région d'étude, notamment dans les placages quasi continus de ruissellement diffus. 4) Un programme de surveillance a été lancé à l'emplacement d'un glissement de terrain récemment actif qui pourrait évoluer en un effondrement catastrophique risquant d'endommager le pont de la rivière White le long de la route de l'Alaska.

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INTRODUCTION

Surficial geology mapping provides a foundation for many topical studies into Quaternary history, placer geology, permafrost characteristics and terrain hazards. The aim of this paper is to provide highlights from current research that is being conducted in the Wellesley Basin and Nisling Range of southwest Yukon. These results are part of a multi-year mapping project in the Stevenson Ridge (115J) and northern Kluane Lake map area (115G; Fig. 1). The goal of the project is to provide 1:100 000-scale surficial geology maps, detailed descriptions of the surficial materials, permafrost characteristics and terrain hazards, interpretations on the Quaternary history, and insights into the region's placer potential. Highlights from the 2007 field season are summarized in four sections below that outline the glacial limits, placer potential, permafrost distribution, as well as a landslide case-study.

GLACIAL LIMITS

INTRODUCTION

Previous glacial-limit mapping in the southwest Yukon has been undertaken by Rampton (1978a,b,c,d,e), Hughes (1989a, b), Huscroft (2002a,b c) and Jackson (2005) in the areas surrounding Stevenson Ridge and northern Kluane Lake map areas. Duk-Rodkin (1999) produced a glacial-limits map of the entire Yukon Territory based on a compilation of previous work and aerial-photo mapping. The Stevenson Ridge map area straddles the limits of multiple Pleistocene glaciations that advanced northward out of the St. Elias Mountains (Fig. 1). The St. Elias lobe comprised the northwestern portion of the Cordilleran Ice Sheet. Field investigations were conducted in 2007 to confirm and describe the maximum limit of glaciation in this region. Field confirmation of the glacial limits had not been previously completed for this map area. The closest related field-based studies were undertaken by Rampton (1978a, b) and Hughes (1989a, b) in the adjoining Snag (115K) and Aishihik (115H) map areas respectively.

MAPPING GLACIAL LIMITS

Glacial limits are mapped through a combination of landform identification (moraines and meltwater channels) from aerial photography, and field-based analyses such as the identification of erratics and glacial sediments. Glacial limits have been mapped for three glacial periods in this region: the earliest 'pre-Reid' group of glaciations began in the early Pleistocene, *ca.* 3 Ma BP; the penultimate Reid (Illinoian) and Gladstone (early Wisconsinan) glaciations occurred during marine isotope stages 6 (140-190 ka BP) and 4 (55-75 ka BP) respectively; and the most recent McConnell glaciation occurred in the late Wisconsinan during marine isotope stage 2 (*ca.* 22-10 ka BP) (Fig. 1; Ward *et al.*, 2007b).

Mapping the limits of glaciations older than the McConnell glaciation can be challenging. Widespread permafrost and colluvial processes are highly effective at eroding glacial depositional landforms, especially in mountainous terrain. Identifiable landforms related to pre-Reid glaciations are almost entirely limited to meltwater channels cut into bedrock, as well as glacial erratics. Depositional landforms such as moraines, kames, or eskers from these earlier glaciations are less likely to be preserved. Moraines from the Gladstone or Reid glaciations are sometimes mappable, but they tend to be discontinuous and preserved only where moraine accumulations were thick and the topography is moderate enough that surface expressions are preserved.

Previous glacial-limit mapping based on aerial photo interpretation in Stevenson Ridge map area (Duk-Rodkin, 1999) shows that the pre-Reid glacial limit extends north of Wellesley Lake to the confluence of the White and Donjek rivers (Fig. 1). In the adjoining Snag map area to the west (115K), Duk-Rodkin (1999) mapped the pre-Reid glacial limit extending north up Scottie Creek (Fig. 1). This contrasts with Rampton (1978a), who previously mapped Scottie Creek as unglaciated.

METHODS AND RESULTS

In order to better constrain pre-Reid glacial limits in the study area, two foot traverses were completed near Grace Lake and Tincup Lake (Fig. 1) to investigate the distribution of erratics. The traverses were conducted on flat plateau summits that were mapped by Duk-Rodkin (1999) as glaciated during the pre-Reid glaciations and unglaciated during subsequent glaciations. Alpine environments are ideal for mapping the distribution of erratics because organic cover is thin and frost boils are present, resulting in a veneer of exposed pebbles at the surface. Lithologies can be easily identified and distinguished from surrounding local bedrock lithologies. Flat plateau surfaces were targeted for erratic mapping to minimize the potential for downslope remobilization of the pebbles.

Results from both traverses revealed no erratics within the pre-Reid glacial limit, whereas at lower elevations the

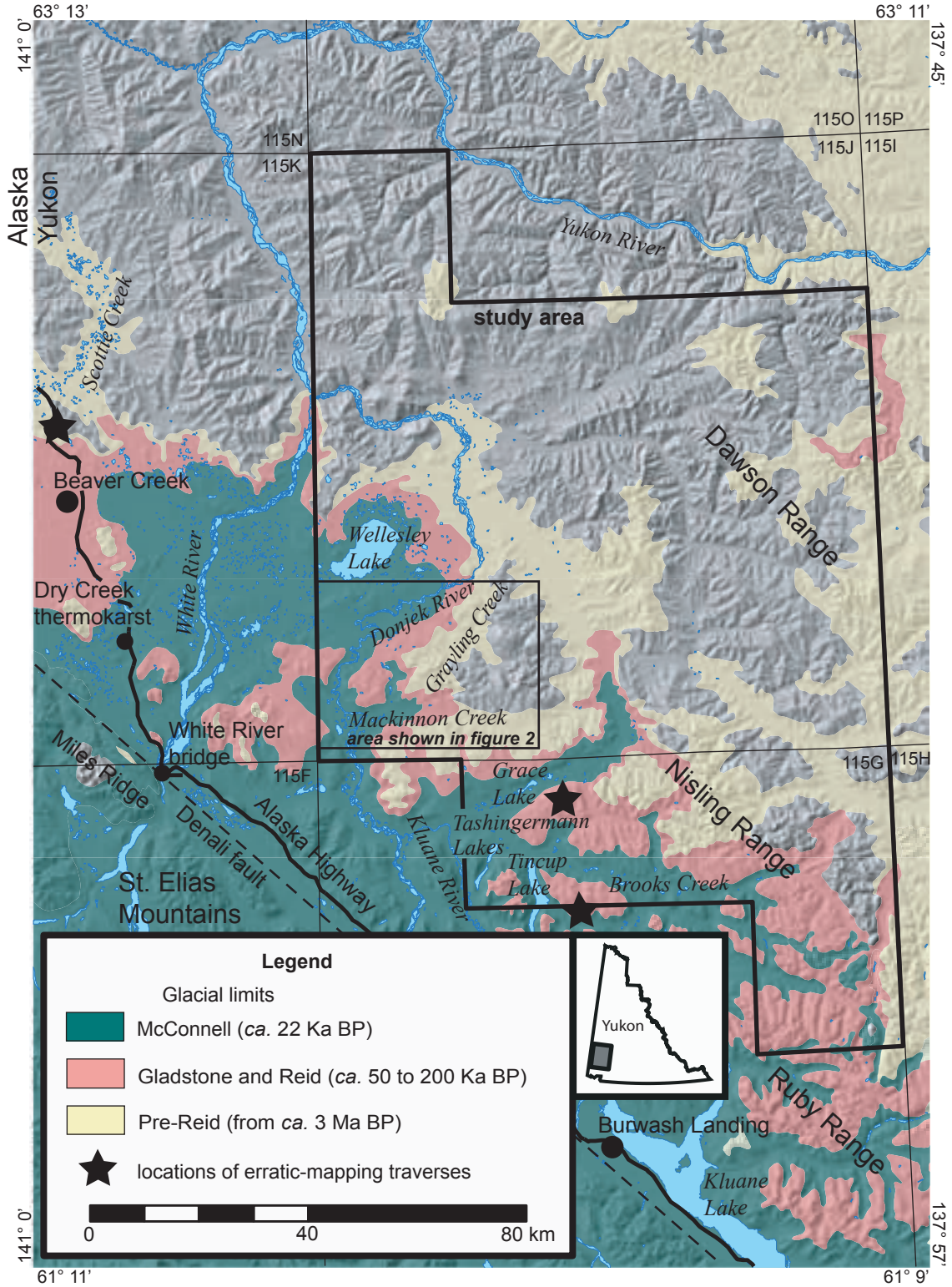

Figure 1. *Location of the Stevenson Ridge and northern Kluane map study area (115J and G) is outlined in black; location of Figure 2 is also displayed. Glacial limits depicted here are after Duk-Rodkin, 1999.*

penultimate Reid or Gladstone glacial limit was marked sharply by erratics and meltwater channels. To further investigate the presence of pre-Reid glaciations in this region, a road traverse was completed along the Alaska Highway in the Snag map area (115K) near the border with Alaska (Fig. 1). This traverse also revealed no erratics beyond the limit of the penultimate glaciation.

These initial results suggest that the penultimate glaciation (either Reid or Gladstone) was the most extensive glaciation that originated from the St. Elias Mountains during the Pleistocene. Additional field-based glacial-limit mapping is required near the outer margin of the currently mapped pre-Reid limit (near the Donjek River, for example) to further clarify this potential revision to Yukon's glacial-limit map.

IMPLICATIONS

The potential absence of relatively extensive pre-Reid glaciations in southwest Yukon is significant for both mineral exploration and our understanding of Cordilleran Ice Sheet history in this region. Mineral exploration relies heavily on soil and stream-sediment geochemistry for locating potential prospects. Different approaches are required to determine the potential source of geochemical anomalies when they are located in glaciated or unglaciated terrain. The maximum Pleistocene glacial limit is therefore critical for determining whether bedrock geochemical anomalies have experienced glacial erosion and subsequent transport.

Recent investigations into the history of the northern Cordilleran Ice Sheet by Ward *et al.* (2007a) have shown that ice extents in areas of limited annual precipitation may not correspond with global glacier extent patterns, both temporally and volumetrically. In addition, the maximum ice extent of different lobes that comprised the northern Cordilleran Ice Sheet may not be synchronous during a single phase of glaciation. In the case of this study, the absence of relatively extensive pre-Reid ice in southwest Yukon contrasts greatly with pre-Reid ice extents in central Yukon. This example raises important and unresolved questions regarding precipitation controls in northwestern North America during the Pleistocene.

CONCLUSIONS

Previous glacial limit mapping in the Stevenson Ridge and northern Kluane map areas had not been field checked. Two foot traverses on alpine plateaus and a road traverse in the adjoining Snag map area revealed an absence of pre-Reid glacial indicators beyond the penultimate Reid or Gladstone glacial limit. These results indicate possible revisions to the glacial limits map of Yukon which will have implications for mineral exploration in the area. In addition, refined ice limits provide important information regarding Cordilleran Ice Sheet history and paleo-climatic controls.

GRAYLING CREEK PLACER POTENTIAL

GLACIAL DIVERSION OF GRAYLING CREEK

Grayling Creek is located at the northwestern end of the Nisling Range and flows into the Donjek River southeast of Wellesley Lake (Figs. 1 and 2). The indirect modern trajectory of Grayling Creek toward the Donjek River is the result of a glacial diversion that occurred during the penultimate Reid or Gladstone glaciation (Duk-Rodkin, 2001; Fig. 2). Prior to this glaciation, the paleo-drainage of Grayling Creek was westward into the Donjek River via Mackinnon Creek (Fig. 2). Near the height of the penultimate glaciation, ice advancing northward down the Donjek River valley spilled into, and advanced eastward up, the paleo-Grayling Creek valley (Fig. 2). The ice flowing up-valley likely dammed the paleo-drainage and caused a glacial lake to form in upper Grayling Creek. Once the lake reached sufficient depth, it established an outlet to the north, across an unnamed upland of the Nisling Range (Fig. 2). The ice dam held long enough for the diversion channel to downcut and permanently capture Grayling Creek. A second similar diversion occurred further north and extended Grayling Creek's route to the Donjek River, and in doing so, captured additional drainages in the diversion channel (Fig. 2).

THE LANDSCAPE CHANGE AND PLACER POTENTIAL

The landscape change resulting from the diversion of Grayling Creek enhanced the placer potential for many streams captured by the diversion channel. The diversion channel cut through the northern flank of the Nisling Range, lowering the base level for local streams that it captured. These streams incised their floodplains in order to reach equilibrium with the diversion channel (Fig. 3). The incision process created a narrow, v-shaped valley morphology which is highly conducive for concentrating heavy minerals in fluvial sediment.

The main diversion channel containing Grayling Creek may also be prospective for placer development. The

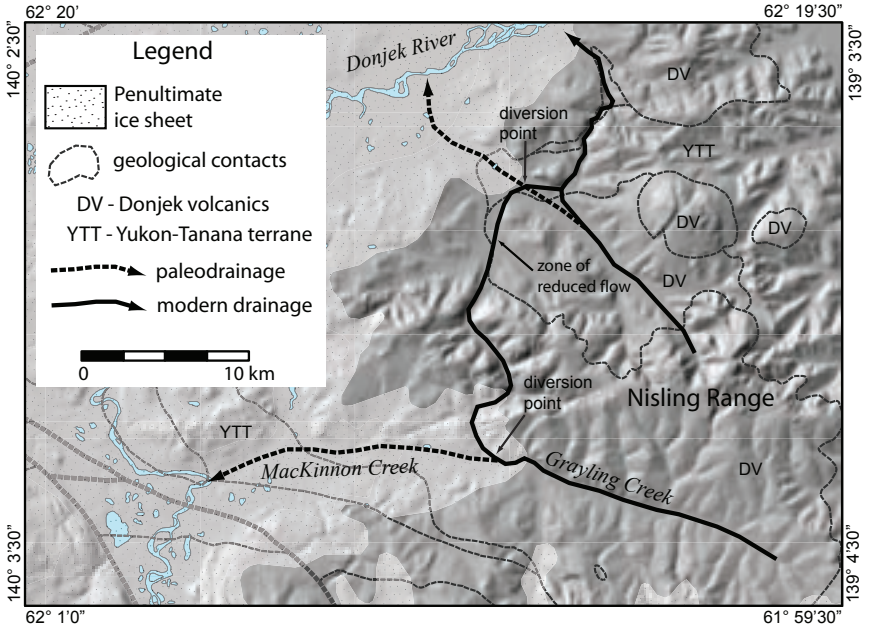

Figure 2. *Grayling Creek was diverted northward when the penultimate ice sheet blocked the westward drainage of paleo-Grayling Creek (presently named MacKinnon Creek). Two diversion points indicate the location of ice dams responsible for the deflection of Grayling Creek. A zone of reduced paleo-flow, which may have placer potential, is identified between the diversion points. General bedrock geology for the surrounding area is after Murphy et al., 2007.*

high-energy stream responsible for cutting the diversion channel possibly reworked any pre-existing placers and either concentrated them within the drainage, or redistributed them into the Donjek River. Zones of reduced paleo-flow within the diversion channel should therefore be targeted for placer exploration (Fig. 2).

Grayling Creek's paleo-valley, which is now the right-fork tributary of Mackinnon Creek, is less prospective for placer development, compared to the tributaries captured by the diversion channel. During ice recession from the lower part of paleo-Grayling Creek, thick blankets of glacial moraine and lake sediment were deposited over the paleo-valley and would likely reduce the economic viability of any future placer development in the area.

GEOLOGY

The potential for finding gold-bearing rocks within drainages affected by the diversion channel is favourable. Most of the upland eroded by the diversion channel consists of Cretaceous to Tertiary Donjek volcanics (Murphy *et al.*, 2007). These consist of resistant dacite with massive tuff breccia, olivine basalt and recessive-weathering rhyolite (Murphy *et al.*, 2007). The Donjek volcanics erupted through dark grey carbonaceous phyllite or schist and quartzite belonging to Yukon-Tanana terrane (YTT). These also locally contain felsic metavolcanic rocks (Murphy *et al.*, 2007).

The stream sediment geochemistry for gold in the local area is generally low (8-11 ppb) with the highest values (up to 60 ppb) occurring in YTT rocks. However, caution should be used when interpreting the gold concentrations from the regional stream sediment geochemistry (RGS) database. It is generally recognized that RGS samples are particularly effective for locating fine-grained gold in bedrock, but they are less consistent in detecting coarse-grained gold sources. The volcanic rocks underlying Grayling Creek would likely produce coarser grained gold

Figure 3. *A view to the southwest over the Nisling Range and the Grayling Creek diversion channel. The local drop in base level triggered by the diversion is noticeable in the tributary valley located in the bottom left-hand corner of the photograph. The v-shaped morphology of the tributary valley provides an ideal setting for concentrating fluvial deposits.*

sources, such as those found in stockwork, lode and brecciated zones.

RECOMMENDATIONS FOR EXPLORATION

Placer exploration should focus within diversion channel tributaries that have a well defined v-shaped morphology. These drainages should have relatively thin fluvial deposits and therefore an accessible bedrock surface for testing. Geochemical analyses of the local rock units should be completed to further investigate the mineral potential of the volcanic rocks compared to the YTT lithologies. This provides the best guide for locating potentially economic placers in tributaries entering the Grayling Creek diversion channel.

CONCLUSIONS

The landscape changes resulting from the glacial diversion of Grayling Creek are conducive for enhancing the placer gold potential of the area. The diversion channel established a new base level causing local streams to downcut. This erosion process potentially concentrated heavy minerals in the pre-existing fluvial sediments. The gold potential in the surrounding rocks is relatively unknown and would likely be associated with a volcanic-hosted deposit model. Future placer exploration in this area will benefit from systematic geochemical analyses of the local bedrock to further isolate prospective drainages.

PERMAFROST DISTRIBUTION AND ICE-CONTENT

PERMAFROST CONDITIONS IN ADJACENT AREAS

While no regional permafrost mapping or detailed permafrost studies have been carried out within the study area, a variety of localized work has been conducted in surrounding areas. Collectively, this work provides a comprehensive characterization of permafrost in the region, exemplifying the permafrost conditions that would most likely be encountered within the study area itself.

On a national scale, the entire study area has been classified within the extensive discontinuous permafrost zone, in which 50-90% of the land surface is underlain by permafrost with low to medium ground ice content (up to 20% visible ice) in the top 10-20 m (Heginbottom, 1995).

More detailed regional-scale mapping south and west of the study area indicates that continuous permafrost underlies most of the nearby landscape, particularly within alluvial fans, plains and terraces, and till and colluvial blankets (Heginbottom and Radburn, 1992). These landforms have low to moderate ice contents with ground ice in the form of lenses and reticulate veins. Permafrost is also considered continuous in glaciolacustrine plains, but higher ice contents can be found within these materials (Heginbottom and Radburn, 1992). In contrast, active floodplains of the Donjek and White rivers and glaciofluvial sediments south and west of the study area are shown to support only discontinuous or isolated patches of permafrost with low ice content (Heginbottom and Radburn, 1992).

Rampton *et al.* (1983) used geotechnical drillhole data to characterize the distribution and ice content of permafrost along the proposed Alaska Highway gas pipeline route. Results from this study found that more than 80% of the terrain traversed by the right-of-way north of Kluane Lake (roughly paralleling the Alaska Highway) was underlain by permafrost (Rampton *et al.*, 1983). Permafrost thickness in southwestern Yukon is reported to be up to 15 m near Beaver Creek, 18 m at Burwash Landing, and up to 27 m near Aishihik Lake (115H; Smith *et al.*, 2004). The thickness of the active layer, or the surface layer that seasonally thaws and refreezes, is generally between 0.3 and 2.2 m in the same region (Smith *et al.*, 2004).

Geotechnical work conducted by the Yukon Department of Highways and Public Works (YHPW) along the Alaska Highway south and west of the study area has also been useful for characterizing local permafrost conditions. Since 1997, YHPW has monitored permafrost temperatures in ice-rich silt located beneath and adjacent to the Alaska Highway, 5 km south of Beaver Creek. At this location, borehole data indicate up to 6 m of massive ice (with less than 5% soil inclusions) between 1.8 and 7.9 m below the ground surface (Paine and Associates, 1997a). The active layer at the site varies between 30 and 80 cm and generally corresponds to the thickness of the surface organic horizon. The mean annual temperature of the undisturbed permafrost is -2.4°C at 8 m depth, with ±0.5°C annual variation (YHPW, unpublished data).

YHPW also drilled several shallow boreholes near Dry Creek (approximately 40 km southwest of Wellesley Lake) between 1992 and 1994, prior to the realignment of the Alaska Highway in the area. The borehole data (currently being compiled by YGS) indicate up to 4 m of massive ice between 8 to 12 m below the ground surface within glaciofluvial outwash gravel (YHPW, unpublished data).

Subsequent removal of surface gravel for aggregate use has since caused major thermokarst subsidence adjacent to both sides of the highway. While coarse-textured glaciofluvial materials are commonly assumed to have little or no ice content, this area demonstrates that this is not always the case, and highlights the importance of detailed subsurface investigations prior to development. It also illustrates the potential consequences of ground surface disturbance in permafrost terrain.

Rampton *et al.* (1983) also highlighted specific sedimentary conditions that are commonly associated with shallow ground ice in the Alaska Highway corridor, all of which relate to the presence of fine-grained sediments and ample groundwater supply. These areas include locations where fine-grained material overlies, truncates, or is interstratified with more permeable coarse-textured material, poorly drained areas adjacent to wetlands and streams, and sites adjacent to bedrock valley walls (Rampton *et al.*, 1983).

FIELD OBSERVATIONS

Ground and aerial observations from the 2007 field season confirm that permafrost is nearly continuous throughout the study area. In some cases, permafrost was not directly observed in soil pits or cutbanks, but it was generally assumed to be present at greater depth or further back from exposure scarps, based on the morphology of local landforms, or evidence of periglacial processes in the vicinity.

In alpine areas, various periglacial landforms suggest the presence of permafrost. Evidence of frost action, cryoturbation and gelifluction is widespread at high elevations. Stone polygons, stone stripes and frost boils are common along exposed ridge crests and plateaus above approximately 1500 m. Solifluction lobes and nivation terraces were occasionally noted in the Nisling Range, particularly on west-facing slopes. Rock glaciers are also common at the base of steep talus slopes in the eastern Nisling Range.

One of the most notable indicators of permafrost in the study area is the widespread evidence of sheetwash (or slopewash) on gentle to moderately sloped valley sides that are blanketed by till or colluvium. Sheetwash occurs when surface water flows in sheets, rather than in channels, along a shallow impermeable permafrost table. The process gradually transports fine sediment (sand, silt and clay) down to valley bottoms. Evidence of sheetwash is reflected by a diagnostic surface expression in which the land surface appears to be flowing; this feature is visible from the air on saturated slopes (Fig. 4).

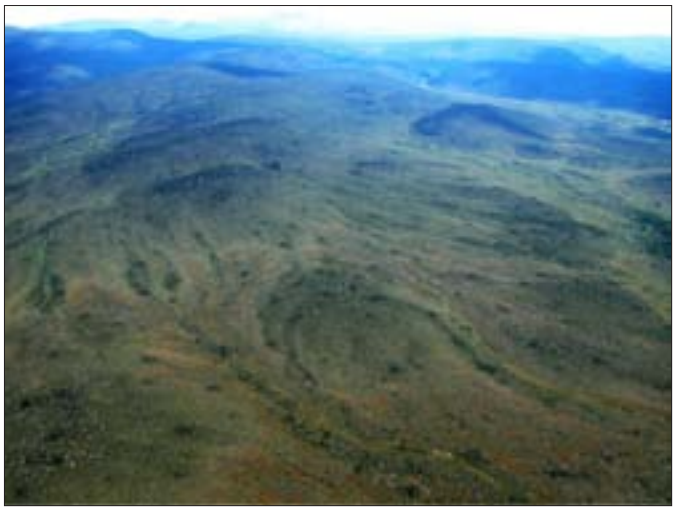

Figure 4. *The flowing surface appearance on many slopes throughout the study area is inferred to be a result of a shallow permafrost table and extensive sheetwash and soil-creep processes. Also note the highly regular pattern of clustered black spruce trees that creates the polka-dot pattern on the landscape; this could be related to the underlying permafrost structure.*

Because the active layer is typically thin and the permafrost table is impermeable, surface soils are commonly saturated and subject to downslope creep through the processes of gelifluction and frost creep. The combined effects of sheetwash and enhanced soil creep may explain why pre-McConnell valley-side glacial features are either highly subdued or absent in the region.

In valley bottoms, permafrost was commonly observed in alluvial terraces, organic plains and glaciolacustrine plains. Frost tables were encountered between 22 and 110 cm below the surface in low, forested alluvial terraces adjacent to the Donjek River. Where peat or thick moss cover existed, frost tables were generally encountered 20 to 40 cm below the surface, commonly beneath highly saturated soils or standing water. In Brooks Creek and Mackinnon Creek valleys, thick, frozen glaciolacustrine sand, silt and clay was exposed along stream cuts (Fig. 1). At one location along Mackinnon Creek, permafrost was at least 11 m thick and contained approximately 40%

Figure 5. *Jeff Bond with a large piece of clear ice removed from a 50-cm-thick vein within glaciolacustrine silty clay in a cutbank beside Mackinnon Creek. The ice content within the exposure indicates that permafrost is at least 11 m thick in this valley.*

visible ice with massive ice lenses up to 50 cm thick (Fig. 5).

Extensive thermokarst terrain was also observed within glaciolacustrine sediments along portions of the Grace Lake and Kluane River valley bottoms. Permafrost is at least 6.5 m thick within clayey silt exposed in Kluane River cutbanks, south of Tashingermann Lakes. At this location, ice content varied between 30-80% by volume (visually estimated) and consisted of small crystals (<2 mm in diameter) and stratified veins up to 10 cm thick. At a thermokarst pond exposure in the Grace Lake valley, ice content within glaciolacustrine sediment was lower (15% by volume) and consisted of thin, stratified and randomly oriented veins with an average thickness of 2 mm.

Permafrost-related landslides observed in the area were limited to small retrogressive thaw-flow slides along actively eroding river banks, and small active layer detachments on valley sides. One active layer detachment was documented during the 2007 field season on an 18° west-facing slope in the Grace Lake valley; the landslide occurred following a large forest fire that burned the area in 2004. This failure was 80 m long, 14 m wide and had a failure plane depth of 70 cm, corresponding to the depth of the local active layer. This morphology is typical of active layer detachments documented in other parts of the Yukon Territory (Lipovsky *et al.*, 2007). Forest fires, river erosion and anthropogenic surface disturbance have been attributed as common triggers for permafrost-related landslides in nearby areas and other parts of southern and central Yukon (Huscroft *et al.*, 2004; Lipovsky *et al.*, 2006; Lipovsky and Huscroft, 2007).

In many locations within the study area, the permafrost table was located near the base of the thick (10-40 cm) layer of coarse-textured White River tephra. This interface has been documented as a failure plane for at least one active layer detachment located just outside the study area (Huscroft *et al.,* 2004). It also forms the failure plane for several other small active layer detachments observed during aerial surveys in the region.

CONCLUSIONS

Based on ground observations and interpretation of surface landforms, the study area is underlain by nearly continuous permafrost. Ice-rich permafrost in the area is generally associated with fine-grained alluvial and glaciolacustrine sediments in valley bottoms, although massive ice was found in coarse-grained glaciofluvial materials in the region. The frost table is commonly very shallow (<50 cm), resulting in poor drainage and saturated surface soils. Permafrost thicknesses up to at least 11 m were observed. A variety of geomorphological processes related to the presence of permafrost are active at all slope positions throughout the study area, including periglacial processes in high-elevation alpine areas, and sheetwash, soil creep and active layer detachment landslides on valley sides. Retrogressive thaw-flow slides were observed where river erosion has exposed ice-rich glaciolacustrine sediments, and thermokarst subsidence occurs in valley-bottom sediments, usually within glaciolacustrine materials. Forest fires, river erosion and anthropogenic surface disturbance have been attributed as common triggers for thermokarst subsidence and permafrost-related landslides in south and central Yukon (Huscroft *et al.,* 2004).

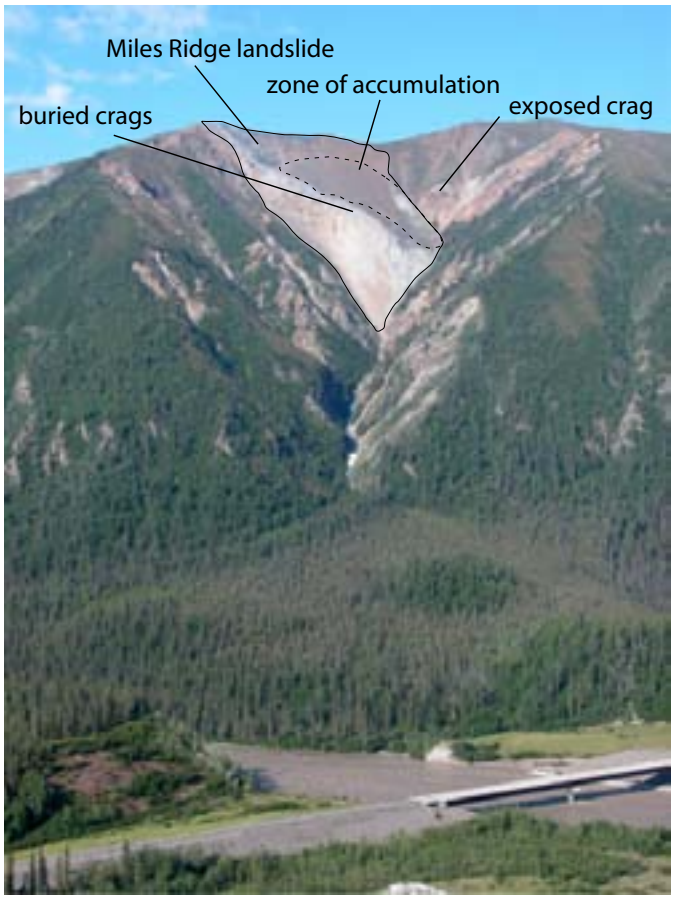

Figure 6. *The Miles Ridge landslide in relation to the Alaska Highway and White River bridge. View is to the southwest.*

MILES RIDGE LANDSLIDE

A landslide on Miles Ridge has recently developed at the head of an unnamed drainage that flows into the White River, immediately upstream of the Alaska Highway crossing (Fig. 1). The landslide debris has accumulated in the upper reaches of the drainage and is perched over 500 vertical metres above the river (Fig. 6). Catastrophic release of the debris could potentially impact the White River bridge and disrupt transportation in the Alaska Highway corridor.

HISTORY

The history of landslide activity at this site has been established using both aerial and historical photographs and reports from local highway maintenance personnel. A 1988 aerial photograph (NAPL A27370-79) displays no evidence of landslide activity in the drainage (Fig. 7a). Likewise, a local pamphlet advertising the White River RV Park in the 1980s contains a photograph of Miles Ridge with no evidence of landslide activity (Fig. 7b). According to Chief David Johnny of the White River First Nation, landslide activity at the head of the drainage was first noticed in the early 1990s. The landslide has continued to expand since then, including distinct changes following the 2002 earthquake on the Denali fault (David Johnny, pers. comm., 2007).

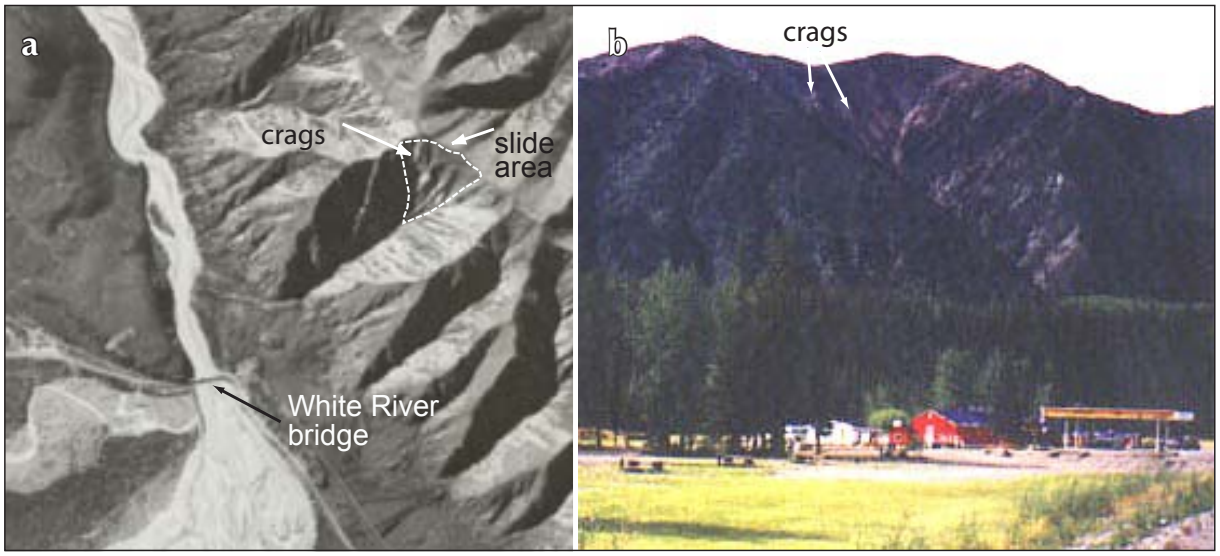

Figure 7. *Photos illustrating the absence of landslide activity in the drainage in the late 1980s.* ***(a)*** *Photo is cropped from an aerial photograph taken in 1988 (NAPL A27370-79). Crags of bedrock line the upper reaches of the drainage and no evidence of slide activity is present.* ***(b)*** *Photo is from a pamphlet advertising the White River RV Park in the 1980s. The drainage containing the slide is visible in the background and no landslide scar is present.*

GEOLOGICAL SETTING

Miles Ridge is bound by the Denali fault to the north (Fig. 1) and splays off the main Denali fault system in the south. Several of these secondary splays extend through the source zone of the landslide. Rocks in this zone consist of strike-slip fault-bounded volcanic and altered intrusive rocks. The lowermost rocks within the initiation zone of the landslide consist of interbedded volcanic breccia and volcaniclastic rocks of the Station Creek Formation (Fig. 8; Israel *et al.*, 2007). These rocks are relatively resistant and form erosional remnants (crags) that are visible in 1988 aerial photographs (Fig. 7a). A thin zone of highly altered Late Triassic ultramafic rock lies in fault contact above the Station Creek formation (Fig. 8; Israel *et al.*, 2007). Alteration is significant within the ultramafic unit, and much of the rock has altered to clay.

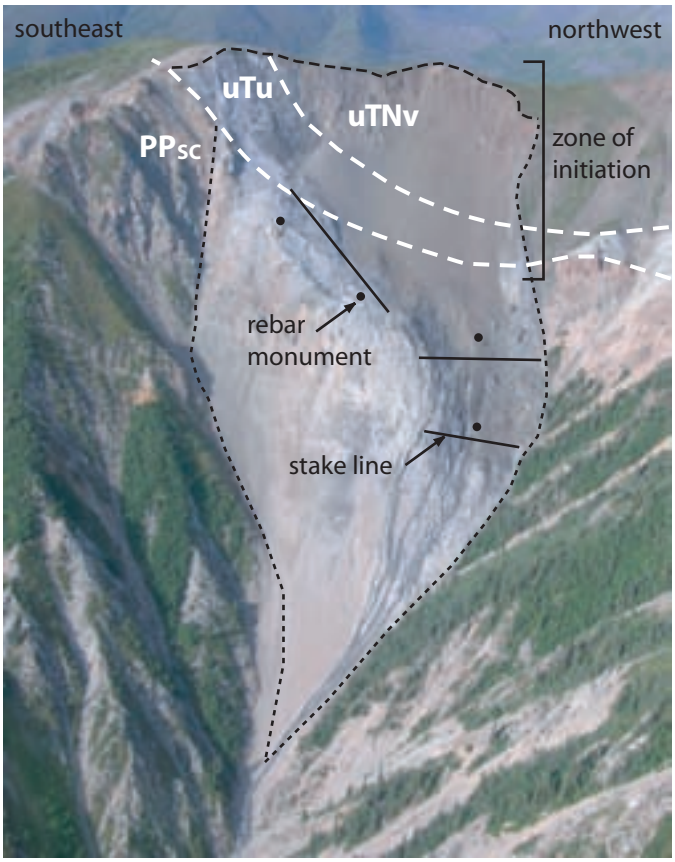

Figure 8. *An oblique aerial photograph view looking southwest at the Miles Ridge landslide. The locations of stake lines and monuments for deformation monitoring, as well as geological contacts are shown schematically (after Israel et al., 2007). Bedrock unit labels are defined as follows: PPsc = Pennsylvanian-Permian Station Creek Formation; uTu = Late Triassic Kluane mafic-ultramafic complex; uTNv = Late Triassic Nikolai formation.*

Vesicular basalt of the Nikolai formation is in fault contact adjacent to the ultramafic rock and extends to the top of Miles Ridge (Fig. 8; Israel *et al.*, 2007). Localized foliation within the Nikolai formation is parallel to movement along the strike-slip fault and is sub-parallel to the crest of Miles Ridge.

The drainage containing the Miles Ridge landslide is 1.9 km long and is divided into three morphologically distinct sections (Fig. 9). The upper section contains the landslide and is a steep basin filled with talus and bedrock crags. The middle section becomes narrower and contains a canyon at its base. The bottom section is an alluvial/colluvial fan in the White River valley.

FAILURE MECHANISM

Initial field observations in 2007 suggest that the Miles Ridge landslide is largely controlled by the character of the local bedrock. The Station Creek Formation appears to be buttressing the extremely incompetent overlying units of altered ultramafic rock and foliated basalt. Partial collapse of the Station Creek Formation has likely triggered failure of the overlying rocks. Active slumping along the headscarp in the Nikolai formation and debris-flow activity in the highly altered ultramafic rock indicates that the landslide is still actively responding to unstable slope conditions (Fig. 10).

The ongoing erosion of the initiation zone has caused a significant amount of fine- and coarse-grained debris to accumulate in the upper part of the drainage basin. This is most noticeable on the southeast side of the slide, where slopes may be stabilized at depth by crags of *in-situ* Station Creek Formation (Fig. 8). In contrast, the northwest side of the slide has no supporting *in-situ* rock and the debris is continually transported away by secondary debris flows and slides (Fig. 8). Further accumulation of debris on the southeast side of the slide will add stress to the supporting Station Creek Formation. With ongoing seismic activity in this area, it is probable that the southeast side of the basin will eventually collapse.

MONITORING PROGRAM

A monitoring program was initiated so that any future activity in the landslide can be detected and characterized. A series of wooden stake lines and rebar monuments were installed and surveyed using single-frequency differential GPS (DGPS) receivers (Thales Promark 3s) and post processing. A reference base station,

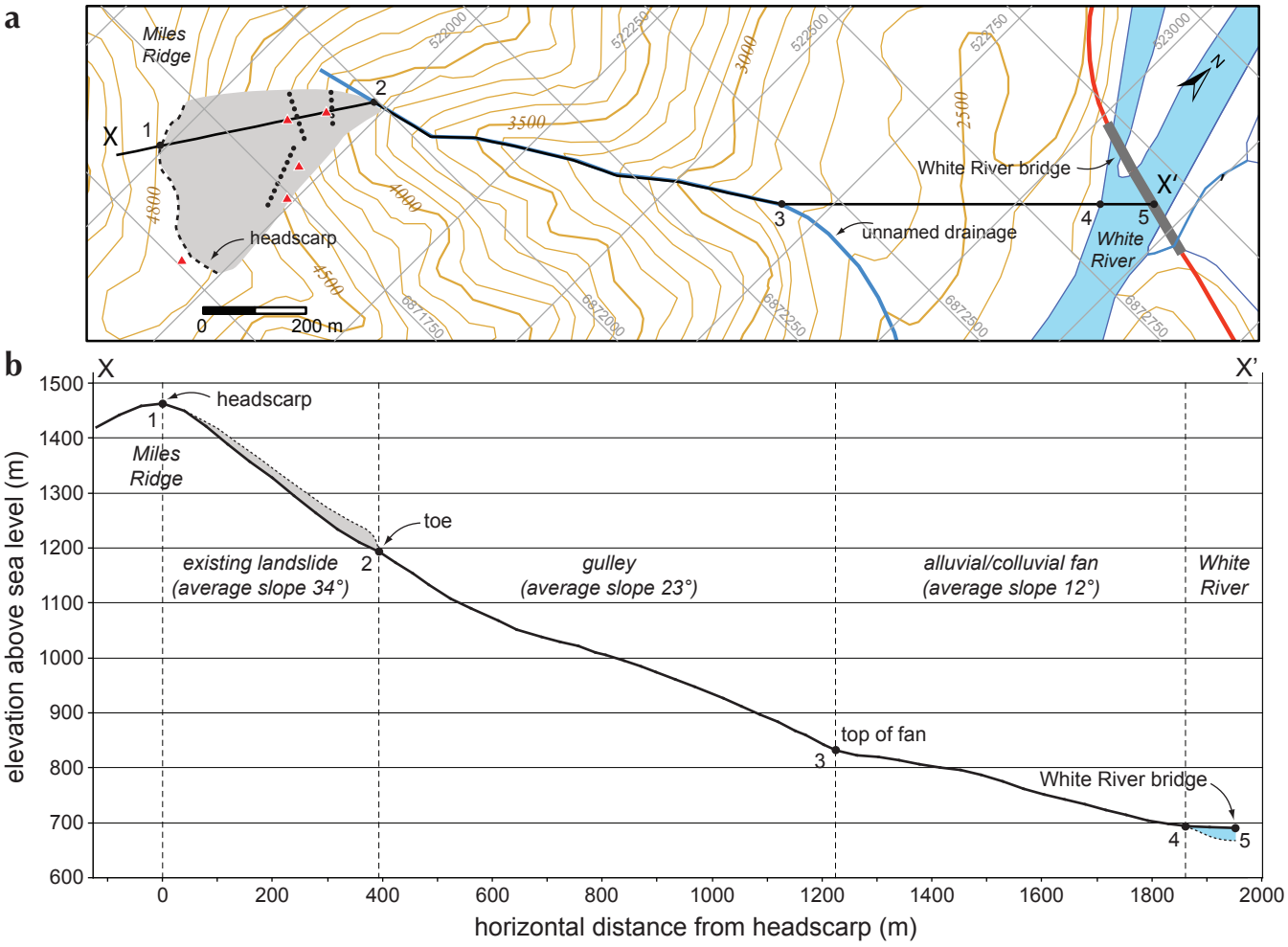

Figure 9. ***(a)*** *Plan view map of cross-section x-x'; triangles represent the rebar monuments and the dotted lines are the wooden stake lines constructed for the monitoring program.* ***(b)*** *Cross-section view of the slide area marking the morphological components and slope changes within the drainage and proximity of the landslide to the White River bridge.*

established at the White River RV Park about 2.5 km from the landslide, was occupied for 8 hours using a 1-second collection interval. The position of the base station was then determined by submitting this data in RINEX format to the Geodetic Survey of Canada's online post processing service (precise point positioning). Both the horizontal and vertical coordinates of the base station were fixed to within 10 cm at 95% confidence.

Although the survey was conducted on a steep north-facing slope, good satellite geometry was maintained for the entire survey. Due to time constraints, all GPS point positions were collected using 'stop-and-go' survey mode, where the DGPS rover receiver is leveled over a point using a range pole supported with a bi-pod; wooden stake positions were occupied for 1 minute and rebar monuments were occupied for 10 minutes. Horizontal and vertical positions were measured to within 8 mm, and most positions had reported accuracies of 5 mm or less (with 95% confidence). The survey lines and monuments were established as follows (Figs. 8 and 10):

1. 17 wooden stakes at approximately 30-m spacing were placed 1 m behind the headscarp in order to provide a reference for ongoing erosion of the initiation zone.
2. 49 stakes with 5-pace spacing were installed along the crest of the southeast debris accumulation zone (Figs. 8 and 9).
3. 26 stakes with 10-pace spacing were installed in two lines across the northwest active debris flow zone (Figs. 8 and 9).

Figure 10. *A view to the northwest along the headscarp of the Miles Ridge landslide. Active slumping is visible in the foreground. A pogo stick with 25-cm intervals is shown for scale.*

4. Four rebar monuments were established throughout the southeast and northwest debris zones as more permanent control points (Figs. 8 and 9).

POSSIBLE OUTCOMES OF A LARGE-SCALE LANDSLIDE

To date, landslide activity at Miles Ridge has been limited to the upper reaches of the drainage and has had no downstream impact. Preliminary field observations of rock characteristics in the source zone indicate that a larger landslide could occur in the future. If this debris follows a straight trajectory of 1.9 km in the direction of the upper two thirds of the drainage, it will directly impact the White River bridge (Fig. 9). However, near the mouth of the drainage, the stream channel deflects to the east side of the fan, redirecting the flow slightly away from the bridge. Depending on the magnitude of a future landslide, the run-out could follow the stream channel to the river, or it could abandon the stream channel at the apex of the fan, and continue its straight trajectory toward the bridge.

Four potential scenarios exist if a more catastrophic landslide were to occur:

1. The landslide debris will have limited run-out and settle in the upper reaches of the drainage with no impact to the White River bridge.
2. The landslide debris will lodge near the top of the confined or gullied portion of the drainage, temporarily damming it and causing ponding. Subsequent failure of the dam at a later time could then generate a catastrophic debris torrent into the White River.
3. The landslide debris will reach the White River and subsequently be deposited into the river channel. This could temporarily deflect the White River into the footings of the White River bridge and cause undercutting of the structure.
4. The landslide debris will travel 1.9 km in a straight trajectory, directly impacting the White River bridge.

CONCLUSIONS

The Miles Ridge landslide is currently active and threatens to impact the Alaska Highway corridor. The landslide is perched in the upper reaches of a steep drainage, less than 2 km from the White River bridge. The landslide source zone occurs within volcanic and highly altered ultramafic rocks that are bounded by strike-slip faults in the Denali fault system. Ongoing slumping and debris-flow activity in the initiation zone of the slide highlights the present instability of the site. A monitoring program was initiated to allow detection of future ground deformation at the site; rebar monuments and a series of wooden stake lines will be used to provide both survey control points and visual measures of ongoing deformation.

SUMMARY

The 2007 surficial geology mapping program in the Stevenson Ridge and northern Kluane map sheets addressed a number of diverse topics reflecting the complex landscape of southwest Yukon.

1. The study area straddles the glacial limits of four Pleistocene glacial periods. Preliminary results indicate that the earliest (pre-Reid) glacial limits are less extensive than previously thought in this area.
2. Placer gold potential was identified at the margin of the penultimate (Reid or Gladstone) glaciation where a drainage diversion occurred. The resulting change to the morphology of local drainages (*e.g.,* base level change and downcutting) is conducive for concentrating fluvial sediment and therefore potentially increasing placer gold grades.
3. Surficial geology features and stratigraphic exposures suggest that permafrost is widespread in the map area. This is reflected by a diverse number of periglacial landforms and processes that are found at all elevations across the landscape.
4. Finally, a monitoring program was established on a recently developed landslide located on Miles Ridge, above the White River bridge on the Alaska Highway. Future landslide activity at the site has the potential to impact the White River bridge and disrupt transportation along the Alaska Highway corridor. Future field observations will be used to further quantify the hazard at this site.

ACKNOWLEDGEMENTS

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U-Pb zircon ages for the Nordenskiold formation (Laberge Group) and Cretaceous intrusive rocks, Whitehorse trough, Yukon

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ABSTRACT

We report here the results of U-Pb zircon analyses for samples collected during regional mapping of the northern Whitehorse trough. Three samples of the Nordenskiold formation, a crystal-rich volcaniclastic unit that occurs at several stratigraphic horizons in the Laberge Group, yielded concordant U-Pb zircon ages of 188.1 ± 0.4 Ma, 187.2 ± 0.4 Ma and 186.5 ± 0.3 Ma, respectively. These results clearly indicate multiple eruptive events rather than recycling of the volcaniclastic material. Zircons from a thin layer of ash tuff in the Tanglefoot formation (Laberge Group) yielded a concordant U-Pb age of 187.1 ± 0.7 Ma, confirming correlation with the Nordenskiold formation. A sample of porphyritic granite from the only pluton intruding the northern Whitehorse trough, near Carmacks, yielded a concordant U-Pb zircon age of 112.8 ± 0.2 Ma, whereas a precise age could not be resolved from zircons extracted from a porphyry dyke intruding the Tantalus Formation in the southern Whitehorse trough.

RÉSUMÉ

Nous présentons ici les résultats des datations U-Pb sur les zircons pour des échantillons collecté lors de la cartographie régionale de la partie septentrionale de la fausse de Whitehorse. Trois échantillons de la formation de Nordenskiold, une unité de roche volcaniclastique riche en cristaux qui occupe plusieurs niveaux stratigraphiques dans le Groupe de Laberge, ont donnés des âges U-Pb sur les zircons concordants à 188,1 ± 0,4 Ma, 187,2 ± 0,4 Ma et 186,5 ± 0,3 Ma, respectivements. Ces résultats indiquent clairement qu'il y a eu plusieurs éruptions plutôt qu'un recyclage des dépôts volcaniclastiques. Les zircons extraits d'une mince couche de tuf fin au sein de la formation de Tanglefoot (Groupe de Laberge) ont aussi produis un âge U-Pb concordant à 187,1 ± 0,7 Ma, confirmant ainsi la corrélation avec la formation de Nordenskiold. Un échantillon de granit porphyrique collecter du seul pluton que l'on retrouve dans la partie septentrionale de la fausse de Whitehorse, près de Carmacks, a produit un âge U-Pb sur les zircons concordant à 112,8 ± 0,2 Ma, tandis que l'on ne peut pas déterminer un âge précis des zircons extraits d'un dyke de porphyre recoupant la Formation de Tantalus dans la portion sud de la fausse de Whitehorse.

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INTRODUCTION

The Whitehorse trough is an elongated, northwest-trending, predominantly marine sedimentary basin of Mesozoic age that extends some 650 km from near Dease Lake in northern British Columbia to just north of Carmacks in central Yukon (Fig. 1). It originated as a forearc basin in the Middle to Late Triassic, adjacent to the emerging Lewes River arc, and had received more than 7000 m of clastic deposits by Middle Jurassic time

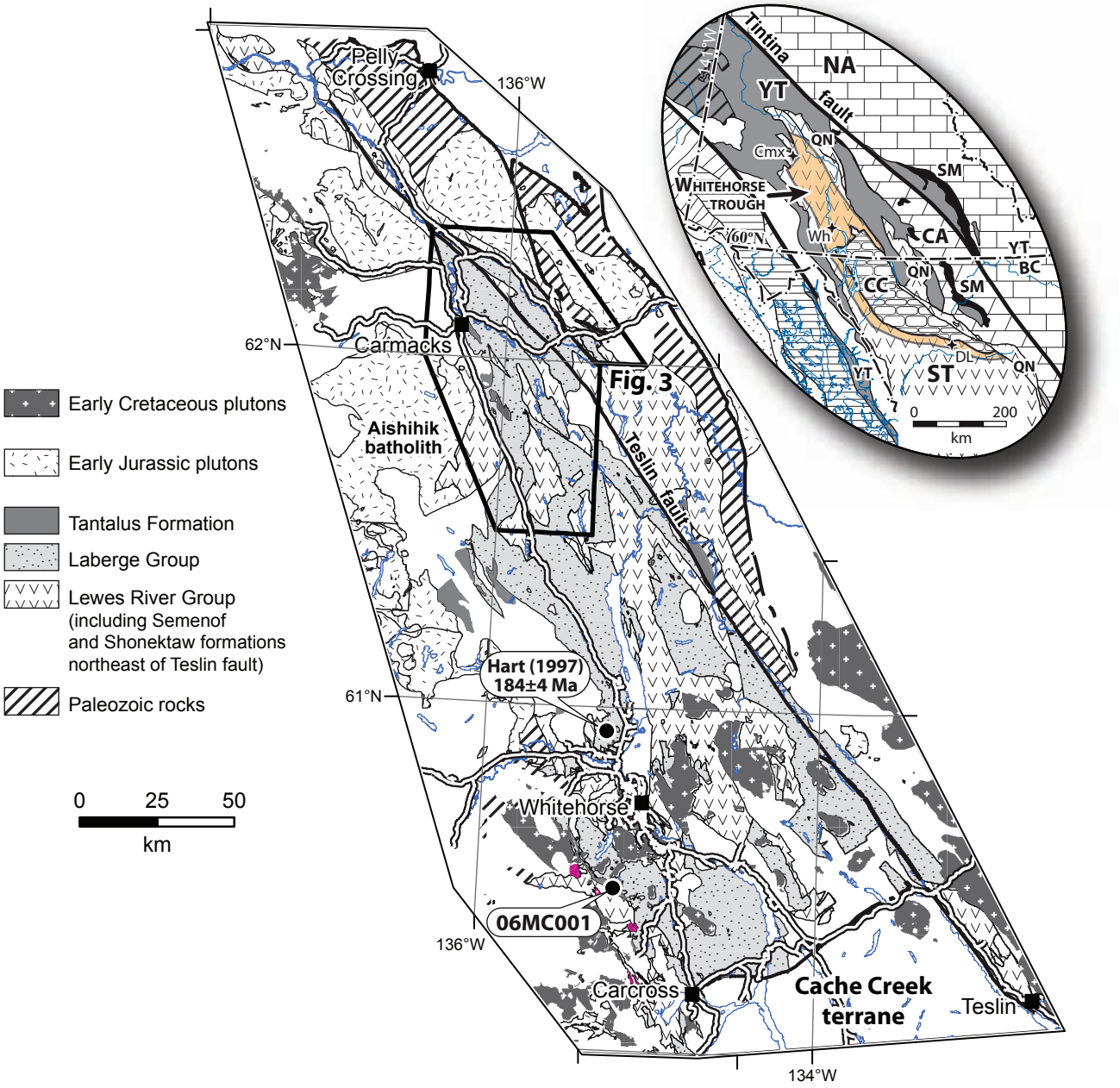

Figure 1. *Regional geology of Stikinia and the Whitehorse trough in south-central Yukon (compiled from Gordey and Makepeace, 1999; Colpron, 2006; and Colpron et al., 2007). Locations of sample 06MC001 (see text) and of a sample of Nordenskiold formation previously dated by Hart (1997) are also shown. Oval regional map shows the location of Whitehorse trough (shaded) with respect to terranes of the northern Cordillera. Terranes: CA = Cassiar (North America); CC = Cache Creek; NA = ancestral North America; QN = Quesnellia; SM = Slide Mountain; ST = Stikinia; YT = Yukon-Tanana; CMX = Carmacks; DL = Dease Lake; Wh = Whitehorse.*

(Wheeler, 1961; Tempelman-Kluit, 1979). It is underlain by late Paleozoic and early Mesozoic arc volcanic rocks of Stikinia and is structurally overlain, in southern Yukon and northern British Columbia, by the oceanic Cache Creek terrane (Fig. 1). The Whitehorse trough overlies Stikinia at its northern apex, where it is bounded on three sides by polydeformed and metamorphosed mid- to late Paleozoic rocks of the Yukon-Tanana terrane.

The Whitehorse trough includes the upper sedimentary strata of the Upper Triassic Lewes River Group (Aksala formation) and the clastic sedimentary and volcaniclastic rocks of the Lower to Middle Jurassic Laberge Group (Fig. 2; Wheeler, 1961; Hart, 1997). In Yukon, the Laberge Group comprises a southern unit of deep-water turbidite (sandstone-siltstone-mudstone) and mass-flow conglomerate, the late Hettangian(?) to Bajocian Richthofen formation (equivalent to the Inklin Formation of northern British Columbia; Johannson *et al.*, 1997; Mihalynuk, 1999); and a northern, in part coeval unit of shallow marine to fluvial sandstone, conglomerate and minor shale with coal seams, the Sinemurian to Bajocian Tanglefoot formation (Fig. 2; Tempelman-Kluit, 1984; Hart, 1997; Lowey, 2004). A crystal-lithic tuff unit, the Pliensbachian Nordenskiold formation, occurs at multiple stratigraphic levels and is common to both the Richthofen and Tanglefoot formations (Fig. 2).

The Laberge Group is unconformably overlain by the Middle Jurassic to Lower Cretaceous Tantalus Formation (Fig. 2; Bostock, 1936; Tempelman-Kluit, 1984; Long, 2005), a coal-bearing sequence of fluvial chert-pebble conglomerate and sandstone that marks the end of deposition in the Whitehorse trough. Near Whitehorse, the Whitehorse trough is intruded by numerous Early Cretaceous plutons (Fig. 1); a single Early Cretaceous pluton is mapped in the northern Whitehorse trough near Carmacks (Fig. 3; Colpron *et al.*, 2007; this study). Late Cretaceous volcanic rocks of the Mount Nansen and Carmacks groups unconformably overlie Jurassic and older strata throughout south-central Yukon.

In this report, we present the results of U-Pb zircon geochronology for three samples of Nordenskiold formation, one sample of ash tuff in the Tanglefoot formation and one sample of Cretaceous granite that were collected during regional mapping of the northern Whitehorse trough (Fig. 3; Colpron *et al.*, 2007). We also present U-Pb zircon geochronological results from a felsic dyke intruding the Tantalus Formation near Coal Lake, south of Whitehorse (06MC001 on Fig. 1).

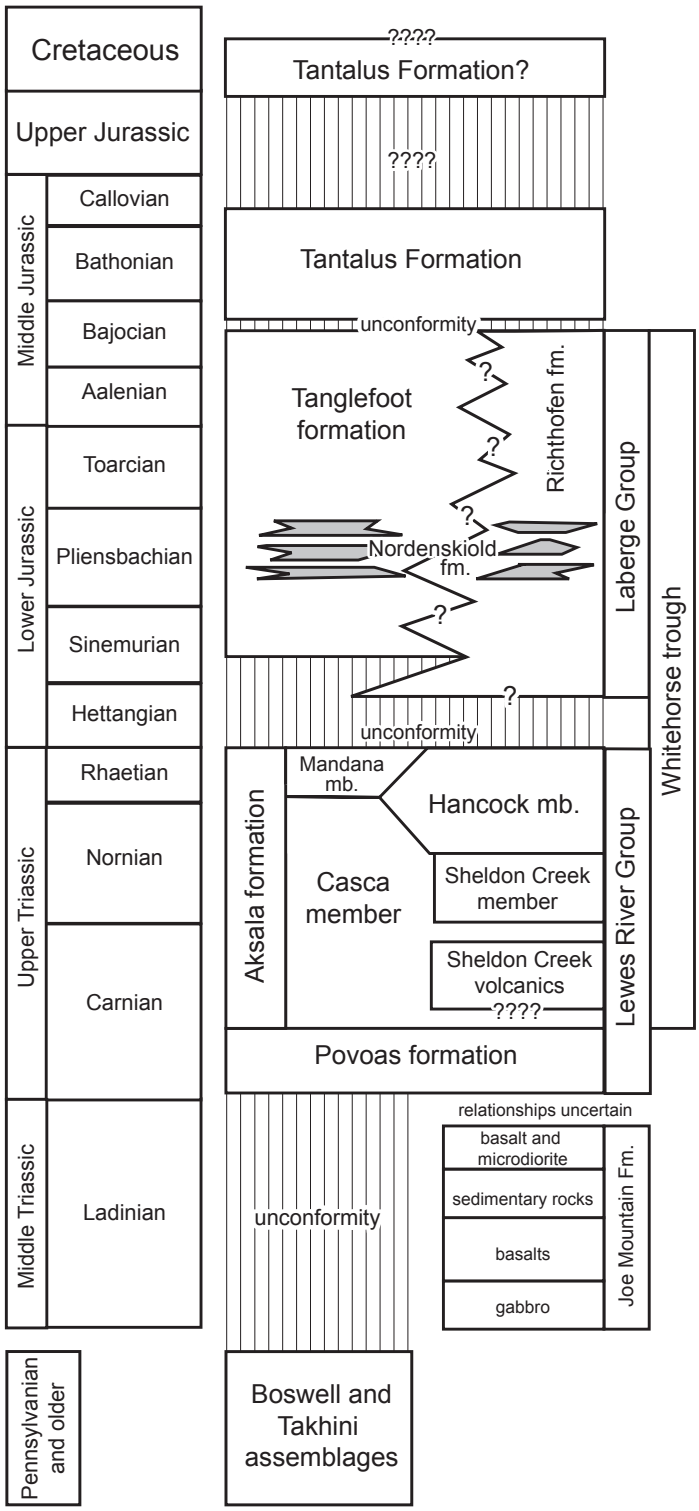

Figure 2. *Composite stratigraphic chart for Stikinia and Whitehorse trough in Yukon (modified after Hart, 1997; Lowey, 2004, and unpublished data). Fm = Formation; mb = member.*

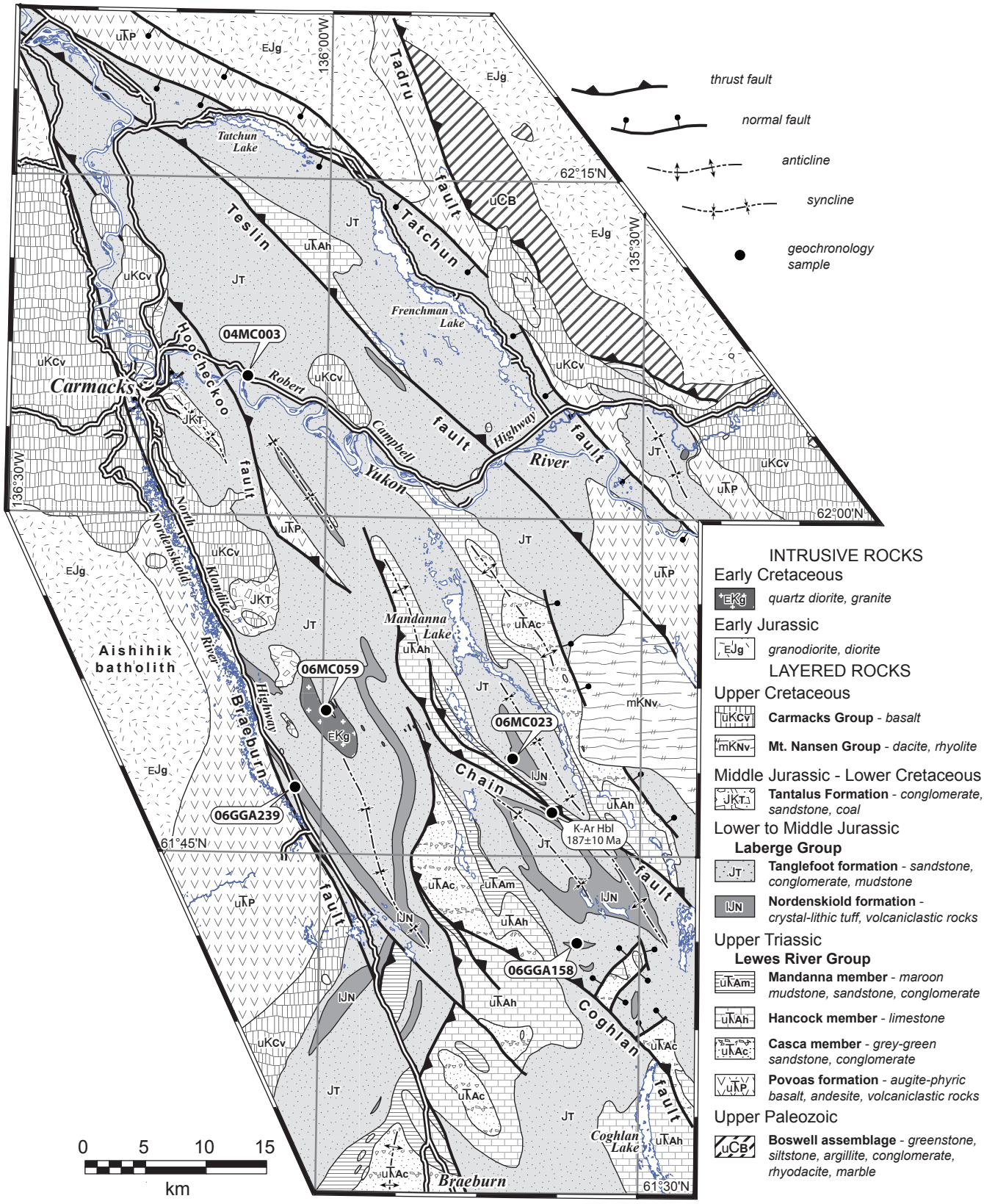

Figure 3. *Geological map of the northern Whitehorse trough (after Colpron et al., 2007) depicting the location of geochronological samples discussed in this report. Location of a sample of Nordenskiold formation previously dated by the K-Ar method on hornblende (Hbl; Tempelman-Kluit, 1984) is also shown.*

NORDENSKIOLD FORMATION

The Nordenskiold formation consists of a medium to coarse-grained, dark grey to orange-weathering, generally massive, crystal-rich volcaniclastic unit (Fig. 4a). It typically forms resistant, featureless outcrops, although locally, it may be soft and friable. Faint, parallel and cross-bedded laminations are only locally preserved (Fig. 4b). The Nordenskiold is composed predominantly of angular to subangular plagioclase and quartz crystals, with subordinate amounts of K-feldspar, biotite and hornblende in a cryptocrystalline matrix. Quartz crystals commonly have embayed grain boundaries. Sparse lithic clasts up to 10 cm in size are mostly of mudstone and siltstone, with rare occurrences of porphyritic dacite to andesite.

In the northern Whitehorse trough, volcaniclastic rocks of the Nordenskiold formation are interbedded with sandstone and conglomerate of the Tanglefoot formation (Fig. 3; Colpron *et al.*, 2007). They occur at several stratigraphic levels (three or more) within the Tanglefoot,

Figure 4. ***(a)*** *Typical exposure of crystal-rich volcaniclastic rocks of the Nordenskiold formation; this photo was taken at the sampling locality of Hart (1997), north of Whitehorse (see Fig. 1).* ***(b)*** *Decimetre-thick interbed of crystal-rich volcaniclastic rock within conglomerate of the Tanglefoot formation in the northern Whitehorse trough. Note cross-bedding near top of the bed indicating reworking of the pyroclastic material. At this locality, the conglomerate section contains three lenticular horizons of reworked tuffaceous sedimentary rocks.* ***(c)*** *A 3-cm-thick ash tuff horizon near the top of an organic-rich shale bed in sandstone of the Tanglefoot formation; this locality along the Robert Campbell Highway was sampled for geochronology (04MC003, Fig. 3).* ***(d)*** *Porphyritic hornblende diorite intruding the Whitehorse trough near Carmacks; photo by Steve Gordey.*

ranging from several hundred metres to a few centimetres in thickness. In addition, thin (<5 cm) ash tuff layers, found locally in mudstone-dominated horizons of the Tanglefoot formation (Fig. 4c), are likely lateral equivalents to the Nordenskiold.

In the southern Whitehorse trough, the Nordenskiold is interbedded with deep-water turbidite and conglomerate assigned to the Richthofen formation (Hart, 1997; Lowey, 2004). Volcaniclastic rocks occur in at least four distinct horizons within a narrow stratigraphic interval (Hart, 1997). Fossils and a single U-Pb zircon date (184.1 +4.2/-1.6 Ma; location shown on Fig. 1) suggest that the Nordenskiold formation is Pliensbachian in age (Hart, 1997). A similar age was also obtained from a tuffaceous horizon in the Inklin Formation of northern British Columbia (U-Pb zircon age of 186.6 ± 1.0 Ma; Johannson *et al.*, 1997).

The crystal-rich volcaniclastic rocks of the Nordenskiold formation generally have the composition of dacite to andesite (Fig. 5a; Table 1). On trace element diagrams, the Nordenskiold has the character of calc-alkaline arc rocks (Figs. 5b, 6a). Fillmore (2006) conducted a study comparing the Nordenskiold formation to coeval granitic batholiths in southern Yukon; she suggested on the basis of similar trace element geochemistry (Figs. 5, 6b) that the Aishihik batholith (186.0 ± 2.8 Ma; Johnston *et al.*, 1996), exposed immediately to the west of the Whitehorse trough (Fig. 1), is probably the magmatic parent for the volcaniclastic rocks of the Nordenskiold formation.

The Nordenskiold formation was probably emplaced as pyroclastic deposits. Hart (1997) suggested that volcaniclastic horizons occurring higher in the stratigraphy were likely reworked from older pyroclastic deposits. Evidence of reworking can be documented locally (e.g. Fig. 4b; Fillmore, 2006), although the typical lack of primary structures in these rocks precludes general application of this interpretation. In fact, the new geochronological data presented below clearly suggests deposition as a result of at least two or three distinct pyroclastic surges.

CRETACEOUS INTRUSIVE ROCKS

A single pluton (~2 x 7 km) and related dykes intrude the Tanglefoot formation in the northern Whitehorse trough (Fig. 3; Colpron *et al.*, 2007). Previous mapping had only recognized the occurrence of dykes in the region and assumed a Middle Jurassic age for these intrusive rocks (Tempelman-Kluit, 1984). On Saddle Mountain (see Colpron *et al.*, 2007), the main intrusive body consists of fine- to medium-grained, porphyritic hornblende (± biotite) diorite (Fig. 4d). A medium- to coarse-grained porphyritic granite phase that occurs locally was sampled for geochronology (see below). To the east, on Porphyry Mountain (see Colpron *et al.*, 2007), the intrusive rocks consist of a swarm of fine-grained hornblende diorite and feldspar porphyry dykes intruding coarse arkosic sandstone of the Tanglefoot formation.

The southern Whitehorse trough is intruded by large granitic plutons of Early Cretaceous age (generally south

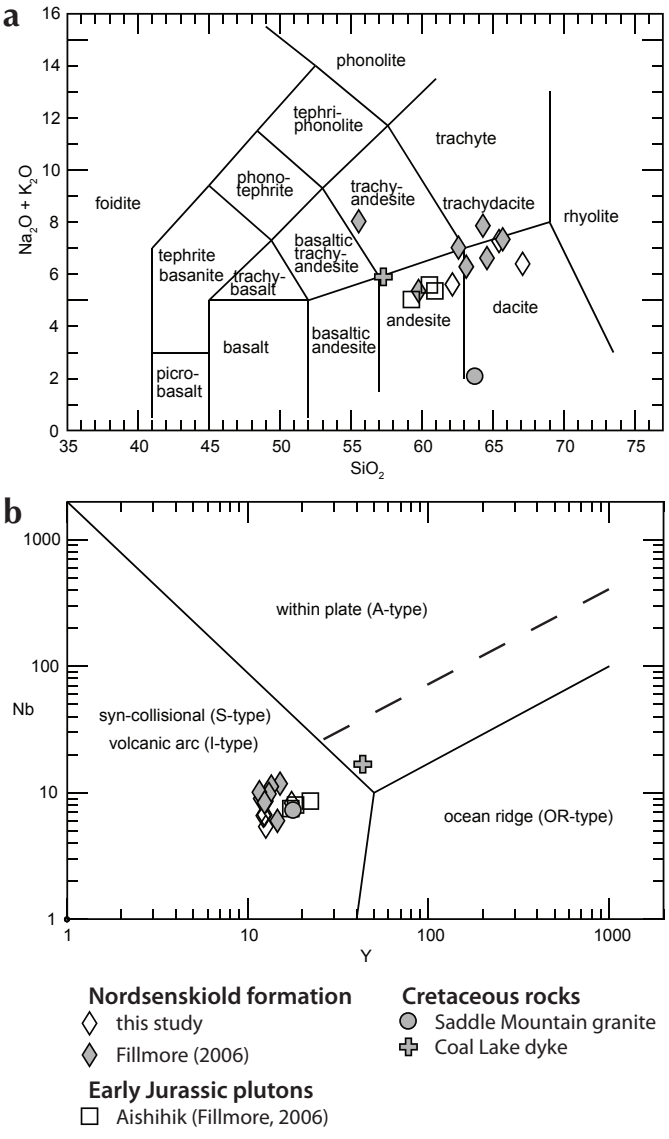

Figure 5. *Geochemical discriminant diagrams;* ***(a)*** *total alkali versus silica diagram of LeBas (1986); and* ***(b)*** *Niobium (Nb) vs. Yttrium (Y) diagram of Pearce et al. (1984). Geochemical data is presented in Table 1.*

Table 1. *Geochemical analyses for the Nordenskiold formation.*

Sample	06GGA158-1	06GGA239-1	06MC023-1	05N1-1	05N1-2M	05N1-3C	05N1-3M	05N1-5C	05N1-5M	05N2-13	05N8-30	05N8-31	05N8-32	06MC059-1	06MC001-1
unit	Nordenskiold										Aishihik batholith			Saddle Mountain	Coal Lake
Rock type	Dacite				Dacite - matrix	Dacite - clast	Dacite - matrix	Dacite - clast	Dacite - matrix	Dacite	Granitoid			granite	QFP
SiO_2	65.44	62.15	67.1	59.77	63.13	64.3	65.7	62.58	64.59	55.55	59.26	60.53	60.92	63.68	57.29
Al_2O_3	16.28	17.22	15.19	17.99	15.73	15.76	15.6	16.37	15.6	15.46	17.24	16.58	16.84	16.19	16.32
Fe_2O_3	4.06	5.05	4.07	5.68	4.47	4.88	4.2	5.76	5	3.22	6.54	6.01	5.98	4.36	7.55
MnO	0.052	0.058	0.059	0.101	0.075	0.071	0.067	0.083	0.071	0.102	0.118	0.108	0.1	0.063	0.137
MgO	1.07	1.26	1.11	2.76	1.65	1.76	1.66	2.4	2.09	0.48	2.81	2.67	2.51	2.44	1.87
CaO	3.5	3.76	3.13	4.4	5.25	3.18	3.32	2.52	2.91	8.74	6.5	5.79	5.68	3.74	3.26
Na_2O	4.45	3.9	4.22	3.83	3.86	4.55	4.48	4.6	4.31	5.57	3.82	3.61	3.84	4.46	4.79
K_2O	2.82	1.71	2.18	1.53	2.43	3.31	2.86	2.42	2.31	2.46	1.21	1.98	1.52	2.53	1.11
TiO_2	0.47	0.51	0.38	0.515	0.389	0.421	0.415	0.417	0.436	0.493	0.673	0.637	0.689	0.51	1.45
P_2O_5	0.19	0.19	0.12	0.2	0.15	0.17	0.16	0.17	0.18	0.22	0.29	0.27	0.28	0.17	0.74
Cr_2O_3	< 0.01	< 0.01	< 0.01											0.01	< 0.01
LOI	1.44	3.93	2.72	2.92	2.85	1.13	1.45	2.44	2.49	7.29	1.4	1.06	1.21	1.63	5.66
Total	99.77	99.74	100.3	99.7	99.98	99.53	99.91	99.75	99.99	99.58	99.86	99.25	99.57	99.78	100.2
V	73	100	80	104	76	74	71	80	99	91	117	122	111	80	100
Cr	40	40	60	90	70	100	90	90	80	140	100	90	70	60	< 20
Co	7	9	6	7	2	8	4	9	7	< 1	4	6	6	7	11
Ni	< 20	< 20	< 20	< 20	< 20	< 20	< 20	< 20	< 20	< 20	< 20	< 20	< 20	< 20	< 20
Cu	10	20	< 10	20	< 10	< 10	< 10	< 10	< 10	30	30	< 10	< 10	20	< 10
Zn	250	80	80	100	60	60	60	90	90	90	110	100	100	60	100
Ga	20	21	20	25	22	21	21	23	21	17	24	23	24	20	23
Ge	1.1	1.2	1.1	2.4	1.9	1.6	1.4	1.2	0.8	< 0.5	< 0.5	1	0.5	1.1	1.7
As	< 5	28	6	< 5	< 5	< 5	< 5	< 5	< 5	< 5	< 5	< 5	< 5	< 5	12
Rb	67	49	56	38	51	79	70	59	56	48	28	41	41	87	26
Sr	665	1210	626	903	634	469	561	552	536	636	866	852	851	810	276
Y	12.4	12.6	12.2	15.1	12.6	13.5	13.1	11.6	12.4	14.6	22.2	18.4	17.3	14.2	43.3
Zr	105	105	117	120	106	114	101	109	99	106	104	153	184	116	337
Nb	6.7	5.4	6.6	11.8	8.6	11.2	9.8	10.1	8.4	6	8.6	8	7.5	6.7	16.8
Mo	< 2	< 2	< 2	< 2	< 2	< 2	< 2	< 2	< 2	< 2	< 2	< 2	< 2	< 2	4
Ag	< 0.5	< 0.5	< 0.5	< 0.5	< 0.5	< 0.5	< 0.5	< 0.5	< 0.5	< 0.5	< 0.5	< 0.5	< 0.5	< 0.5	< 0.5
In	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1
Sn	< 1	1	1	4	4	5	5	4	5	6	6	6	7	1	2
Sb	1.5	1.7	1.9	< 0.2	0.3	0.3	0.3	0.2	0.2	0.3	< 0.2	< 0.2	< 0.2	2	2.3
Cs	1	2.3	1	1	0.8	1.1	1	1.9	1.9	1.6	0.2	0.5	0.3	2.6	0.9
Ba	1440	1350	1560	1355	1280	1281	1323	1046	1109	1911	714	2201	862	1370	1170
La	22	20.4	25.2	20.5	30.2	25.2	22.1	15	19.5	19.2	24.7	26.2	32.1	28.9	64.8
Ce	41.8	39.1	46.4	39.6	45.6	48.2	42.2	30.8	37.2	38.4	49.4	51.2	57.8	52	124
Pr	4.69	4.43	5.07	4.55	4.74	5.21	4.65	3.52	4.14	4.44	6.03	5.81	6.26	5.64	14.1
Nd	17.4	17.2	18.8	17.8	17.6	18.8	17.3	13.6	15.8	17.2	24.4	22.3	22.5	19.9	53.5
Sm	3.21	3.32	3.3	3.58	3.34	3.41	3.31	2.63	3.02	3.26	5.31	4.4	4.18	3.52	9.9
Eu	0.973	1.07	0.997	1.01	0.938	0.908	0.938	0.756	0.87	0.909	1.43	1.24	1.13	1.13	2.63
Gd	2.63	2.71	2.54	3.25	2.88	3.02	2.97	2.28	2.62	2.84	4.88	4.04	3.72	2.64	8.15
Tb	0.41	0.43	0.39	0.46	0.41	0.43	0.42	0.35	0.37	0.42	0.76	0.59	0.57	0.44	1.36
Dy	2.2	2.42	2.15	2.43	2.09	2.26	2.14	1.81	2.03	2.37	3.94	3.11	2.91	2.54	7.58
Ho	0.42	0.46	0.41	0.45	0.41	0.44	0.42	0.36	0.39	0.48	0.76	0.6	0.54	0.48	1.41
Er	1.25	1.31	1.17	1.33	1.22	1.32	1.25	1.11	1.18	1.42	2.19	1.75	1.58	1.38	4.14
Tm	0.186	0.2	0.174	0.206	0.179	0.204	0.191	0.174	0.178	0.215	0.318	0.266	0.23	0.211	0.629
Yb	1.23	1.31	1.12	1.37	1.15	1.38	1.23	1.21	1.2	1.41	1.99	1.7	1.4	1.37	4.09
Lu	0.199	0.201	0.17	0.204	0.176	0.208	0.177	0.189	0.188	0.209	0.289	0.236	0.203	0.203	0.593
Hf	2.8	2.6	2.9	3	2.8	3.2	2.8	3	2.6	3	2.9	3.8	4.5	3	7.4
Ta	0.6	0.44	0.59	0.5	0.53	0.78	0.66	0.68	0.54	0.32	0.44	0.35	0.23	0.71	1.24
W	< 0.5	1	< 0.5	0.6	0.6	0.5	0.5	0.9	1	0.8	< 0.5	< 0.5	< 0.5	0.7	1
Tl	0.31	0.31	0.28	0.19	0.27	0.39	0.34	0.42	0.39	0.17	0.14	0.25	0.21	0.55	0.18
Pb	27	13	12	19	9	15	12	11	10	21	12	13	13	20	15
Bi	< 0.1	< 0.1	0.1	0.2	< 0.1	0.1	0.1	0.3	0.2	< 0.1	< 0.1	< 0.1	< 0.1	0.5	0.2
Th	6.11	5.02	4.67	4.77	4.87	7.5	6.07	7.38	5.1	4.65	3.85	4.29	5.25	9.58	20.1
U	2.09	0.82	1.19	2	2.18	3.13	2.49	2.69	2.44	1.77	0.56	0.42	0.38	3.06	5.62
Sc	6.8	9.3	6.3	10	8	9	8	8	10	9	15	14	12	9	14.8

Notes: 1- samples with the prefix "05N-" are reproduced from Fillmore (2006)

All samples were analysed at Activation Laboratories, Ancaster, Ontario, by XRF and ICP-MS (Code 4 Litho Research) following the procedures outlined at www.actlabs.com

of Whitehorse, Fig. 1). Near Coal Lake, approximately 27.5 km southwest of Whitehorse (see location for 06MC001 on Figure 1), a <1.5-m-wide dyke of fine-grained quartz-feldspar porphyry intrudes sandstone and mudstone of the Tantalus Formation approximately 3 m above the main coal seam at the Whitehorse Coal deposit (105D 042, Yukon MINFILE[1]). Long and Lowey (2006) report an occurrence of peperite at the margin of a similar dyke in the area, although peperite could not be confirmed at our sampling locality. A sample of the dyke was collected with the aim of providing a minimum age constraint on the Tantalus Formation in this region.

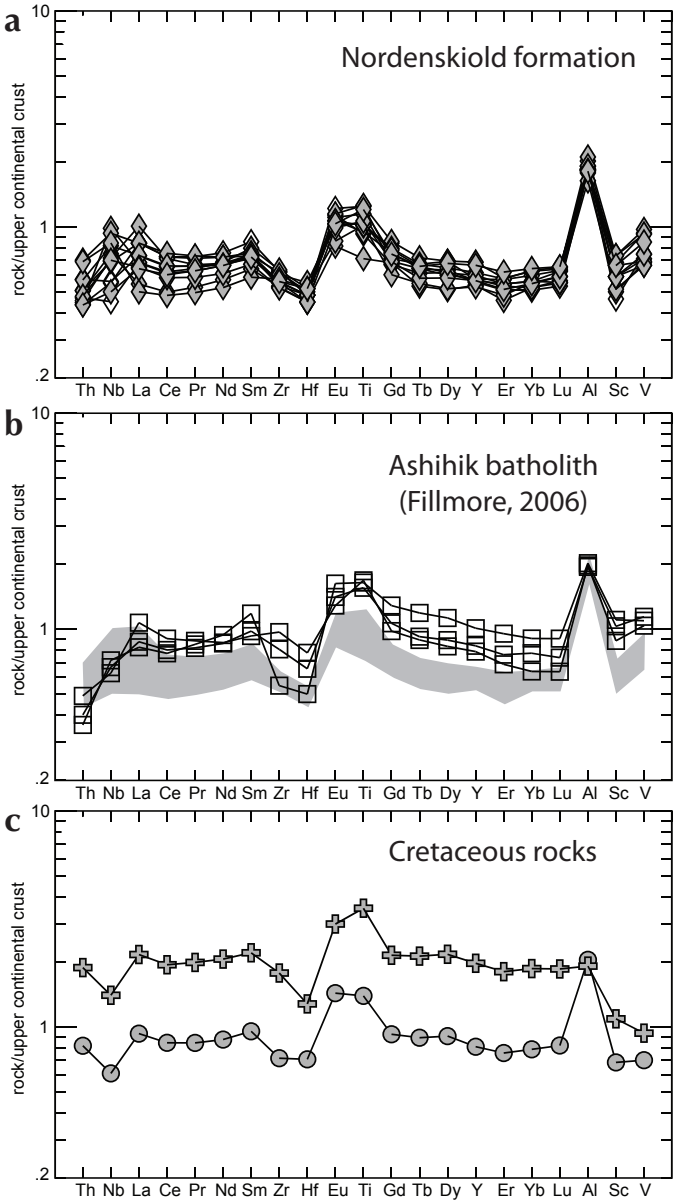

Figure 6. *Trace-element patterns normalized to upper continental crust values of McLennan (2001).* ***(a)*** *Nordenskiold formation: samples from this study (open diamond) and from Fillmore (2006; grey diamond).* ***(b)*** *Aishihik batholith: samples from Fillmore (2006); grey shaded area represents envelope of Nordenskiold data from (a).* ***(c)*** *Cretaceous intrusive rocks: Saddle Mountain granite (circle), Coal Lake porphyry dyke (cross). Geochemical data is presented in Table 1.*

U-PB GEOCHRONOLOGY

All sample preparation and analytical work for the U-Pb isotopic ages presented here were conducted at the Pacific Centre for Isotopic and Geochemical Research (PCIGR) at the Department of Earth and Ocean Sciences, University of British Columbia, using the Thermal Ionization Mass Spectroscopy (U-Pb TIMS) technique. Details of analytical techniques are presented in Logan *et al.* (2007). U-Pb results are plotted on standard concordia diagrams (Fig. 7) and listed in Table 2.

Figure 7 *(next page)****.*** *U-Pb concordia plots for samples of the Nordenskiold and Tanglefoot formations, and Cretaceous intrusives rocks. Error ellipses display zircon Pb/U data at the 2σ confidence level. Concordia curve is shown as a band that includes decay constant errors.* ***(a)*** *Nordenskiold formation, 06GCA158: three-point concordia age, excluding discordant grain interpreted to contain older inherited core. Lower part of reference discordia line fit through all data gives an upper intercept age of 988 ± 680 Ma, (2σ errors) providing the best estimate for age of inherited core;* ***(b)*** *Nordenskiold formation, 06GCA239: two-point concordia age, excluding results for two older grains interpreted to contain older inherited cores. Lower part of reference discordia line fit through all data gives an upper intercept age of 743 ± 310 Ma, (2σ errors) providing the best estimate for an averaged age of inherited cores in two older grains;* ***(c)*** *Nordenskiold formation, 06MC023: five-point concordia age;* ***(d)*** *ash tuff layer in the Tanglefoot formation, 04MC003: three-point concordia age, excluding youngest grain that does not overlap with all others;* ***(e)*** *Saddle Mountain granite, 06MC059: four-point concordia age;* ***(f)*** *quartz-feldspar prophyry intruding Tantalus Formation near Coal Lake, 06MC001: precise age interpretation not possible given significant dispersion of age results.*

[1] *www.geology.gov.yk.ca/databases_gis.html.*

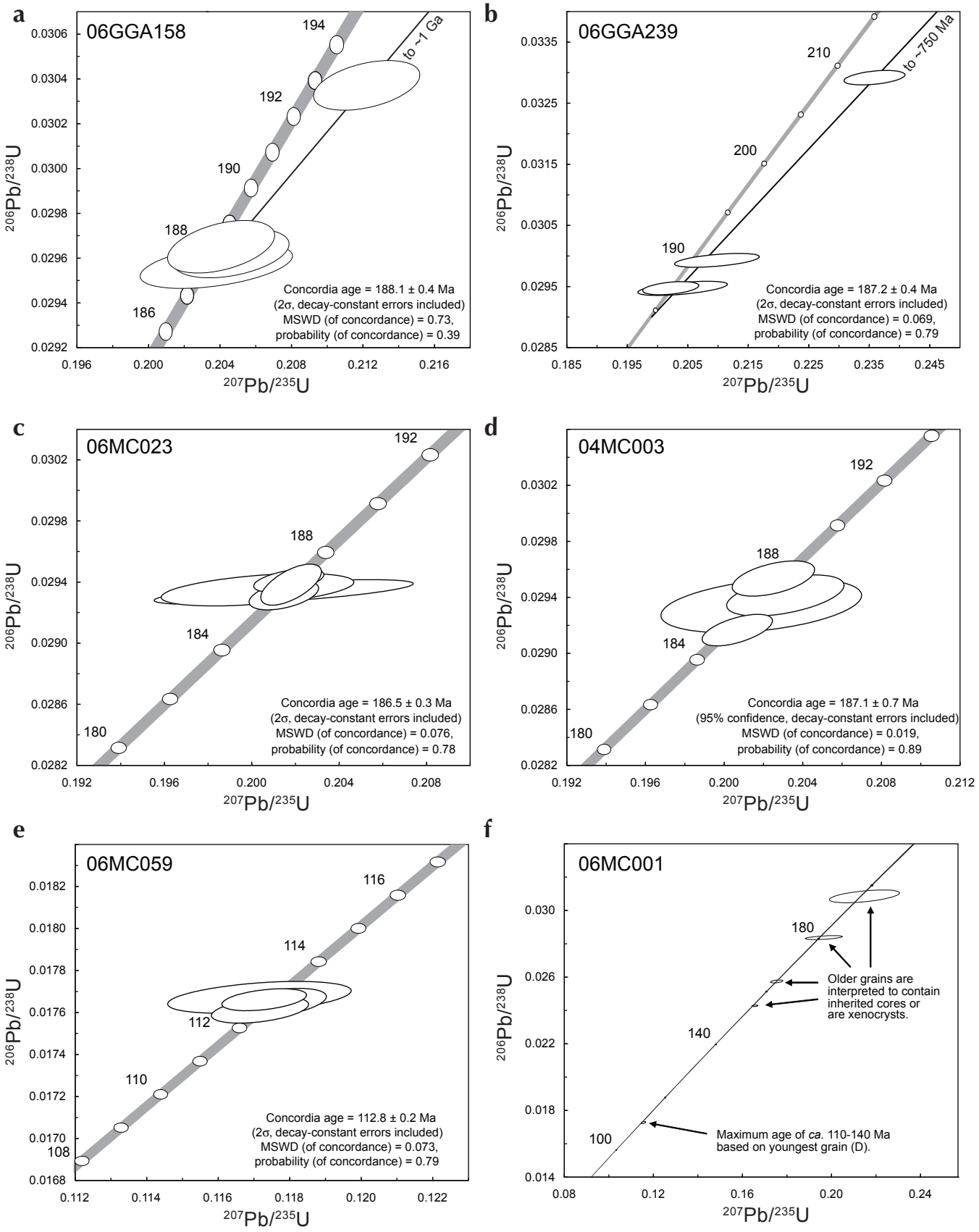

Figure 7 *(caption on previous page)***.**

Table 2. *U-Pb Thermal Ionization Mass Spectroscopy analytical data.*

Fraction[1]	Wt	U[2]	Pb*[3]	^{206}Pb	Pb[5]	Th/U[6]	Isotopic ratios ±1s,%[7]			ρ[8]	%[9]	Apparent ages ±2s,Ma[7]		
	(μg)	(ppm)	(ppm)	^{204}Pb	(pg)		$^{206}Pb/^{238}U$	$^{207}Pb/^{235}U$	$^{207}Pb/^{206}Pb$		discordant[9]	$^{206}Pb/^{238}U$	$^{207}Pb/^{235}U$	$^{207}Pb/^{206}Pb$
06MC023 (UTM coordinates10, Zone 8, 463127E, 6854639N)														
A	6	254.7	7.8	3300	0.8	0.50	0.02932 ± 0.14	0.2015 ± 0.32	0.04985 ± 0.28	0.46601	0.9	186.3 ± 0.5	186.4 ± 1.1	188.0 ± 13.1/13.2
B	7	304.6	9.3	4668	0.8	0.50	0.02938 ± 0.19	0.2018 ± 0.28	0.04982 ± 0.22	0.62983	-0.1	186.7 ± 0.7	186.7 ± 1.0	186.4 ± 10.1/10.1
C	3	557.4	16.9	1263	2.4	0.47	0.02934 ± 0.11	0.2015 ± 1.20	0.04981 ± 1.12	0.67939	0.0	186.4 ± 0.4	186.4 ± 4.1	186.3 ± 51.5/53.2
D	5	247.7	7.4	1281	1.8	0.41	0.02935 ± 0.15	0.2003 ± 0.89	0.04950 ± 0.84	0.46585	-8.9	186.5 ± 0.6	185.4 ± 3.0	171.4 ± 38.5/39.5
E	7	344.7	10.4	1684	2.6	0.46	0.02941 ± 0.11	0.2017 ± 0.32	0.04975 ± 0.29	0.49730	-2.1	186.9 ± 0.4	186.6 ± 1.1	183.2 ± 13.3/13.4
04MC003 (UTM coordinates, Zone 8, 441252E, 6886234N)														
A	3	734.7	22.4	1307	3.1	0.52	0.02917 ± 0.16	0.2007 ± 0.36	0.04991 ± 0.30	0.59231	2.9	185.3 ± 0.6	185.7 ± 1.2	190.7 ± 13.8/13.9
B	3	519.2	15.9	1428	2.0	0.49	0.02954 ± 0.17	0.2025 ± 0.42	0.04973 ± 0.37	0.49877	-2.9	187.6 ± 0.6	187.3 ± 1.4	182.5 ± 16.9/17.1
C	2	535.2	16.5	1067	1.9	0.54	0.02934 ± 0.27	0.2019 ± 1.03	0.04991 ± 0.96	0.37099	2.2	186.4 ± 1.0	186.7 ± 3.5	190.6 ± 44.1/45.3
E	3	447.7	13.5	882.4	2.8	0.45	0.02941 ± 0.20	0.2031 ± 0.60	0.05009 ± 0.53	0.49144	6.2	186.9 ± 0.8	187.8 ± 2.1	199.1 ± 24.3/24.7
06GGA158 (UTM coordinates, Zone 8, 468403E, 6839376N)														
A	2	365.3	11.2	522.5	2.6	0.49	0.02957 ± 0.14	0.2038 ± 0.85	0.05000 ± 0.80	0.45061	3.8	187.8 ± 0.5	188.4 ± 2.9	195.1 ± 36.5/37.4
B	2	470.1	14.6	861.4	2.0	0.53	0.02962 ± 0.15	0.2047 ± 0.64	0.05011 ± 0.60	0.38623	6.1	188.2 ± 0.6	189.1 ± 2.2	200.3 ± 27.7/28.2
C	2	485.0	15.1	803	2.3	0.54	0.02965 ± 0.16	0.2041 ± 0.60	0.04992 ± 0.55	0.43225	1.7	188.4 ± 0.6	188.6 ± 2.1	191.5 ± 25.3/25.7
E	2	557.6	17.8	1632	1.3	0.54	0.03037 ± 0.15	0.2122 ± 0.57	0.05068 ± 0.53	0.42113	15.0	192.9 ± 0.6	195.4 ± 2.0	226.2 ± 24.2/24.5
06GGA239 (UTM coordinates, Zone 8, 445057E, 6852318N)														
A	2	262.8	8.3	779.7	1.3	0.53	0.02993 ± 0.16	0.2100 ± 1.36	0.05088 ± 1.28	0.51707	19.5	190.1 ± 0.6	193.5 ± 4.8	235.3 ± 58.2/60.3
B	2	352.7	12.3	929.6	1.6	0.55	0.03292 ± 0.15	0.2358 ± 0.87	0.05197 ± 0.82	0.39725	26.9	208.8 ± 0.6	215.0 ± 3.4	283.9 ± 37.1/37.9
D	2	358.0	11.3	1085	1.2	0.62	0.02947 ± 0.15	0.2023 ± 0.93	0.04979 ± 0.88	0.40156	-1.2	187.3 ± 0.6	187.1 ± 3.2	185.1 ± 40.5/41.5
E	2	284.3	8.8	710.3	1.5	0.52	0.02947 ± 0.16	0.2043 ± 1.47	0.05027 ± 1.39	0.56939	10.0	187.3 ± 0.6	188.8 ± 5.1	207.7 ± 63.0/65.6
06MC001 (UTM coordinates, Zone 8, 485376E, 6706458N)														
A	2	510.3	13.1	1610	1.0	0.33	0.02574 ± 0.14	0.1752 ± 0.62	0.04936 ± 0.57	0.42131	0.7	163.8 ± 0.5	163.9 ± 1.9	165.0 ± 26.6/27.0
B	1.6	123.4	3.8	107.6	4.2	0.31	0.03085 ± 0.51	0.2144 ± 3.00	0.05041 ± 2.76	0.53002	8.6	195.9 ± 2.0	197.3 ± 10.7	214.0 ± 123.0/133.1
C	1.2	946.1	23.5	1943	0.9	0.44	0.02428 ± 0.10	0.1655 ± 0.33	0.04943 ± 0.30	0.42887	8.1	154.7 ± 0.3	155.5 ± 1.0	168.1 ± 14.2/14.3
D	1.2	1269.2	22.2	1778	0.9	0.41	0.01728 ± 0.16	0.1157 ± 0.39	0.04856 ± 0.36	0.40446	13.1	110.4 ± 0.4	111.2 ± 0.8	126.9 ± 16.7/16.9
E	0.5	774.9	22.4	528.9	1.3	0.43	0.02837 ± 0.18	0.1963 ± 1.72	0.05017 ± 1.63	0.53843	11.2	180.4 ± 0.6	182.0 ± 5.7	202.8 ± 74.1/77.6
06MC059 (UTM coordinates, Zone 8, 447484E, 6858476N)														
A	2.8	782.0	13.5	1758	1.4	0.28	0.01761 ± 0.14	0.1172 ± 0.47	0.04826 ± 0.43	0.42995	-0.7	112.6 ± 0.3	112.5 ± 1.0	111.8 ± 20.2/20.4
B	2.3	1103.1	19.1	2206	1.3	0.29	0.01766 ± 0.12	0.1173 ± 0.41	0.04817 ± 0.38	0.42160	-4.8	112.9 ± 0.3	112.6 ± 0.9	107.7 ± 17.8/17.9
C	1.9	970.3	16.8	1184	1.7	0.29	0.01767 ± 0.18	0.1172 ± 0.89	0.04809 ± 0.83	0.41729	-9.0	112.9 ± 0.4	112.5 ± 1.9	103.6 ± 38.9/39.8
D	1.7	1411.4	24.2	2243	1.2	0.25	0.01765 ± 0.16	0.1177 ± 0.47	0.04837 ± 0.43	0.43674	3.8	112.8 ± 0.4	113.0 ± 1.0	117.2 ± 20.0/20.2

[1]All analysed zircon grains air abraded; all single grain analyses.

[2]U blank correction of 0.2 pg ± 20%; U fractionation corrections were measured for each run with a double $^{233-235}U$ spike.

[3]Radiogenic Pb.

[4]Measured ratio corrected for spike and Pb fractionation of 0.23/amu ± 20% (Daly collector) a value determined by repeated analysis of NBS Pb 982 reference material throughout the course of this study.

[5]Total common Pb in analysis based on blank isotopic composition: $^{206}Pb/^{204}Pb$ = 18.5 ± 3%, $^{207}Pb/^{204}Pb$ = 15.5 ± 3%, $^{208}Pb/^{204}Pb$ = 36.4 ± 3%.

[6]Model Th/U derived from radiogenic ^{208}Pb and the $^{207}Pb/^{206}Pb$ age of fraction.

[7]Blank correction of 0.5-1.0 pg Pb with blank isotopic composition listed above; 0.2 pg U. Remaining common Pb is based on Stacey-Kramer model (Stacey and Kramer, 1975) compositions at the age of the rock or fraction; 06MC023, 06MC003: 187 Ma; 06GCA158, 06GCA239: 188 Ma; 06MC059: 113 Ma; 06MC001: $^{207}Pb/^{206}Pb$ age of the fraction.

[8]Correlation coefficient.

[9]Discordance in % to origin.

[10]Universal Transverse Mercator (UTM) projection, North American Datum 1983 (NAD83).

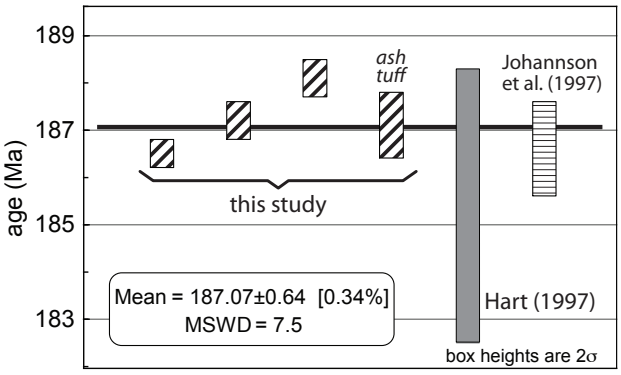

Figure 8. *Weighted-average age plot for all dated volcaniclastic rock units in the Laberge Group.*

U-Pb single-grain analyses were performed on air-abraded zircons recovered from six samples. Three of these samples were collected from mappable horizons of Nordenskiold formation in the northern Whitehorse trough (06GGA158, 06GGA239 and 06MC023 on Fig. 3; Colpron *et al.*, 2007). All three Nordenskiold samples yielded concordant and overlapping results that allow concordia age interpretations of 188.1 ± 0.4 Ma, 187.2 ± 0.4 Ma and 186.5 ± 0.3 Ma, respectively (Figs. 7a-c; K.R. Ludwig[1], pers. com. 2003). Zircons from two of these Nordenskiold samples (06GGA158 and 06GGA239) also gave older discordant results indicating the presence of inherited cores (Figs. 7a and b). It is important to note that the three Nordenskiold samples yielded different U-Pb zircon ages that do not have overlapping errors (Fig. 8), thus indicating three distinct crystallization (eruptive?) events.

Zircons from a 3-cm-thick ash tuff layer near the top of an organic-rich mudstone horizon in the Tanglefoot formation along Robert Campbell Highway, ~9 km east of Carmacks (04MC003; Figs. 3, 4c), also yielded concordant and overlapping results indicating a concordia age of 187.1 ± 0.7 Ma (Fig. 7d). This age is in good agreement with the ages presented above for the Nordenskiold formation (Fig. 8), confirming the interpretation that ash tuff horizons in the Tanglefoot formation are lateral equivalents to the Nordenskiold.

Four single zircon grains from the Saddle Mountain granite (06MC059; Fig. 3) yielded overlapping concordant results and a concordia age of 112.8 ± 0.2 Ma (Fig. 7e). This age is slightly older than nearby Cretaceous magmatism in the Dawson Range, west of Carmacks (U-Pb zircon ages between 106-108 Ma; Breitsprecher and Mortensen, 2004), but is comparable with the ages of older Cretaceous plutons intruding the southern Whitehorse trough near Whitehorse (*ca.* 110-115 Ma; Hart, 1997).

Age results for the quartz-feldspar porphyry dyke collected near Coal Lake, southwest of Whitehorse (06MC001 on Fig. 1), exhibit significant dispersion such that a precise age could not be confidently estimated (Fig. 7f). However, the youngest zircon grain (06MC001-D, Table 2) suggests a maximum age of ~110-140 Ma for the dyke, which is in general agreement with the age of mid-Cretaceous magmatism in the area (Hart, 1997).

SUMMARY AND CONCLUSIONS

The new U-Pb zircon geochronological data presented here provide the most precise age constraints for the Nordenskiold formation to date. Our results confirm the Pliensbachian (Early Jurassic) age indicated by previous isotopic dating (Table 3) and fossil collections (Tempelman-Kluit, 1984; Hart, 1997; Johannson *et al.*, 1997). A key contribution of our high-precision U-Pb data is to demonstrate that occurrences of crystal-rich

Table 3. *Summary of U-Pb and K-Ar age constraints for the Nordenskiold formation, Whitehorse trough.*

Sample	Age (Ma)	Error (Ma)	Method	Comments	Source
06GCA158	188.1	0.4	U-Pb zircon	3 point concordia	this study
06GCA239	187.2	0.4	U-Pb zircon	2 point concordia	this study
06MC023	186.5	0.3	U-Pb zircon	5 point concordia	this study
04MC003	187.1	0.7	U-Pb zircon	3 point concordia; ash tuff in Tanglefoot formation	this study
92CH 85-1	184.1	+4.2/-1.6	U-Pb zircon	weighted average of three concordant fractions	Hart (1997)
GGAJ-92-127	186.6	1.0	U-Pb zircon	weighted average of four nearly concordant fractions	Johannson *et al.* (1997)
TO79-17-5	187	10	K-Ar hbl		Tempelman-Kluit (1984)
TO79-16-3	209	9	K-Ar hbl	likely contains excess Ar	Tempelman-Kluit (1984)

Note: hbl = hornblende

[1] *Isoplot 3.00 - A geochronological tool kit for Microsoft Excel. University of California at Berkeley, kludwig@bgc.org.*

volcaniclastic rocks at various stratigraphic levels in the Laberge Group reflect at least three distinct eruptive events over a period of ~2.3 m.y. (Fig. 8), rather than reworking of a single pyroclastic event into younger sediments. Further U-Pb geochronological studies of the Nordenskiold formation and ash tuff horizons in the Laberge Group would help refine interpretation of syn-depositional eruptive events adjacent to the Whitehorse trough. Volcaniclastic deposits of the Nordenskiold formation provide an important stratigraphic tie between the contrasting depositional environments of the Tanglefoot (deltaic and shallow-marine) and Richthofen (deep-marine) formations.

We also report here a concordant U-Pb zircon age of 112.8 ± 0.2 Ma for the only pluton intruding sedimentary rocks of the northern Whitehorse trough, near Carmacks. Analyses of zircons from a quartz-feldspar porphyry dyke intruding the Tantalus Formation south of Whitehorse did not yield results that permit a precise age interpretation for that sample.

ACKNOWLEDGEMENTS

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Kluane Ranges bedrock geology, White River area (Parts of NTS 115F/9, 15 and 16; 115G/12 and 115K/1, 2)

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ABSTRACT

The Kluane Ranges, located in southwest Yukon, are underlain by Late Paleozoic to Late Triassic volcanic and sedimentary rocks assigned to Wrangellia. Bedrock mapping completed within the White River area indicates Wrangellian rocks underwent several phases of deformation between Late Triassic and Miocene time. Middle Triassic marine, fine-grained sedimentary rocks are preserved in grabens where they are overlain by basal conglomerates and breccias of the Nikolai formation. The grabens are related to uplift associated with the deposition of Nikolai formation flood basalts and intrusion of ultramafic bodies. Late Jurassic to Early Cretaceous compression resulted in structural stacking of older rocks and northeast- and southwest-verging overturned folds. Latest (?) Cretaceous to Miocene dextral strike-slip along the Denali fault system led to the formation of steeply dipping faults, extensional and compressional basins and refolding of older regional scale folds. Reactivation of Jura-Cretaceous faults also occurred at this time. An enigmatic pre-Middle Triassic deformation event is believed to be preserved locally in rocks of the Hasen Creek Formation.

RÉSUMÉ

Les chaînons Kluane du sud-ouest du Yukon se composent de roches volcaniques et sédimentaires du Paléozoïque tardif au Trias tardif assignées à Wrangellia. La cartographie du substratum rocheux complétée dans la région de la rivière White révèle que les roches de Wrangellia ont subi plusieurs phases de déformation entre le Trias tardif et le Miocène. Des roches sédimentaires de milieu marin à grain fin du Trias moyen sont conservées dans des grabens où elles ont été recouvertes par les conglomérats et les brèches de base de la Formation de Nikolai. Les grabens sont reliés au soulèvement associé au dépôt des basaltes de plateau de la Formation de Nikolai et à l'intrusion des corps ultramafiques. Une compression du Jurassique tardif au Crétacé précoce a engendré un empilage structural de roches plus anciennes et la formation de plis déversés de vergence nord-est et sud-ouest. Le plus récent (?) rejet horizontal du Crétacé au Miocène le long du réseau de failles de Denali a entraîné la formation de failles au pendage abrupt, et de bassins d'extension et de compression ainsi qu'un nouveau plissement de plis plus anciens d'échelle régionale. Il y a également eu à cette époque une réactivation de failles jurasso-crétacées. Un énigmatique épisode de déformation antérieur au Trias moyen pourrait être préservé par endroits dans les roches de la Formation de Hasen Creek.

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INTRODUCTION

The Kluane Ranges bedrock mapping project is a multi-year study focused on the mountainous terrain south of the Denali fault (Fig. 1). The aim of the project is to provide detailed 1:50 000-scale bedrock mapping in an area that has undergone only regional 1:250 000-scale mapping. Reconnaissance 1:250 000-scale geological maps covering the Kluane Ranges and surrounding areas were completed by Muller (1967) and later by Dodds and Campbell (1992a,b,c). Limited 1:50 000-scale maps for the area between the Donjek and Jarvis rivers were produced by Read and Monger (1976) and were built upon during this study in 2004 and 2005 (Israel and van Zeyl, 2004; Israel *et al.*, 2005).

Mapping for the Kluane Ranges bedrock project is focused on upper Paleozoic to Upper Triassic stratigraphy of Wrangellia along with Jura-Cretaceous overlap

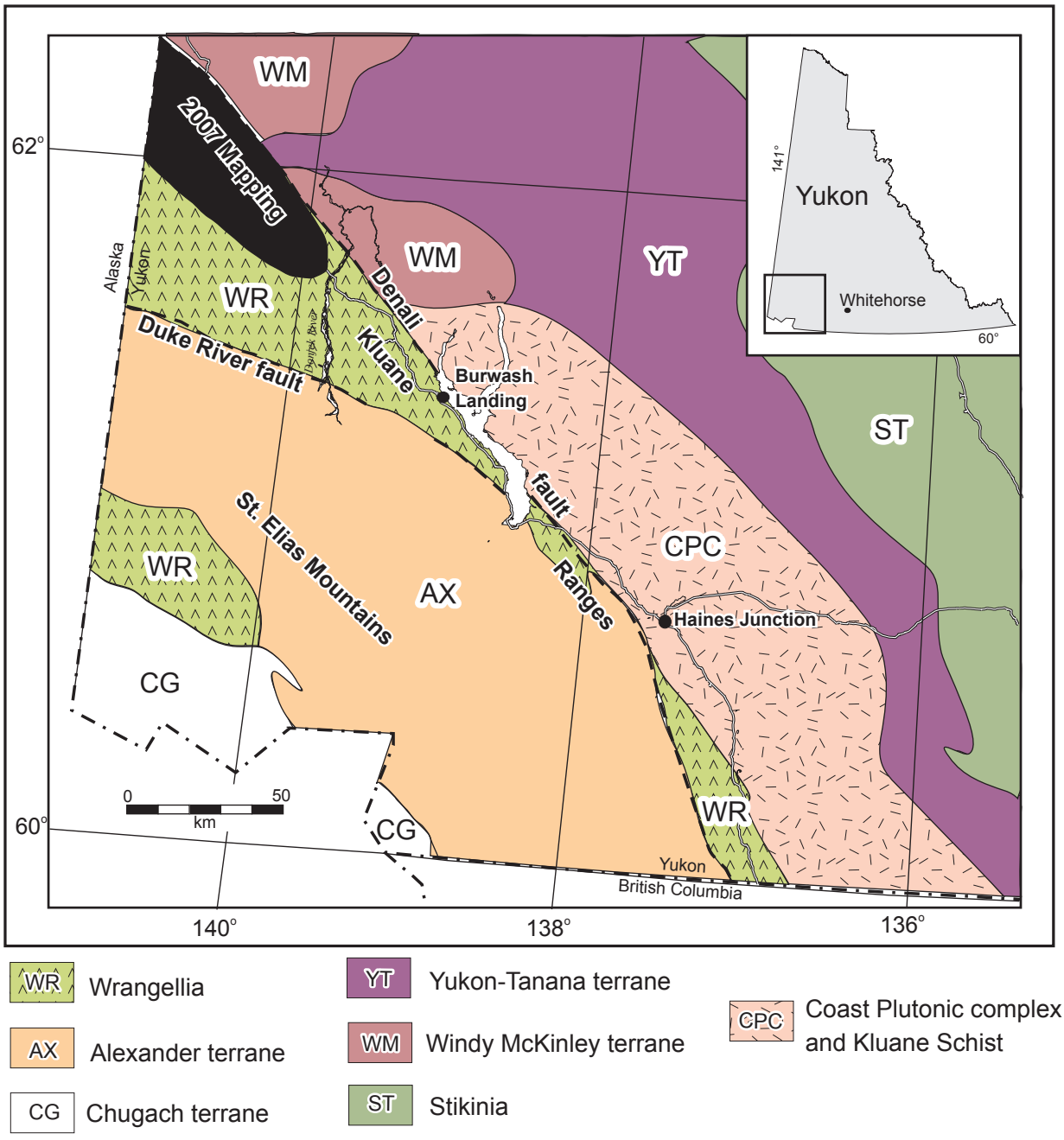

Figure 1. *Tectonic terrane diagram for southwestern Yukon illustrating the location of 2007 bedrock mapping.*

assemblages, Cenozoic sedimentary and volcanic deposits, and lower Paleozoic to Triassic rocks of the Alexander terrane (Fig. 1). The purpose of the Kluane Ranges project is to gain a better understanding of the stratigraphic and structural relationships within Wrangellia through detailed bedrock mapping. This data will be used to determine the tectonic framework of southwest Yukon and to better interpret the mineral potential of the area.

Mapping of the White River area, including the portion of the Kluane Ranges between the Donjek River and the Yukon/Alaska border, was conducted during the latter part of the 2006 and the 2007 field seasons (Fig. 1). In this region, the Kluane Ranges form rugged foothills that extend to the high, ice-covered St. Elias Mountains farther to the south. Topography varies greatly with rugged, long ridges separated by narrow and wide valleys. Outcrop on ridges and north-facing slopes is plentiful, while valleys and southern aspects are variably covered by vegetation. Access to much of the area is by helicopter only, with very few trails and rare roads reaching the base of the mountains.

REGIONAL GEOLOGICAL FRAMEWORK

Wrangellia underlies most of the project area. It consists of upper Paleozoic to Upper Triassic volcanic and sedimentary rocks (Jones *et al.*, 1977). Upper Paleozoic volcanic rocks comprise the Skolai arc, a volcanic arc that is the lowest exposed tectonic entity within the Yukon portion of Wrangellia (MacKevett, 1971; Read and Monger, 1976; Hulbert, 1997). The basement to Wrangellia is nowhere exposed. Upper Triassic flood basalts unconformably overlie the Paleozoic units and are associated with large mafic to ultramafic intrusive complexes that intrude the older rocks. These flood basalts are considered the hallmark of Wrangellia; they characterize the terrane from Vancouver Island to Alaska. The basalts are considered to be part of a large igneous province that may have a mantle plume origin (Richards *et al.*, 1991). In southwest Yukon, Wrangellia is juxtaposed next to the Alexander terrane across the Duke River fault. The Alexander terrane here is composed of lower Paleozoic volcanic and sedimentary rocks that are variably metamorphosed and deformed (Dodds and Campbell, 1992a). In Alaska, a Pennsylvanian pluton intrudes rocks of the Skolai arc and metamorphic rocks interpreted as part of the Alexander terrane, tying the two terranes together by this time (Gardner *et al.*, 1988).

Wrangellia and the Alexander terrane were accreted to the western margin of the Intermontane terranes, including Stikinia, Quesnellia and the Yukon-Tanana terrane, as early as Middle Jurassic time (van der Heyden, 1992; Gehrels, 2001). Upper Jurassic-Lower Cretaceous sedimentary assemblages overlie both Wrangellia and the Alexander terrane and, in Yukon, are at least in part syntectonic with respect to compressional deformation. Large Early Cretaceous intrusions related to the Kluane arc intrude the older units. As much as 400 km of latest Cretaceous to present dextral motion along the Denali fault system juxtaposes Wrangellia next to the Windy-McKinley and Yukon-Tanana terranes (Fig. 1; Lowey, 1998). Terrestrial coarse-grained sedimentary rocks were deposited within transtensional and compressional basins formed between the Duke River and Denali faults in Cenozoic time (Ridgway *et al.*, 1992). Late Cenozoic subduction of the Yakutat terrane beneath southern Yukon and Alaska resulted in the eruption of voluminous volcanic rocks of the Wrangell arc.

LITHOLOGIC UNITS

Figure 2 illustrates the distribution of the main lithologic units within the White River area. The oldest unit is the Upper Paleozoic Skolai Group consisting of the lower Station Creek Formation and the upper Hasen Creek Formation. The Skolai Group is exposed extensively across the map area. It generally occurs as northwest-trending packages and is structurally interleaved with Upper Triassic volcanic rocks of the Nikolai formation and Upper Triassic carbonate of the Chitistone Limestone and the McCarthy Formation. Mafic and ultramafic intrusions related to the Nikolai formation intrude the Skolai Group and are found as northwest-striking bodies in the northern part of the map area. The Chitistone Limestone and the McCarthy Formation are restricted to the southwest portion of the map area, where they are overlain by Jura-Cretaceous sedimentary rocks of the Dezadeash Formation. A Late Triassic granodiorite to granite pluton intrudes rocks of the Skolai Group in the north-central White River area and large diorite to quartz diorite plutons of the Early Cretaceous Kluane Ranges Suite intrude all older rocks.

SKOLAI GROUP

The Skolai Group includes volcanic and sedimentary rocks of the Station Creek and Hasen Creek formations. The group is named for Skolai Creek in Alaska (Smith and

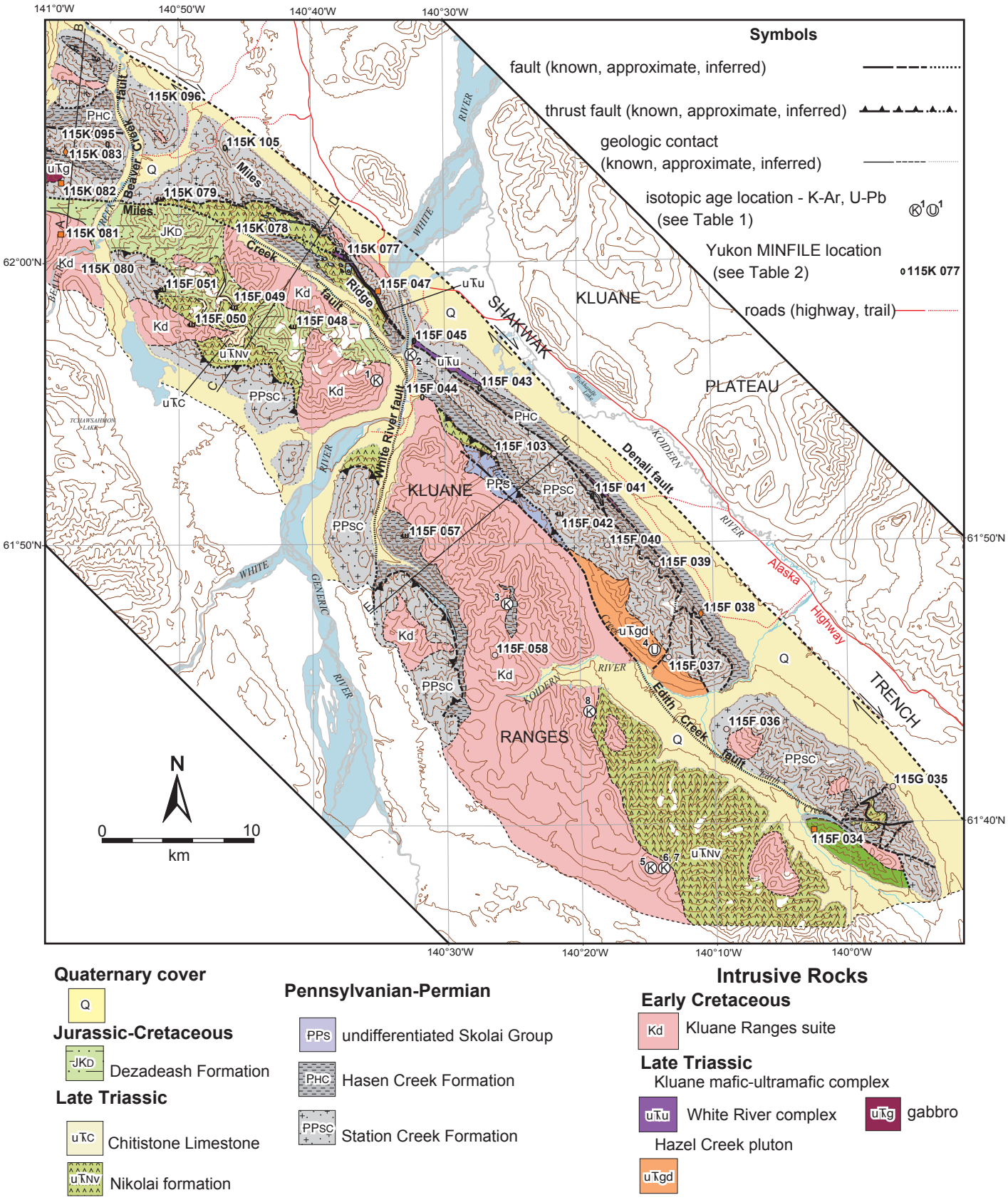

Figure 2. *Generalized geology map for the White River area, modified from Israel et al., 2007a,b. Note, McCarthy Formation included within Chitistone Limestone.*

MacKevett, 1970). Rocks of the Skolai Group are the most abundant within Wrangellia in southwest Yukon and extend from northern British Columbia into Alaska. The Skolai Group was first described in detail by Muller (1967). He assigned the rocks, with some hesitation, to the Cache Creek Group based on age and lithologic similarities with rocks in northern British Columbia. Subsequent work by Read and Monger (1976) led to the re-assignment of the rocks to the Skolai Group as described by Smith and MacKevett (1970).

Skolai Group undivided

A sequence of strongly deformed metavolcanic and metasedimentary rocks, located on the south side of Hazel Creek, is assigned to the Skolai Group (Fig. 2). These rocks are thrust to the northeast over less deformed and metamorphosed Skolai Group and volcanic rocks of the Nikolai formation. To the south, the sequence of metamorphic rocks is intruded by a large Early Cretaceous pluton. This sequence includes structurally interleaved chlorite schist, dark grey and brown phyllite, and metagabbro (Fig. 3a). All rocks are cut by extensive quartz and epidote veins. Deformation and metamorphism does not allow for differentiation between the volcanic and sedimentary rocks.

Station Creek Formation

The Station Creek Formation outcrops extensively in the White River area and consists primarily of volcanic breccia, tuff, volcaniclastic sandstone, and basalt to andesite flows. Work by Read and Monger (1976) elsewhere in the Kluane Ranges, suggests that the formation is dominated by volcanic flows in the southeast and by more volcaniclastic rocks in the northwest. Thickness of the Station Creek Formation is not known as the base of the unit is not exposed. However, Read and Monger (1976) and Smith and MacKevett (1970) suggest a thickness of at least 1000 m for the Station Creek Formation in southwest Yukon and Alaska. Although the thickness of the Station Creek Formation is difficult to assess due to the complex structural relationships in the White River map area, it is likely on the order of 1000 m thick as suggested by these authors.

In the White River area, the dominant rock types in the Station Creek Formation are volcanic breccia and tuff. Clast types and composition of the volcanic breccia vary greatly. The most abundant breccia in the Station Creek Formation consists of green/grey-weathered, dark green, fresh pyroxene porphyry (Fig. 3b). Clasts range in size from <1 cm to 50 cm and are angular to sub-rounded

Table 2. *Yukon MINFILE occurrences from the White River area. See Figure 2 for locations.*

Mineral Occurrences					
115K 078	Chair	prospect	Ag, Pb, Zn	vein
115K 079	Nutzotin	prospect	Cu	skarn
115K 080	California	unknown	Au	intrusion
115K 081	Wrangell	anomaly		porphyry
115K 082	Nikki	drilled prospect	Cu, Au	porphyry
115K 083	Rip	showing		ultramafic
115K 095	Nutz/Sea	showing		VMS
115K 096	Gruber	unknown		
115K 105	Yellow	showing		ultramafic
115F 034	Garlic	prospect	Au	porphyry
115F 035	Nox	unknown		
115F 036	Hankins	unknown		
115F 037	Koidern	unknown		
115F 038	Liberty	showing	Au, Cu	vein
115F 039	Quebec	unknown		anomaly
115F 040	Duensing	unknown		
115F 041	Cats and dogs	showing	Cu	ultramafic
115F 042	Mexico	showing		skarn
115F 043	Pickhandle	drilled prospect	Cu, Ni	ultramafic
115F 044	Sevensma	anomaly		
115F 045	Canalask	deposit	Cu, Ni, PGE	ultramafic
115F 047	Epic	showing	Cu, Mo	porphyry
115F 048	Arn	drilled prospect	Au, Cu	skarn
115F 049	Sampete	prospect	Cu	skarn
115F 050	Monday	prospect		skarn
115F 051	Az/Hump	drilled prospect	Cu, Au	skarn
115F 057	Lep	drilled prospect	Zn, Cu	skarn
115F 058	Down	unknown		
115F 077	Onion	drilled prospect	Ni, Cu, PGE	ultramafic
115F 103	Harjay	unknown		anomaly

Table 1. *Isotopic age determinations from samples within the White River area. See Figure 2 for sample locations; labels are marked numerically with corresponding U or K, which represents U-Pb and K-Ar respectively.*

	Type	Station #	Age	Mineral	Interpretation	Reference
1	K-Ar	W169	121.3±3.6	hornblende	cooling	Farrar *et al.*, 1988
2	K-Ar	White River	225±14	biotite	cooling	Campbell, 1981
3	K-Ar	WN-136-74	108±5	biotite	cooling	Stevens *et al.*, 1982
4	U-Pb	06-SI-040	211.7±2.5	zircon	crystallization	R. Friedman, pers. comm., 2007
5	K-Ar	MV-164-102	114±4	biotite	cooling	Stevens *et al.*, 1982
6	K-Ar	WN-135-74	112±4	biotite	cooling	Stevens *et al.*, 1982
7	K-Ar	WN-135-74	115±5	hornblende	cooling	Stevens *et al.*, 1982
8	K-Ar	W167	123.7±2.5	biotite	cooling	Farrar *et al.*, 1988

Figure 3. ***(a)*** *View towards the southeast of deformed and metamorphosed volcanic and sedimentary rocks included in the Skolai Group (undivided).* ***(b)*** *Volcanic breccia of the Station Creek Formation; clasts are entirely composed of augite-phyric mafic volcanic rock.* ***(c)*** *Polymictic volcaniclastic breccia from the Station Creek Formation.* ***(d)*** *Very fine-grained, green/grey tuff from the upper portion of the Station Creek Formation.* ***(e)*** *Interbedded dark grey and brown siltstone and mudstone from the Hasen Creek Formation.* ***(f)*** *Folded limestone unit near the top of the Hasen Creek Formation.*

within a fine-grained matrix that has a similar composition as the clasts. The breccia varies from clast-supported to matrix-supported and it is commonly difficult to distinguish clasts from the matrix. Units of pyroxene-porphyry breccia can be up to tens of metres thick.

Interbedded with the breccias are coarse-grained volcaniclastic sandstone units that include thick layers of polymictic breccia. The sandstone weathers grey/green in colour and contains coarse fragments of plagioclase, quartz and lesser amounts of pyroxene±hornblende. The sandstone units are well bedded to massive with the thickness of individual beds ranging from 1 cm to 20 cm. Polymictic breccia interbedded with the sandstone are mainly matrix-supported and weather to a light to medium grey. Clasts are generally <10 cm and include sub-rounded to angular, black, aphanitic volcanic rocks, dark grey siltstone, coarse-grained volcaniclastic sandstone and light grey chert (Fig. 3c). The matrix is coarse-grained and contains phenocrysts of plagioclase, quartz and pyroxene up to 2 mm.

Thick sections of fine-grained tuff are abundant in the Station Creek Formation and generally overlie the coarser grained units, but are not always present. Contrasting light grey/green- and maroon-weathering colours in the tuff accentuate bedding (Fig. 3d). Bedding ranges from <1 to 10 cm thick, but is generally on the order of a few centimetres thick. Some beds are crystal-rich with phenocrysts of feldspar and rare occurrences of quartz.

Volcanic flows are rare in the Station Creek Formation of the White River area. They locally form sequences that are several tens of metres thick with individual flows up to 1 m thick. The flows are composed of basalt to andesite that weather to a light green/grey or dark green with varying amounts of pyroxene and plagioclase phenocrysts. They are generally massive, but locally are strongly amygdaloidal; amygdules are filled with chlorite and quartz±calcite. Flows are commonly interbedded with light grey-weathering carbonate up to 50 cm thick.

The age of the Station Creek Formation is not well constrained. A late Pennsylvanian to Early Permian age is suggested based on fossils retrieved from interbedded siltstones in Alaska and the fact that the gradationally overlying Hasen Creek Formation is Early Permian in age (Smith and MacKevett, 1970).

Hasen Creek Formation

The Hasen Creek Formation is dominantly a sedimentary unit characterized by siltstone, mudstone, sandstone, carbonate, pebble conglomerate, rare volcanic flows, tuff and minor chert. In the northwest corner of the map area, it gradationally overlies the Station Creek Formation, the contact being drawn where sedimentary rocks dominate over volcanic rocks (Smith and MacKevett, 1970; Read and Monger 1976). Everywhere else in the study area, the two formations are in fault contact (Fig. 2).

The Hasen Creek Formation is variable in thickness. In southwest Yukon, it is up to 800 m thick (Read and Monger, 1976). Locally, Triassic rocks overlie and are in direct contact with the Station Creek Formation, with no intervening Hasen Creek Formation (Read and Monger, 1976).

Laminated dark grey to brown-weathering siltstone and mudstone and interbedded light grey to brown-weathering sandstone comprise the majority of the Hasen Creek Formation in the White River area (Fig. 3e). Fine-grained siltstone and mudstone beds range in thickness from <1 cm to 10 cm. Locally, siltstone dominates and forms beds up to several metres thick. Primary sedimentary features such as flame structures, load casts and cross-bedding are common. Near fault zones, the fine-grained rocks become phyllitic and have a penetrative platy cleavage. Interbeds of medium- to coarse-grained sandstone occur throughout the siltstone/mudstone unit and can be up to several metres in thickness, but are more commonly less than 1 m thick. The sandstone is composed of lithic fragments from older units, quartz and feldspar grains, and occasional 2 to 3 mm chert clasts. Siltstone rip-up clasts are common near the base of sandstone beds. Beds are massive to graded with sharp basal contacts and only rarely have laminations and cross-bedding. Locally, the sandstone beds coarsen upwards to a matrix-supported pebble conglomerate. Clasts within the conglomerate are well rounded to subangular and are composed of siltstone, aphanitic mafic and intermediate volcanic rocks, carbonate, and dark grey to black chert. Beds of conglomerate are between 1 and 5 m thick.

Several carbonate horizons occur within the Hasen Creek Formation. These range from thin (≤1 m) featureless units, to very thick (≤100 m) fossiliferous limestone. Thin carbonate horizons weather light grey and commonly contain clasts of underlying rocks. These beds are laterally discontinuous and form lenses in the surrounding siliciclastic rocks. The fossiliferous limestone units are commonly located near the top of the formation. They weather light grey and are massive to well bedded. Bedding, where evident, is defined by alternating light and

Figure 4. ***(a)*** *Boulder conglomerate from the basal section of the Nikolai formation.* ***(b)*** *Matrix-supported polymictic conglomerate from the base of the Nikolai formation.*

dark grey layers up to 30 cm thick. The dark grey layers are more argillaceous and locally display faint laminations. Thick limestone units commonly stand out as resistant bands that continue along strike for several hundreds of metres (Fig. 3f).

Rare beds of dark grey to black chert occur near the top of the Hasen Creek Formation and are associated with limestone horizons. The thickness of these upper chert layers is poorly constrained, however, at one locality, several metres of black chert occur unconformably below Triassic volcanic rocks of the Nikolai formation.

The Hasen Creek Formation is Early Permian in age based on abundant fossil collections (Smith and MacKevett, 1970; Read and Monger, 1976; Dodds *et al.*, 1993; Israel and van Zeyl, 2005).

NIKOLAI FORMATION

Subaerial to submarine basalt flows characterize Wrangellia from southern Vancouver Island to Alaska (Smith and MacKevett, 1970; Read and Monger, 1976; Jones *et al.*, 1977; Nikolai greenstone or basalt of MacKevett, 1971). In Yukon and Alaska, these are assigned to the Nikolai formation (Read and Monger, 1976). Correlative units on Vancouver Island are known as the Karmutsen Formation (Carlisle, 1963; Muller, 1977). Previous descriptions of the Nikolai and Karmutsen formations focused on the basalt. Subsequent work showed that these formations also contain a basal volcanic conglomerate and breccia, and interbedded argillite and carbonate (Carlisle and Suzuki, 1974; Read and Monger, 1976; Greene *et al.*, 2005; Israel and van Zeyl, 2005; Israel *et al.*, 2006). In the White River area, the Nikolai formation consists largely of basalt with minor amounts of basal breccia and conglomerate. It is either in fault contact with, or unconformably overlies older units. Rocks of the Chitistone Limestone unconformably overlie the Nikolai formation.

Observations of the basal conglomerate and breccia during the 2007 season were limited to a single ridge above Edith Creek (Fig. 2). Outcrops are not large enough to be mapped separately at 1:50 000 scale and are thus included in the undivided Nikolai formation. The basal conglomerate and breccia consist of very angular to well rounded pebbles to boulders of siltstone, carbonate, mafic and intermediate plagioclase±augite porphyritic volcanic rocks, and dark grey to black chert (Fig. 4a). The conglomerate/breccia unit is typically clast-supported, but is locally matrix-supported. Matrix composition varies from coarse-grained sandstone to crystal-rich volcaniclastic material (Fig. 4b). Deposition of the conglomerate and breccia unit is laterally restricted and appears to be fault-controlled (see Discussion).

Basalt comprises the majority of the Nikolai formation in the White River area. Individual flows are up to 2 m thick and can be identified by vesicular bases and tops and more massive centres. Vesicles are most commonly filled with quartz±calcite. The basalt weathers a deep olive-green to maroon and is dark green to dark grey on fresh surfaces. The flows are locally plagioclase-phyric and contain small (1 mm) olivine phenocrysts in only a few localities.

The age of the Nikolai formation is bracketed by fossils found in bounding and interbedded units elsewhere in Wrangellia that include a poorly preserved Middle Triassic sedimentary unit occurring beneath the basalt, and from carbonate interbedded with basalt near the top of the formation that host Norian (Late Triassic) conodonts (Read and Monger, 1976; Israel *et al.*, 2006; Nixon and Orr, 2006).

CHITISTONE LIMESTONE AND MCCARTHY FORMATION

Both the Chitistone Limestone and the McCarthy Formation get their names from the McCarthy quadrangle in Alaska, just across the border from the White River map area (Smith and MacKevett, 1970; MacKevett, 1971). The units were not closely examined during the present study and are only briefly described here. More complete descriptions of these units in the Kluane Ranges are given by Israel *et al.* (2006) and Read and Monger (1976) and in Alaska by MacKevett (1971).

The Chitistone Limestone is exposed near Hump Mountain where it forms horizons several hundred metres thick between the Nikolai and Dezadeash formations. It unconformably overlies the Nikolai formation, and consists of massive to well bedded limestone and calcareous argillite. The carbonate is pale grey to beige, and unlike older limestone units, this unit is devoid of macrofossils. It is locally brecciated with clasts of siliceous carbonate occurring in a medium-grained crystalline carbonate matrix. The Chitistone Limestone is Norian (Late Triassic) in age, based on abundant conodont collections from the Kluane Ranges and Alaska (Dodds *et al.*, 1993).

The McCarthy Formation is characterized by interbedded light and dark grey calcareous, carbonaceous argillite and carbonate layers. The McCarthy conformably overlies the Chitistone Limestone, and in places, the two units can not be distinguished. The McCarthy Formation is Late Triassic to Early Jurassic based on fossil collections from southwest Yukon and Alaska (MacKevett, 1971; Dodds *et al.*, 1993).

DEZADEASH FORMATION

The Dezadeash Formation was not examined during the present study; however, it is included in this paper as there is a significant amount of exposure of Dezadeash Formation along several ridges south of the Miles Creek fault (Fig. 2). Detailed descriptions of the unit are mainly from previous authors describing outcrops of the Dezadeash in the Kluane Ranges southeast of the present study area. The relationship between the Dezadeash Formation and underlying units is unknown; elsewhere in the Kluane Ranges outside the study area, the base of the formation is not exposed, or is faulted (Eisbacher, 1976). The Lower to Middle Jurassic Tatamagouche succession of Israel *et al.* (2006) may in fact be the basal component of the Dezadeash Formation, but more work needs to be done in order to confirm this. The Dezadeash Formation is correlative with the Nutzotin Mountain sequence in Alaska (Eisbacher, 1976; Ridgway *et al.*, 2002) and is part of a series of Jura-Cretaceous basins that occur along the western edge of Wrangellia and the Alexander terrane (McClelland *et al.*, 1992).

The Dezadeash Formation consists of up to 3000 m of turbidites that include siltstone, mudstone, sandstone and conglomerate (Eisbacher, 1976; Lowey, 1992). It is, at least in part, syntectonic with respect to Early Jurassic to Early Cretaceous compressional deformation and constitutes a basin formed in a retroarc depocentre (Trop and Ridgway, 2007). The Dezadeash Formation is Late Jurassic to Early Cretaceous based on fossil collections from the Kluane Ranges (Eisbacher, 1976; Dodds *et al.*, 1993).

INTRUSIVE ROCKS

Three main intrusive complexes are present in the White River area. These include the Late Triassic Kluane mafic-ultramafic complex, a Late Triassic granodiorite to granite body, and the regionally extensive Early Cretaceous Kluane Ranges Suite. Several isotopic ages exist for these complexes and preliminary results of new U-Pb data are presented below. Ages and locations of samples are shown on Figure 2.

Kluane Mafic-Ultrmafic Complex

Mafic and ultramafic bodies have been recognized throughout the Kluane Ranges since early exploration of southwest Yukon (Muller, 1967). These bodies are associated with significant nickel-copper-platinum group element (PGE) mineralization throughout the Kluane Ranges. They intrude rocks of the Skolai Group and are Late Triassic in age (Hulbert, 1997). An extensive study of the complex was undertaken by Hulbert (1997) who described the largest of the intrusions and examined the chemistry and mineralization associated with each. These intrusions overlap in age with basalt of the Nikolai formation and are considered to be the magmatic feeders to the basalt. The mafic-ultramafic bodies are described as

zoned intrusions with a dunite core, passing outwards into peridotite and olivine pyroxenite, and rimmed by a gabbro phase (Hulbert, 1997). This zoning is difficult to observe in the field as many of these bodies are either altered and/or deformed.

In the White River area, the fault-bounded White River complex (Hulbert, 1997) occurs on the north side of Miles Ridge and continues along strike for roughly 20 km (Fig. 2). It is faulted against rocks of the Station Creek, Hasen Creek and Nikolai formations. The complex is up to 300 m wide and is altered and deformed between the White River and areas to the northwest (Fig. 5a). The White River complex is cut by the White River fault, but is exposed to the southeast across the fault suggesting possible normal offset of the complex. It is composed primarily of strongly altered ultramafic rocks, making it difficult to identify the protolith. Locally, peridotite occurs in the least-altered areas. Southeast of the Canalask deposit (Fig. 2), less altered pyroxenite and peridotite with disseminated pyrite occur sporadically in creek bottoms. The age of the White River complex is not known, however a $^{40}Ar/^{39}Ar$ age from phlogopite extracted from a similar intrusion to the southeast yielded an age of *ca.* 228 Ma (Israel and Ullrich, unpublished data).

Light to dark-grey-weathering gabbro dykes and sills intrude the Station Creek and Hasen Creek formations throughout the White River area. These represent the more mafic part of the Kluane mafic-ultramafic complex. They range in size and thickness from 1 m to several tens of metres. The gabbro forms blocky outcrops which are composed of equigranular, fine to medium-grained pyroxene and plagioclase. Plagioclase is variably altered to light green epidote. Where fine grained, it is difficult to distinguish the gabbro from crystal tuff of the Station Creek Formation. Similar gabbro bodies in other areas of the Kluane Ranges have yielded U-Pb zircon ages of *ca.* 232 Ma (Mortensen and Hulbert, 1991).

Hazel Creek Pluton

A granodiorite to granite pluton is exposed just north of Hazel Creek where it intrudes rocks of the Station Creek Formation and is juxtaposed with diorite of the Kluane Ranges suite across the Edith Creek fault (Fig. 2). The Hazel Creek pluton consists of medium to coarse-grained biotite±hornblende granodiorite to granite. It weathers to light grey and has a salt-and-pepper appearance on fresh surfaces. Country rocks near the pluton are hornfelsed and minor dykes and apophyses extend from the main intrusive body. Zircons from this pluton yielded a U-Pb age of *ca.* 212 Ma (Israel and Friedman, unpublished data). Magmatism of this age is not documented elsewhere in Wrangellia in southwest Yukon or eastern Alaska. More work is needed to determine the tectonic significance of the Hazel Creek pluton.

Kluane Ranges Suite

Medium-grained granitic rocks of the Kluane Ranges Suite form extensive exposures in the central and western portions of the White River area (Fig. 2). The granitic rocks intrude all units in the area and a well developed

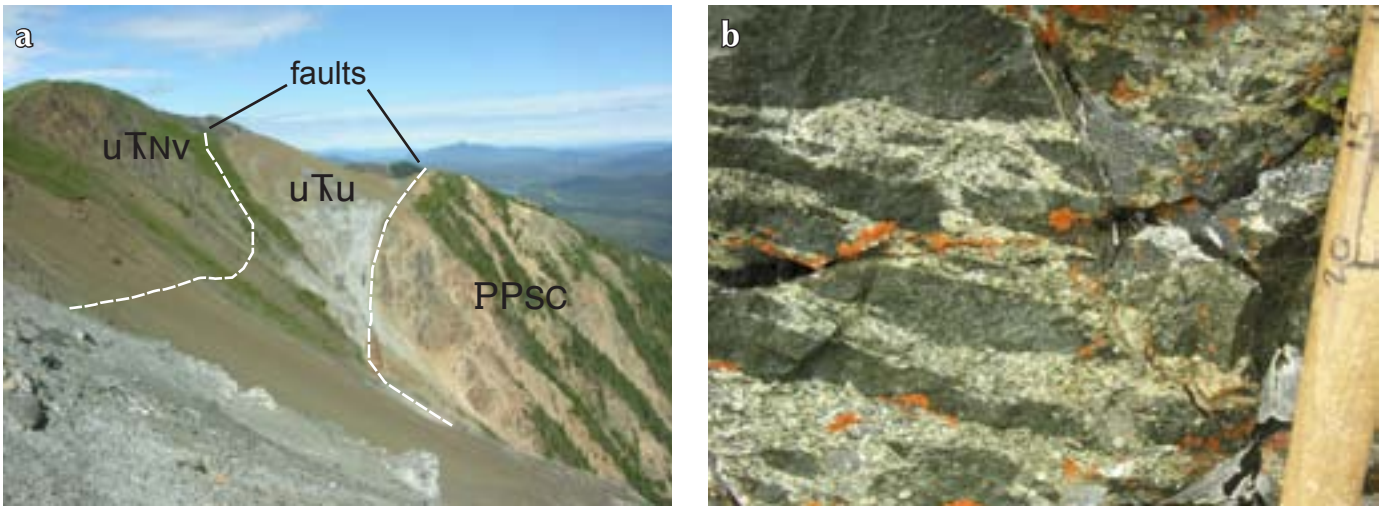

Figure 5. (a) *A view looking northwest at a fault-bounded ultramafic body (uTu) of the White River complex on Miles Ridge. For unit descriptions, see Figure 2.* ***(b)*** *Hornfelsed Nikolai formation basalts near the contact with a Kluane Ranges Suite diorite intrusion.*

hornfels occurs around the main body (Fig. 5b). The Kluane Ranges suite is characterized by medium-grained, light grey-weathering hornblende diorite and hornblende±biotite quartz diorite. It has a salt-and-pepper appearance on fresh surfaces with little alteration of the mafic minerals. It is devoid of penetrative fabric, except near its margins where a magmatic foliation is locally defined by alignment of mafic minerals. K-Ar ages from the White River area range from 124 to 112 Ma (Stevens *et al.*, 1982; Farrar *et al.*, 1988). The Kluane Ranges Suite is likely a southeastern extension of the Early Cretaceous Chisana arc in eastern Alaska (Plafker *et al.*, 1989a).

STRUCTURE

The White River area has experienced several phases of deformation resulting in structural stacking, folding and lateral dissection of units (Fig. 6). Large northwest-dipping faults place older rocks over younger rocks and northeast and southwest-verging map-scale folds are developed throughout the area. A penetrative foliation is only developed near faults and an axial-planar cleavage is not consistently developed. Map-scale, steeply dipping strike-slip and extensional faults separate rock units into northwest-trending blocks. Timing of the main deformational episodes is constrained as pre-Late Triassic, Late Triassic, Jura-Cretaceous and Late Cretaceous to present; these events are described below.

PRE-LATE TRIASSIC DEFORMATION

Evidence for a pre-Late Triassic deformational event is locally preserved in the Kluane Ranges. Evidence consists of the following: 1) local absence of Hasen Creek stratigraphy between the Station Creek and Nikolai formations, suggesting uplift and erosion prior to deposition of the Nikolai basalt; 2) an unconformable contact between the Hasen Creek and a suspected Paleozoic gabbro in the Steele Creek area, suggesting erosion of the Station Creek Formation prior to the Permian (Read and Monger, 1976; Israel *et al.*, 2006); 3) apparent folding of upper Paleozoic strata prior to deposition of Nikolai formation (Israel *et al.*, 2006); and 4) the absence of Lower Triassic strata in the Kluane Ranges and Middle Triassic strata unconformably overlying the Hasen Creek Formation suggests possible pre-Middle Triassic uplift and erosion. These older structures are difficult to identify because of the intensity of the younger deformation. However, this older event likely played an important role in the intrusion of ultramafic sills and dykes which are targets for mineral exploration. More detailed studies should be undertaken in order to determine the nature and extent of pre-Late Triassic deformation.

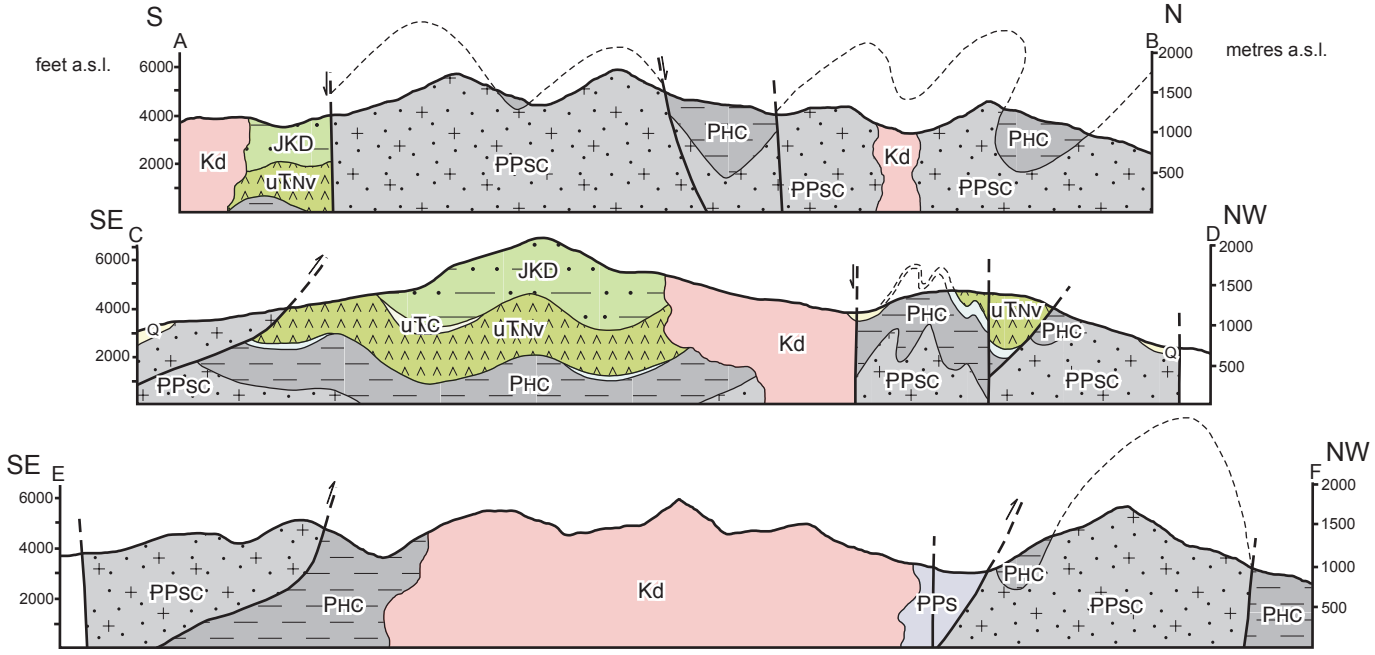

Figure 6. *Schematic geological cross-sections through the White River area. Horizontal scale is the same as vertical scale. Locations of sections are indicated on Figure 2. See Figure 2 legend for unit descriptions. a.s.l. = above sea level.*

LATE TRIASSIC

Late Triassic deformation is related to uplift and extension during deposition of the Nikolai formation and intrusion of the Kluane mafic-ultramafic complex. Laterally discontinuous grabens are defined mainly by the presence of Middle Triassic strata and thick accumulations of basal conglomerate and breccia of the Nikolai formation. Middle Triassic and basal Nikolai strata always occur in proximity of a fault (Fig. 2; Read and Monger, 1976). The basal conglomerate and breccia are interpreted as syntectonic deposits related to graben formation. The faults bounding these grabens were extensively reactivated during younger deformation.

LATE JURASSIC-EARLY CRETACEOUS

Late Jurassic-Early Cretaceous compression has produced the main structures in the Kluane Ranges. Northeast and southwest-verging faults and folds occur along the entire belt of Wrangellia in southwest Yukon. In the White River area, several northwest-striking, southwest-dipping faults place older rocks over younger rocks (Fig. 2). These faults have also locally re-activated stratigraphic contacts (*e.g.,* Nikolai formation over Hasen Creek Formation). Tight, northeast-verging overturned folds and upright, open folds are well developed in the Skolai Group. Folds trend northwest and are refolded and offset by younger structures. In the Kluane Ranges, re-activation of thrust faults into strike-slip faults is indicated by nearly horizontal slickenside and fault-groove lineations. Timing of deformation postdates the Upper Jurassic-Lower Cretaceous Dezadeash Formation, but predates intrusion of crosscutting plutons of the Kluane Ranges suite.

LATE CRETACEOUS TO PRESENT

Post-Cretaceous deformation is associated with the development of the Denali fault system, which includes the Duke River fault. Post-Late Cretaceous dextral strike-slip displacement on the order of 350-400 km is interpreted along the Denali fault (Plafker *et al.*, 1989b; Lowey, 1998). However, fabrics developed in a mid-Cretaceous pluton along the Denali fault suggest a more complicated deformational history including sinistral, dextral and normal displacements (C. van Staal, pers. comm., 2007). Several parallel strike-slip faults, and kinematically linked extensional and compressional structures, were developed concurrently. Terrestrial sedimentary and volcanic deposits accumulated locally in transtensional and transpressional basins that developed along the Denali fault.

In the White River area, steeply dipping strike-slip faults juxtapose units of varying ages and crosscut earlier structures. The amount of offset and exact kinematics across the fault zones are difficult to assess due to a lack of marker horizons. The Miles Creek fault is the largest fault in the White River area after the Denali fault (Fig. 2). This fault is largely inferred based upon the juxtaposition of Dezadeash and Station Creek formations. This geometry implies a component of normal displacement along this fault. The White River intrusive complex is bounded both to northeast and southwest by steeply dipping fault zones (Fig. 2). These faults are defined by several metres of gouge and clay alteration and may be responsible for a significant landslide that occurred in a northeast-facing drainage near the south end of Miles Ridge (see Bond *et al.*, this volume).

Several north- to northeast-striking faults are inferred to occupy large valleys in the White River area (Fig. 2). The White River and Beaver Creek faults are two examples. There are no direct kinematic observations on these faults, but mapping relationships suggest normal displacement (east-side down) with minor strike-slip motion. Elsewhere in the Kluane Ranges, these large north-trending valleys are interpreted as the site of normal faults (J. White, pers. comm.). The relationship between these structures and the Denali fault is currently unknown.

Folds related to strike-slip faulting are steeply, north to northwest-plunging tight folds. Refolding of Late Jurassic-Early Cretaceous structures occurs in the Cottonwood Mountain area and along Miles Ridge (Fig. 2). In places, it is difficult to distinguish between Jura-Cretaceous folds and post-Cretaceous folds as deformation along the Duke River fault resulted in northwest-trending, northeast-verging folds affecting the Wrangell lavas and underlying strata (Ridgway *et al.*, 1992; Israel *et al.*, 2006).

MINERALIZATION

Several different styles of mineralization occur within the White River area (Fig. 2, Table 2; Yukon MINFILE[1], 2007). The most prominent targets for exploration have been magmatic nickel-copper-PGE mineralization associated with the Kluane mafic-ultramafic complex and copper-gold porphyries related to Early Cretaceous granitic intrusions.

Here we discuss briefly the White River complex and mineralization associated with the ultramafic rocks. The

[1]*http://www.geology.gov.yk.ca/databases_gis.html*

reader is referred to Hulbert (1997) for a more complete description of the deposits and mineral occurrences related to the Kluane mafic-ultramafic complex. The Canalask deposit occurs in the Hasen Creek Formation, near an ultramafic body, just east of the White River. Historical reserves are calculated at 390 232 tonnes grading at 1.35% Ni (Yukon MINFILE[2], 2007). High-grade showings at the northwest end of the ultramafic body (Discovery and Onion showings) include samples assayed at 4.69% Ni, 0.8% Cu and 6.83 g/t PGE, and 27.4% Ni and 30.61 g/t Au.

In the White River area, skarns are developed in association with Early Cretaceous granitic plutons and dykes that intrude the Upper Triassic Chitistone Limestone and Nikolai formation. The Arn property, located near Mount Taylor, has undergone the most exploration to date and contains copper and gold mineralization. Drilling in 2002 by ATAC Resources Ltd. intersected 12.67 m of mineralized skarn grading 11.92 g/t Au and 0.22% Cu, including a 1.98 m interval of 64.42 g/t Au and 1.16% Cu (Yukon MINFILE[2], 2007).

CONCLUSIONS

The White River area is underlain by upper Paleozoic to Upper Triassic volcanic, sedimentary and intrusive rocks of Wrangellia; these are overlain by Jura-Cretaceous overlap assemblages. All strata are intruded by granitic plutons of the Early Cretaceous Kluane Ranges Suite.

Several phases of deformation have resulted in structural stacking and dissection of units into northwest-trending, mainly fault-bounded belts. The main deformational episodes include Late Triassic extension, Late Jurassic to Early Cretaceous northeast compression, and prolonged Late Cretaceous to present strike-slip faulting with associated extension and compression. Northeast-verging overturned folds related to Jura-Cretaceous deformation are refolded by steeply plunging tight folds associated with post-Cretaceous strike-slip faulting.

Mineralization associated with ultramafic bodies is widespread, including the Canalask nickel-copper deposit. Several copper-gold porphyry showings and prospects associated with the Early Cretaceous Kluane Ranges suite are found in the western part of the White River area and need further investigation.

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[2]*http://www.geology.gov.yk.ca/databases_gis.html*

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Aggregate resource exploration using a process-depositional model of meltwater channel development in the Eagle Plains area, northern Yukon

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ABSTRACT

Yukon's northern oil and gas basins remained unglaciated during the Pleistocene. The absence of coarse aggregate material generated by glaciation, coupled with continuous permafrost, has required expensive programs of crushing and hauling bedrock for road and infrastructure development. This study examines fluvial deposits associated with the late-Pleistocene Eagle River meltwater channel as potential sources of aggregate for regional development. In particular, it applies a process-depositional model of meltwater channel development to understand the distribution and potential quality of aggregate resources in the area. We identify three zones with meltwater channel development: (i) an upper erosional zone (~ 50 km) of scoured bedrock associated with initial development of the channel; (ii) a middle zone (~ 35 km) of coarse deposition on high terraces associated with initial channel incision; and (iii) a lower zone (~ 75 km) dominated by fine lacustrine and deltaic deposits that likely overlie coarse fluvial deposits with up to 30 m of clay, silt and sand.

RÉSUMÉ

Les bassins pétrolifères et gazifères du nord du Yukon sont restés en grande partie non glaciés pendant le Quaternaire. L'absence de granulats grossiers engendrés par les glaciations associée à la présence de pergélisol continu ont exigé de coûteux programmes de concassage et de transport de matériaux du substratum rocheux pour l'aménagement des routes et de l'infrastructure. Dans le cadre de cette étude on examine les dépôts fluviaux associés au chenal d'eau de fonte de la rivière Eagle au Pléistocène tardif comme sources potentielles de granulats pour le développement régional.

Les résultats préliminaires indiquent que le déversoir d'une longueur de 160 km s'est formé lors d'une débâcle glaciaire d'eau de fonte retenue par un barrage glaciaire qui a causé une incision rapide et une importante érosion. On identifie trois zones de développement du chenal : (i) une zone d'érosion en amont (~ 50 km) de substratum rocheux affouillé associée au développement précoce du chenal ; (ii) une zone centrale (~ 35 km) de dépôts grossiers sur les hautes terrasses associées à l'incision initiale du chenal ; et (iii) une zone en aval (~ 75 km) dominée par des dépôts lacustres et deltaïques fins — limon, argile et sable fin qui atteignent jusqu'à 30 m d'épaisseur — qui recouvrent vraisemblablement des dépôts fluviaux grossiers.

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INTRODUCTION

The Eagle River lies on the former eastern edge of Beringia — the landmass including northern Yukon, Alaska and Siberia that remained ice-free throughout the Pleistocene (past 2 million years). Soft bedrock (predominantly shale) in the area has been subjected to an extended period of *in-situ* weathering that has produced a landscape characterized by frozen, deeply weathered, silt-rich soils. These fine-grained soils, coupled with continuous permafrost, have made road and infrastructure development expensive, logistically challenging, and difficult to maintain. This study examines deposits associated with the late Pleistocene Eagle River meltwater channel and the application of a process-depositional model to aggregate resource exploration in the Eagle Plains region (Figs. 1 and 2).

Hughes (1969), following earlier work by McConnell (1889) and Bostock (1948), described flights of paleo-shorelines and thick, unconsolidated deposits in the Bell, Bluefish and Old Crow basins, and suggested the area had formerly contained large glacial lakes (Fig. 2). Hughes (1969) proposed that one or more advances of Laurentide ice against the Richardson Mountains and onto Peel Plateau, blocked easterly drainage of the Mackenzie River tributaries in northern Yukon. Glacially dammed water in the Bonnet Plume basin was diverted into Bell basin through a meltwater channel occupied by the modern Eagle River (Fig. 2). This diversion rapidly incised the Eagle channel and initiated drainage of meltwater from the Bonnet Plume basin into the Bell, Bluefish and Old Crow basins, forming glacial lake Old Crow. The surface of this lake eventually overtopped the divide of the paleo-Porcupine River system establishing westerly drainage of the Porcupine River into central Alaska and draining the glacial lake system in the Old Crow, Bluefish and Bell basins (Thorson and Dixon 1983; Duk-Rodkin *et al.*, 2004).

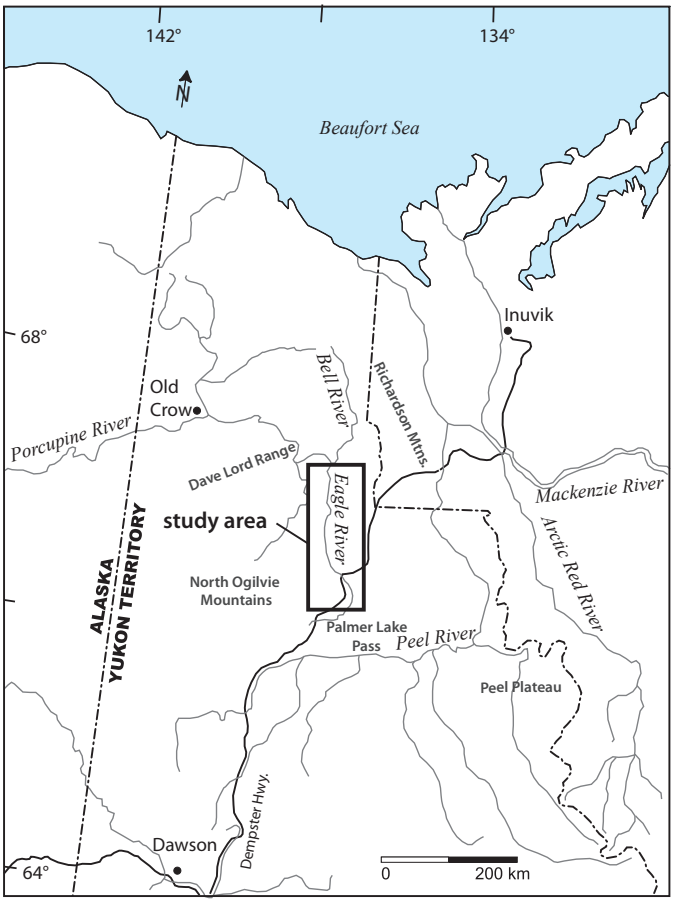

Figure 1. *Location of study area.*

PLEISTOCENE CHRONOLOGY

Flooding of the Eagle River meltwater channel was intimately connected with extensive continental ice in the western Mackenzie basin blocking drainage from the

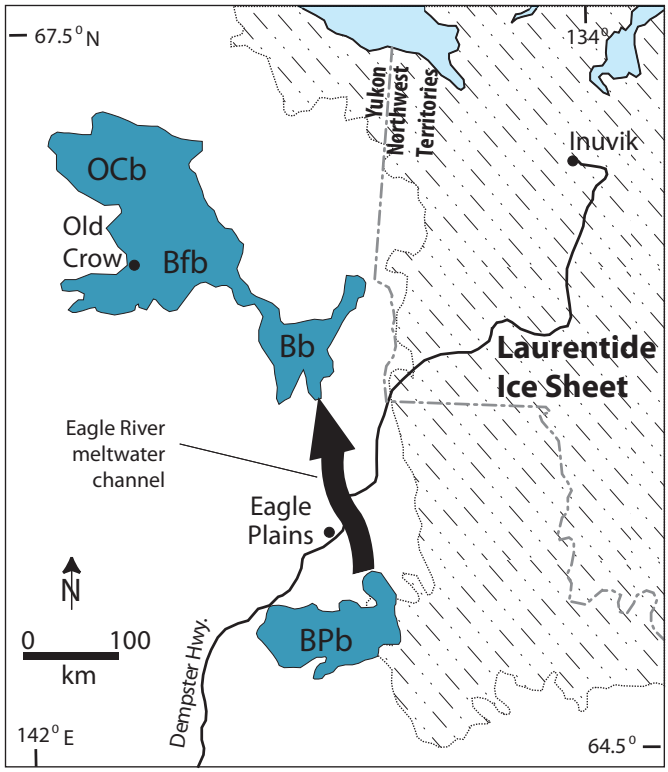

Figure 2. *Glacial lakes (shaded areas) formed by the impoundment of east-flowing drainages by the Laurentide Ice Sheet. The Eagle River meltwater channel linked a lake in Bonnet Plume basin (BPb) with a continuous lake in Bell (Bb), Bluefish (Bfb) and Old Crow (OCb) basins.*

Richardson Mountains south to the Bonnet Plume basin. Meltwater flooding in the Eagle River channel requires the Laurentide Ice Sheet in northwestern North America to be near its maximum extent. Radiocarbon dates have been collected from the eastern Richardson Mountains, and Bell, Old Crow and Bluefish basins, and applied to the stratigraphy in Old Crow basin to produce a chronology for the northwestern Laurentide Ice Sheet. These dates suggest an extensive advance occurring at least 30 000 ^{14}C yrs BP (30 ka BP), followed by a later, less extensive advance *ca.* 16-18 ka BP (Duk-Rodkin *et al.*, 2004; Zazula *et al.*, 2004). Both advances are thought to have activated the Eagle River meltwater channel and created continuous, glacially dammed lakes in the Bell, Bluefish and Old Crow basins. Recent investigations in the Old Crow area suggest that lake sediments in Old Crow basin, originally thought to represent the maximum advance of the Laurentide Ice Sheet at *ca.* 30 ka BP, are more than 40 ka BP and non-glacial in origin (Froese *et al.*, 2007). This suggests that a tectonically controlled basin existed in the Old Crow area prior to meltwater additions associated with the Laurentide Ice Sheet, and only a single late Pleistocene advance may have affected the area (Froese *et al.*, 2007).

REGIONAL SETTING

The Eagle Plains ecoregion is a rolling lowland between the Richardson, North Ogilvie and Dave Lord Mountain ranges (Figs. 1 and 3). Relief is subdued and draped with colluvial deposits that thicken downslope from veneer-covered ridges. West of the Eagle River, drainages are dendritic with broad v-shaped valleys separated by long rounded ridges (Thomas and Rampton, 1982). East of the Eagle River, drainages are more deeply incised with distinct pediment surfaces related to late Tertiary uplift of the Richardson Mountains (McNeil *et al.*, 2001). Regional bedrock is dominated by deep marine basinal rocks. Early Carboniferous shale of the Ford Lake Formation is exposed along most of the upper Eagle River and grades laterally into the underlying Tuttle Formation that outcrops on lower reaches of the Eagle River (Norris, 1997; Lane, 2007). Continuous permafrost underlies all materials in the region and can reach local depths of at least 89 m, with active-layer depths of 20 to 90 cm (Yukon Ecoregions Working Group, 2004).

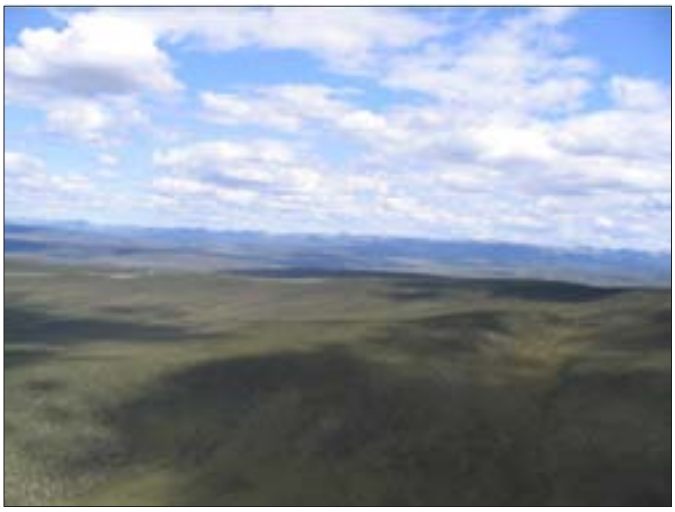

Figure 3. *Easterly view of the Eagle Plains area toward the Richardson Mountains. The Dempster Highway is visible in the middle of the photo.*

PROCESS-DEPOSITIONAL MODELS

Process-depositional models have been developed to understand the formative mechanisms of surficial geologic units and to explain and predict their distribution (Fisher and Smith, 1993). This method has been used successfully to understand the distribution of aggregate resources associated with catastrophic flooding along the margins of the Laurentide Ice Sheet in North Dakota (Lord and Kehew, 1987) and northeastern Alberta (Fisher and Smith, 1993). Process-depositional models for meltwater channels incorporate unique hydrological characteristics of glacial lake outburst floods that differ from traditional paleohydraulic calculations (Lord and Kehew, 1987). Glacial lake outburst channels have relatively consistent channel widths, high depth-to-width ratios, discrete cutbanks, and limited deposition as a result of highly erosive hyper-concentrated flow (Lord and Kehew, 1987).

Development of meltwater outburst channels is thought to occur in three phases (Lord and Kehew, 1987; Fisher and Smith, 1993; O'Connor, 1993). First, initial incision and channel expansion occurs; this is the most erosive phase of flooding and will often dominate for significant distances beyond the drainage divide. Sediment is entrained and carried in suspension with little deposition taking place. Second, channelized flow develops; this is likely caused by changes in paleo-topography or flood energy. Erosive capability is reduced as energy decreases and channel incision begins. This often results in deposition in areas of reduced velocity along channel margins, with deposition of pendant bars (channel-attached bars) and back-flooding of tributary junctions (slackwater sedimentation). The final phase in the

development of meltwater channels is the deposition of remaining fine-grained suspended sediments (sand, silt and clay). This final deposition may occur in the form of an extensive delta plain if the flows go into a proglacial lake; otherwise, slackwater sedimentation may occur where flow is impinged through a narrowing of the channel. The ultimate distribution of erosion and sedimentation in individual channels is dependent on thickness and bedrock composition and resistance to erosion, surficial geology of cover materials, flood power, duration and volume, and the presence and characteristics of pre-existing valley systems occupied by the flood (Lord and Kehew, 1987; O'Connor, 1993).

METHODS

We identified aggregate resources along the Eagle meltwater channel using a process-depositional model of flood channel evolution following similar work by Fisher and Smith (1993) applied to the Fort McMurray region. In order to do this, landforms and surficial materials were identified along the length and breadth of the spillway channel using 1:60 000- and 1:70 000-scale aerial photography, along with previously published surficial and bedrock geological maps at scales ranging from 1:100 000 to 1:250 000. Landforms were identified, mapped and field-checked during the summer of 2007. At select sites, detailed sedimentologic descriptions were completed to record surficial units exposed in section along the Eagle River and its tributaries. The distribution, composition and characteristics of landforms were then used to reconstruct paleohydraulic conditions and predict zones of coarse-aggregate deposition.

RESULTS

The Eagle meltwater channel can be divided into three distinct reaches (upper, middle and lower) based on the distribution of erosion and deposition along the meltwater channel, and quality and quantity of aggregate deposits along its length (Fig. 4).

UPPER REACH (~50 KM)

The upper reach of the Eagle channel is characterized by a narrow, steep-walled canyon almost entirely void of flood deposits (Fig. 5). The flood channel begins ~60 km upstream of the Dempster Highway bridge near the drainage divide at Palmer Lake (Fig. 1). The valley bottom is flat and ranges from 500-1500 m wide with steep-sided valley walls up to 200 m high. The valley bottom is poorly drained and organic soils are thick and well developed. Above the escarpment, surficial materials are composed of thick colluvial deposits, with only minor evidence of flood erosion (Fig. 6). Pediment surfaces are well

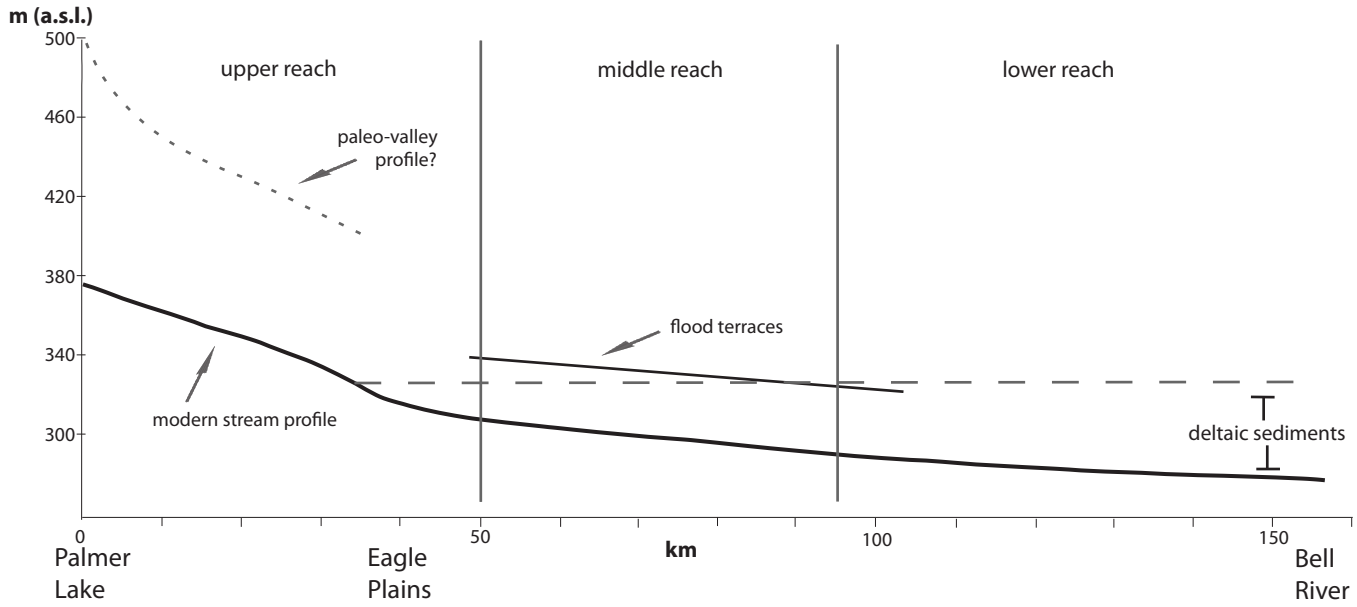

Figure 4. *Longitudinal cross-section of the modern Eagle River stream profile and the hypothesized paleo-Eagle River profile with locations of flood terraces and the area of deltaic sedimentation. The distribution of erosion and deposition along the channel results in three distinct (upper, middle and lower) reaches for aggregate resource assessment. Vertical scale is exaggerated four times the horizontal scale (VE = 4x). a.s.l. = above sea level.*

Figure 5. *Steep valley sides and flat valley floor of the upper channel at Palmer Lake Pass. View is to the south.*

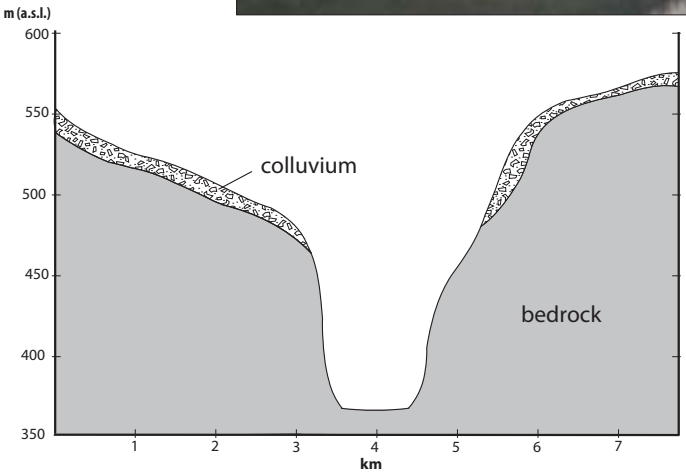

Figure 6. *Schematic cross-section of the upper reach of the Eagle meltwater channel. Steep bedrock on the valley sides is blanketed by colluvial deposits that have likely been formed over long periods of periglacial weathering. (VE = 20x)*

Figure 7. *View downstream of the Eagle River channel, highlighting multiple terrace levels of middle reach with scoured surfaces including shallow lakes. Channelized flow in the middle reach initiated deposition of coarse aggregate deposits.*

developed on the slopes above both margins of the channel's upper reach, suggesting this area may have been a high drainage divide prior to meltwater rerouting. The upper reach has the highest topographic relief in the study area.

MIDDLE REACH (~45 KM)

The middle reach contains the most prospective aggregate deposits in the Eagle River meltwater channel. Beginning ~10 km upstream of the Dempster Highway bridge, the middle reach of the channel is characterized by high, broad bedrock terraces commonly overlain with flood-deposited gravel and sand (Figs. 7 and 8). Terraces are located at elevations of 340-360 m above sea level (a.s.l.) (20-30 m above the modern alluvial plain) and are well developed on the outside bends of the channel and

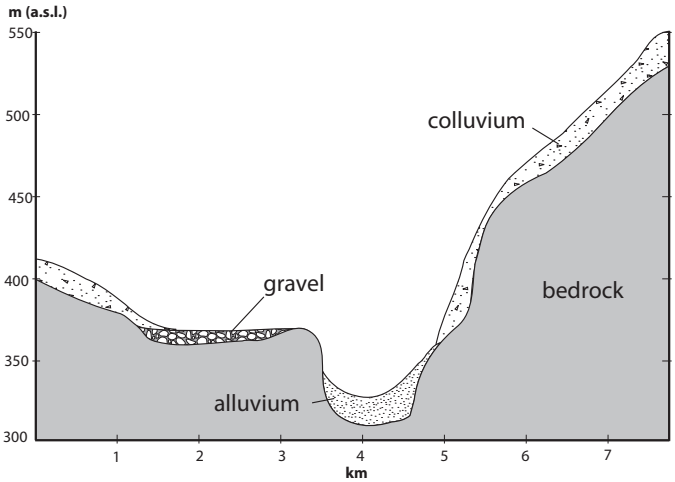

Figure 8. *Schematic cross-section of the middle reach of the Eagle meltwater channel. The broader channel in this reach allows for coarse gravel deposits to be preserved above bedrock terraces. (VE = 20x)*

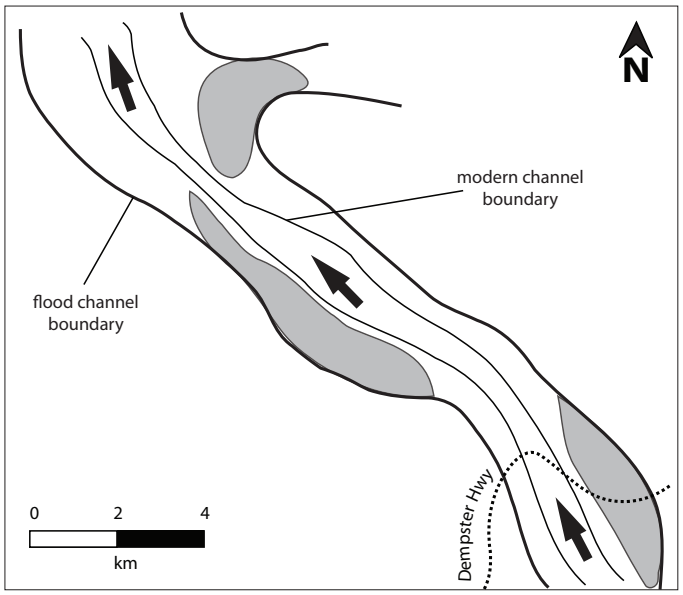

Figure 9. *Schematic view of the middle reach of the Eagle meltwater channel with shaded areas outlining coarse gravel deposits on the outside bends and at tributary junctions of the channel.*

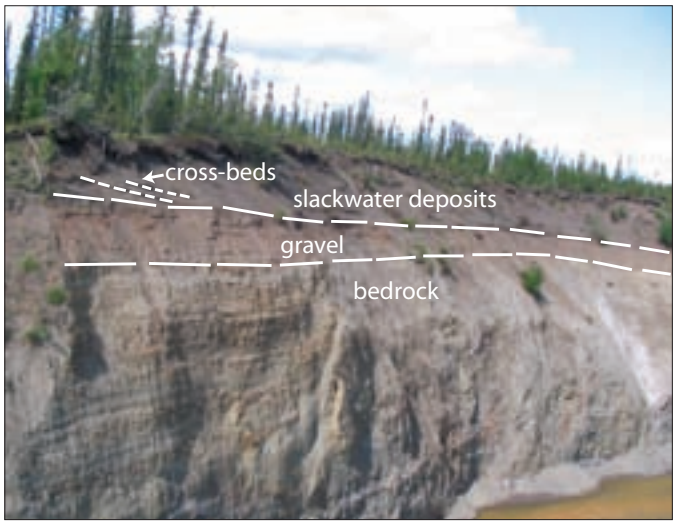

Figure 10. *Upstream-trending slackwater deposits above an erosional bedrock contact on a tributary to the Eagle River. Tributary flow is toward the left, and steep cross-beds in sandy slackwater deposits indicate flow was to the right (upstream) when they were deposited. Section is approximately 30 m thick.*

at the junctions of tributary valleys (Fig. 9). Observed thicknesses of terrace deposits range from <1 m to >5 m, and are generally between 1 and 3 m. Terraces near Eagle Plains are ~500 m wide by up to 2 km long.

Terrace deposits are composed of pebble-cobble gravel (clast sizes with b-axis lengths ranging from 0.5-30 cm with rare boulders up to 50 cm), with a coarse sand matrix-fill. Results of limited sampling of terrace deposits for grain-size distributions are shown in Table 1. Clasts are imbricate downvalley, rounded-to-tabular in shape, and most deposits are moderately to well sorted. Field observations of clast lithology indicate about 90% of deposits are composed of locally derived sandstone, with about 10% of clasts being shale and limestone, with rare granite and gneiss. These latter crystalline rocks are derived from the Canadian Shield and were transported by the Laurentide Ice Sheet and subsequent high-energy flooding along the channel, probably as ice-rafted clasts. Slackwater sediments were documented in the middle reach of the Eagle River channel 30 km downstream from the Dempster Highway bridge with surface elevations of ~ 340 m a.s.l. (Fig. 10). Importantly, these deposits are identified by their up-stream paleo-current indicators, representing back-flooding of tributary valleys. This provides a robust elevation for the flood-water surface in this reach.

Table 1. *Grain-size distribution (% by weight) of four aggregate samples from terraces in the middle reach of the Eagle River.*

	1	2	3	4
Gravel (>4.75 mm)	80%	67%	59%	61%
Sand (<4.75 mm & >0.075 mm)	16%	30%	37%	35%
Silt (<0.075 mm & >0.002 mm)	2%	2%	2%	2%
Clay (<0.002 mm)	2%	1%	2%	2%

Valley-bottom sediments in the middle reach of the channel are coarser than those found in the upper reach due to contributions of coarse material from tributary streams. The channel bottom is armoured in cobbles, most of which is likely a local lag associated with downcutting of tributaries and reworking of terrace gravel remnants.

LOWER REACH (~65 KM)

Terraces of the lower reach of the Eagle channel are dominated by fine-grained deltaic and lacustrine deposits (Fig. 11). Beginning ~25 km downstream of the Dempster Highway bridge, the increasing thicknesses of fine sand, silt and clay obscure underlying deposits of flood material.

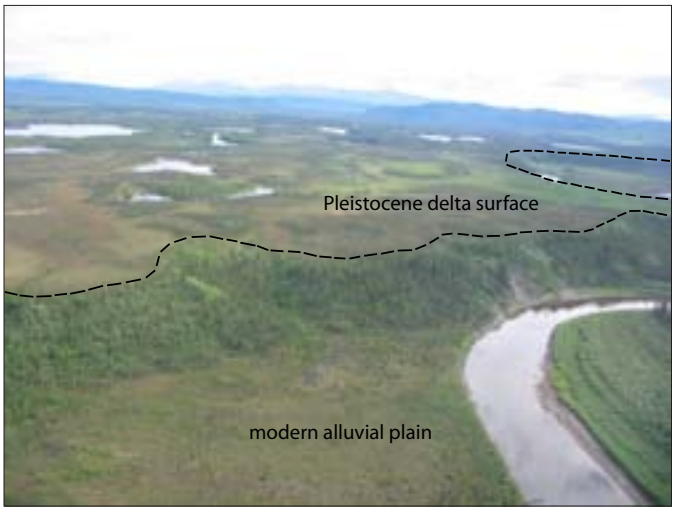

Figure 11. *View of deltaic sediments blanketing the lower reach of the Eagle River. Flow of the river is toward the bottom of the photo, and the delta top is ~20 m above the river surface.*

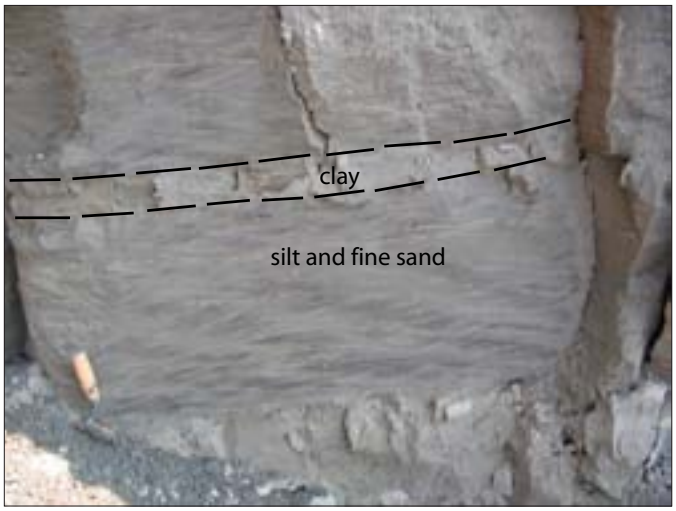

Figure 12. *Stratified deltaic/lacustrine deposits within the lower reach. Massive clay alternating with ripple cross-laminated silt and fine sand.*

Fine-grained deposits thicken downvalley, reaching a thickness of at least 20 m near the junction with the Bell River. These deposits range from stratified sand and silt with rare clasts in the upstream part of the reach to massive clay beds alternating with beds of ripple cross-laminated fine sand and silt in the downstream reach (Fig. 12). Massive clay beds have thicknesses up to 2 m near the base of exposures and thin upward as coarser grained ripple cross-beds become thicker and more frequent. The top of the sediments display evidence of subaerial exposure (ice-wedge casts) and are overlain by up to 1 m of aeolian sand below a cap of modern peat deposits. Coarse aggregate materials may be present at depth, but are not visible where fine-grained sediments are thick.

INTERPRETATION OF FLOOD DYNAMICS

UPPER REACH

The narrow canyon in the upper reach of the Eagle channel represents rapid erosion of bedrock and high-energy flooding. Following initial breach of the drainage divide, flood water was likely contained within the canyon in the upper reach and erosion was focused on downward incision. This incision is typical of early-phase catastrophic flooding (*e.g.,* Lord and Kehew, 1987) and was likely only minimally influenced by pre-existing topography. This initial phase of meltwater flow would likely have begun as a broad sheet of sediment-poor flood water as the divide between the Bonnet Plume and Eagle basins was overtopped by proglacial meltwater associated with the Laurentide Ice Sheet. Rapid incision into underlying shale would have quickly incorporated large volumes of sediment, carried as suspended load, and flood water may have reached sediment loads typical of a hyper-concentrated flow (intermediate between clear stream flow and sediment-dominated debris flow).

MIDDLE REACH

The broad terraces and coarse deposits of the middle reach of the Eagle channel represent a change in flow regime from a single channel to a distributed pattern with one primary channel and multiple secondary channels (Fig. 7). This likely reflects changes in paleo-valley alignment or slope that initiated overtopping of the channel margins by flood water. These changes may also have been initiated as flood waters became channelized in a pre-existing paleo-Eagle valley system.

The middle reach of the Eagle channel remained dominantly erosional; however, lower velocity flow along the margin of the channel and into tributary junctions initiated deposition of coarse, cobble-pebble terraces and pendant (bank-attached) bars. Bedrock terraces are commonly, but not always, overlain by significant gravel

deposits and are concentrated along outside bends of the meltwater channel reflecting expansion of flow onto these surfaces. Eddy or alcove bars were probably formed in tributary mouths as the result of deposition from back-flooding into valleys (Baker, 1973; O'Connor, 1993) (Fig. 13). Upstream-trending cross-beds in slackwater sediments of tributary valleys (Fig. 10) provide a minimum elevation of the flood surface, and additional support for the catastrophic nature of channel formation. Flooding likely remained hyper-concentrated in this reach, and deposition was largely limited to coarse material in areas of flow expansion.

Along the present-day Eagle River, continued adjustments in the base level of tributary valleys provide an important source of aggregate material to the alluvial plain of the Eagle River and those of its tributaries. Aggregate deposits in the active Eagle River alluvial plain are concentrated at tributary junctions, and decrease in concentration downstream from the tributary, producing small fans of coarse deposition in the modern valley. Development on the tributary alluvial plains may be preferred due to the low water levels present in the summer months.

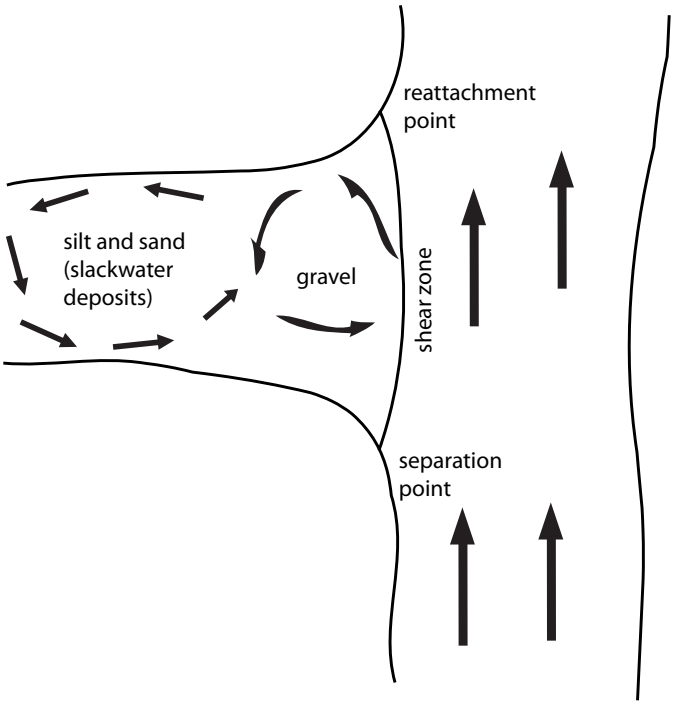

Figure 13. *Flow conditions associated with the formation of slackwater deposits. Flood water in the main channel inundates tributary valleys with turbulent flow that deposits coarse materials near the point of separation (at tributary junction) and finer material further up-valley in the tributary. Figure modified from O'Connor (1993).*

LOWER REACH

Thick occurrences of horizontally stratified sand with interbedded silt up to 20 m thick occur across the lower reaches of the Eagle and Bell rivers and are interpreted as a braid delta built into the upstream extension of glacial lake Old Crow. Crudely inverse (coarsening-upward) grading of these deposits suggests these sediments represent the progradation of deltaic sedimentation into a shallow lacustrine basin. The deltaic sediments lack large cross-beds (foresets), further suggesting a shallow basin that likely aggraded as meltwater influx from the Eagle channel raised lake levels. These sediments and landforms are similar to the Athabasca braid delta at the mouth of the Clearwater-Athabasca meltwater channel in northeastern Alberta (Rhine and Smith, 1988). Coarse aggregate deposits may be present below lacustrine and deltaic sediments in this reach, but would only be accessible near the basin margins where fine-grained deposits are thinner.

Radiocarbon dating of lake sediments in Bluefish basin indicate a lake existed at ~300 m a.s.l. from 18-16 ka BP and may have extended into the Bell basin (Zazula *et al.*, 2004). Flooding of the Eagle River meltwater channel likely contributed to the volume of the lake, and combined with meltwater-related sedimentation, raised lake levels in Bell basin to at least 340 m a.s.l. based on the elevations of deltaic deposits in this study.

DISCUSSION

The distribution of erosional area, flood deposits and deltaic sedimentation in the Eagle meltwater channel is consistent with existing models of flood-channel evolution in a proglacial setting (Lord and Kehew, 1987; Fisher and Smith, 1993; O'Connor, 1993). Depositional and erosional features along the Eagle River meltwater channel closely resemble those of the late Pleistocene Clearwater-Athabasca spillway in northeastern Alberta (Fisher and Smith, 1993). The primary depositional landforms associated with both channels are deltaic and fine-grained, with relatively minor amounts of coarse deposition in middle reaches, and virtually no coarse deposition in upper and lower reaches.

The Eagle River meltwater channel differs from other documented spillways and meltwater channels because of the relatively small clast size in coarse deposits (typically, boulders are common in meltwater channel deposits). The presence of soft Ford Lake shale in much of the upper

channel resulted in a deeply incised valley and few resistant clasts available for transport and deposition in the channel. Rare clasts of granite and gneiss occur in the basin, but likely represent ice-rafted deposition of glacial material transported into the Bonnet Plume basin by the Laurentide Ice Sheet. The large volume of shale removed from the upper channel was likely carried as suspended sediment and transported through to the downstream lacustrine basins. Coarse deposits are mostly (>90%) sandstone, concentrated from limited availability in regional bedrock.

IMPLICATIONS FOR AGGREGATE RESOURCES

Preferred road construction materials are 10-14% silt and clay (for binding), 35-70% sand and 20-60% gravel (J. Marynowski, pers. comm., 2007). The low percentages of silt and clay in sampled terrace deposits (Table 1) require that additional fine-grained materials are added to the deposits before they can be used for road construction. However, most terrace deposits in the middle reach of the Eagle meltwater channel are overlain by fine-grained lacustrine sediments that could easily be mixed at the time of extraction. Although sandstone is not a preferred granular material for aggregate resources, few other options exist in this region, other than crushing of local bedrock.

Economic development on the Dempster Highway corridor could be facilitated by additional research along the Eagle River meltwater channel to further define the quality and quantity of aggregate resources available in the channel's middle reach. Specifically, ground-penetrating radar surveys, coupled with auger drilling and textural analyses would be useful in defining thicknesses, extents and materials available on different terraces or terrace levels in the area.

CONCLUSIONS

Aggregate in the Eagle Plains region is found primarily on high terraces formed by late Pleistocene flooding along the Eagle River associated with rerouting of the Peel River drainage by the Laurentide Ice Sheet. These deposits, along with those found in the mouths of tributary valleys, are the result of specific paleohydraulic conditions that are typical of glacial meltwater channels. This study demonstrates the erosional and depositional features of the Eagle River meltwater channel and fit well within the framework of process-depositional models used to describe meltwater channels. Process-depositional models have proven to be applicable to northern regions and a cost-effective model for developing aggregate resources.

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Summary of the stratigraphy, sedimentology and hydrocarbon potential of the Laberge Group (Lower-Middle Jurassic), Whitehorse trough, Yukon

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ABSTRACT

Whitehorse trough is a northwestward-tapering belt of Upper Triassic to Lower Cretaceous volcanic and sedimentary rocks extending ~650 km from the British Columbia–Yukon border, north to the vicinity of Carmacks in south-central Yukon. It consists of three main stratigraphic units (*i.e.*, the Lewes River Group, Laberge Group and Tantalus Formation) representing three sedimentary basins, partially overlapping in space and time. The Laberge Group (Lower-Middle Jurassic), informally subdivided into the Richthofen, Tanglefoot and Nordenskiold formations, was deposited in the Laberge basin, a collapsing fore-arc basin in which the arc was undergoing uplift and erosion. The Richthofen formation consists of conglomerate, massive sandstone, sandstone-mudstone couplets, volcaniclastic rocks and minor limestone interpreted as submarine fan systems. The Tanglefoot formation consists of coal-bearing sandstone, mudstone, conglomerate, volcaniclastic rocks and minor limestone interpreted as delta systems and shallow marine deposits. The Richthofen and Tanglefoot formations are the same age (*i.e.*, Sinemurian to Bajocian), but the Richthofen formation is restricted to the southern half of the basin, whereas the Tanglefoot formation occurs in the northern half. The Nordenskiold formation consists of subaerially erupted, resedimented volcaniclastics deposited mainly during Pliensbachian time. The Richthofen formation is interpreted as a spent source rock and the Nordenskiold formation is not a source rock. The Tanglefoot formation is interpreted as a potential source rock and possibly an effective source rock. It contains petroleum fluid inclusions (mainly 23°- 32° and 40°- 44° API gravity) indicating a minimum trapping temperature of 110-115°C. The Tanglefoot formation is also a potential reservoir rock.

RÉSUMÉ

La dépression de Whitehorse consiste en une ceinture de roches sédimentaires et volcaniques datant du Trias supérieur au Crétacé inférieur, qui s'effile vers le nord-ouest et s'étend sur quelque 650 km depuis la frontière entre la Colombie-Britannique et le Yukon jusqu'à Carmacks, dans le centre sud du Yukon. Elle est constituée de trois unités stratigraphiques principales, soit le Groupe de Lewes River, celui de Laberge et la Formation de Tantalus, qui représentent trois bassins sédimentaires qui se chevauchent partiellement sur le plan spatial et chronologique. Le Groupe de Laberge, qui se compose des formations informelles de Richthofen, de Tanglefoot et de Nordenskiold, a été mis en place dans le bassin de Laberge, qui consiste en un bassin d'avant-arc en effondrement dont l'arc était soumis à un soulèvement et à une érosion au moment de la mise en place. La Formation de Richthofen est constituée de conglomérat, de grès massif et de couples de grès-mudstone, ainsi que de roches volcanoclastiques et de quantités moindres de calcaire, lesquels sont interprétés comme des réseaux d'éventails sous-marins. La Formation de Tanglefoot est composée de grès renfermant du charbon, de mudstone, de conglomérat, et de roches volcanoclastiques, ainsi que de petites quantités de calcaire, lesquels sont interprétés comme des réseaux deltaïques et des dépôts épicontinentaux. Bien que les formations de Richthofen et de Tanglefoot aient le même âge (du Sinémurien au Bajocien), celle de Richthofen est circonscrite à la moitié sud du bassin, alors que celle de Tanglefoot repose dans sa moitié nord. La Formation de Nordenskiold est formée de roches volcanoclastiques produitent par des éruptions subaériennes et resédimentées principalement pendant le Pliensbachien. La Formation de Richthofen est interprétée comme une roche mère épuisée, alors que celle de Nordenskiold n'en est pas une. Celle de Tanglefoot est interprétée comme une roche mère possible ou peut-être même comme une roche mère réelle. Elle renferme des inclusions fluides de pétrole d'une densité allant principalement de 23 à 32 degrés API et de 40 à 44 degrés API, ce qui témoigne d'une température de piégeage minimale de 110 à 115 °C. La Formation de Tanglefoot pourrait également constituer une roche réservoir.

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INTRODUCTION

Whitehorse trough is one of eight oil and gas basins identified in the Yukon (Fig. 1). It forms a northwestward-tapering belt of Upper Triassic to Lower Cretaceous volcanic and sedimentary rocks extending ~650 km from the British Columbia–Yukon border, north to the vicinity of Carmacks in south-central Yukon. It is the northernmost of four 'Interior Cordilleran' basins in northwestern Canada (*i.e.*, from south to north, Quesnel, Nechako, Bowser and Whitehorse; Teitz and Young, 1982) that exhibit similar patterns of sedimentary history and tectonic evolution and have corresponding oil and gas potential (Teitz and Young, 1982). Koch (1973) described occurrences of oil shale, gas odours and oil seeps in the central part of Whitehorse trough, and Petro-Canada concluded that Jurassic rocks throughout the basin have the potential to generate gas and possibly oil, whereas Cretaceous rocks have the potential to generate gas (Gilmore, 1985; Gunther, 1985). Beaton *et al.* (1992a) determined that coal seams from the Whitehorse trough have a low potential to generate oil and gas, and Allen (2000) provided new data that Jurassic rocks in the central part of the basin have the potential to generate gas and possibly oil. The National Energy Board (2001) concluded that the Whitehorse trough was an "immature, mainly gas-prone" basin and identified potential source rocks (*i.e.*, Triassic carbonates, Jurassic mudstones and Cretaceous mudstones), reservoirs (*i.e.*, Triassic carbonates, and Jurassic and Cretaceous sandstones), seals (*i.e.*, Jurassic mudstones and volcaniclastic rocks) and traps (*i.e.*, anticlines and pinch-outs). It is estimated that up to 4.8 Tcf (140 million cubic metres) of gas and possibly some oil may occur in the Whitehorse trough (K. Ozadetz, pers. comm., 2004). This paper summarizes the stratigraphy, sedimentology and hydrocarbon potential of the Lower and Middle Jurassic rocks (*i.e.*, the Laberge Group) in Whitehorse trough.

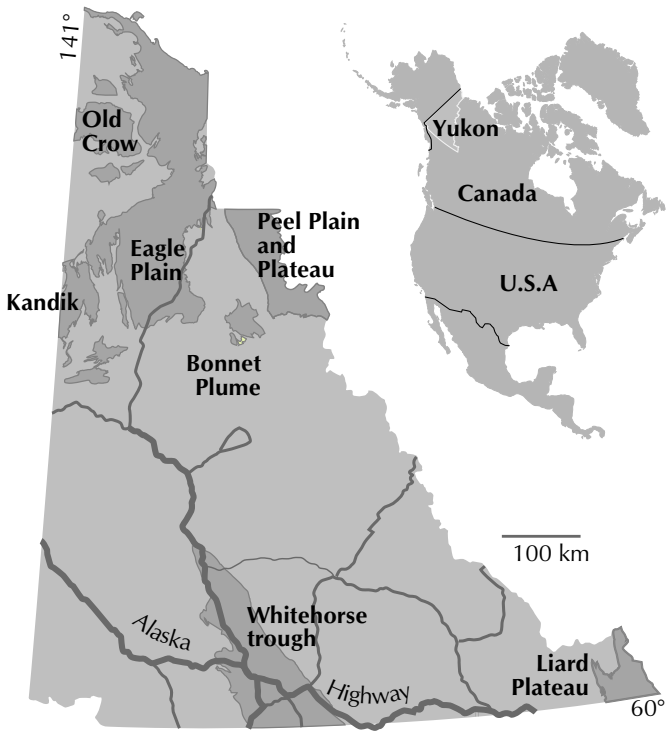


Figure 1. *Petroleum basins in the Yukon (from Oil and Gas Branch, Yukon Government, 2007).*

GEOLOGIC SETTING

Wheeler (1961) introduced the name "Whitehorse trough" for a Late Triassic to early Cretaceous volcanic and sedimentary depocentre extending from northwestern British Columbia, northwestwards to south-central Yukon. It forms part of Stikinia (Fig. 2), which is flanked to the west and east by Yukon-Tanana terrane, and is bordered on the south by Cache Creek terrane (Wheeler and McFeely, 1991).

Although the early history of the Whitehorse trough is obscure, its origin is best explained by the 'oroclinal entrapment' model of Mihalynuk *et al.* (1994). In this model, the Quesnellia and Stikinia volcano-plutonic arcs impinged on the ancient margin of North America (*i.e.*, the Yukon-Tanana terrane) in Latest Permian to Middle Triassic time, followed by indentation and beginning of closure of the oceanic Cache Creek terrane in Late Triassic time; subsequently, Stikinia was rotated into an east-facing arc (locally referred to as the Lewes River arc), resulting in isolation of the Cache Creek terrane in the Early Jurassic, culminating with final closure and uplift in Middle Jurassic time (Mihalynuk *et al.*, 1994). The Whitehorse trough is preserved as a northwest-trending synclinorium characterized by southwest-verging fold-and-thrust belts (Wheeler, 1961; White *et al.*, 2006; Colpron *et al.*, 2007).

In the Yukon, the Whitehorse trough consists of three main stratigraphic units: the Lewes River Group (Upper Triassic), the Laberge Group (Lower-Middle Jurassic), and the Tantalus Formation (Middle Jurassic-Lower Cretaceous). These units represent three sedimentary basins partially overlapping in space and time. The Lewes River basin is interpreted as a fore-arc basin associated with westward subduction (Tempelman-Kluit, 1979; Souther, 1991); the Laberge basin is interpreted as a

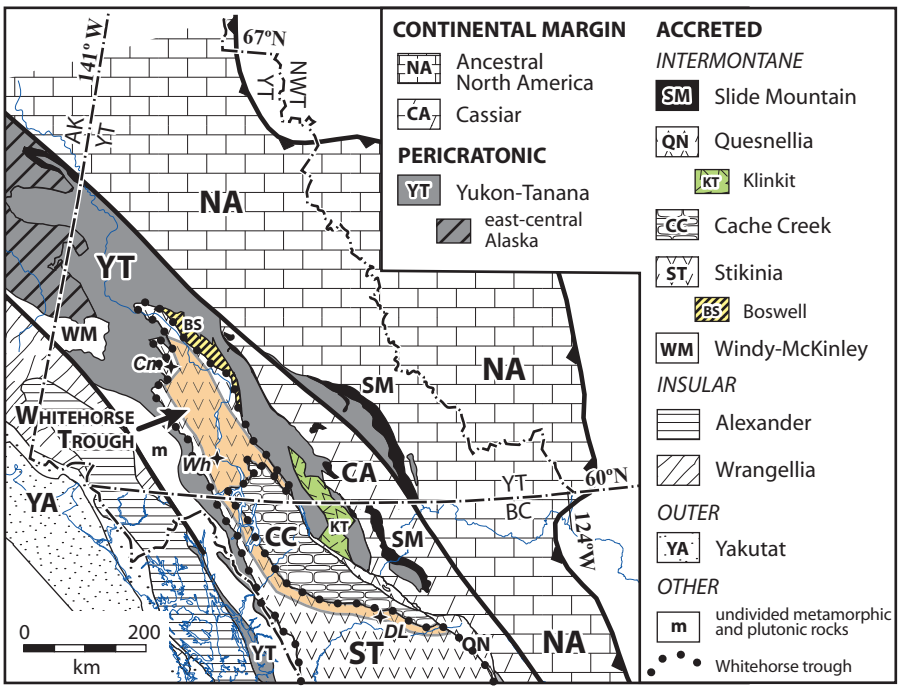


Figure 2. *Location map and geologic setting of the Whitehorse trough, Yukon (modified from Colpron et al., 2007). Wh=Whitehorse, Cm=Carmacks, DL=Dease Lake.*

collapsing fore-arc basin in which the Lewes River arc was being uplifted and eroded (Wheeler, 1961; Lowey and Hills, 1988); and the Tantalus basin represents mainly isolated, terrestrial basins (Wheeler, 1961; Long, 1986; Lowey and Hills, 1988).

STRATIGRAPHY

The Laberge Group (Lower-Middle Jurassic) is underlain by the Lewes River Group and overlain by the Tantalus Formation (Fig. 3). Note that these are lithostratigraphic units (*i.e.*, defined on the basis of lithic characteristics and stratigraphic position, North American Commission on Stratigraphic Nomenclature, 2005). The Lewes River Group (Upper Triassic) is informally divided into the Povoas and Aksala formations, the later of which is informally subdivided into the Casca, Hancock and Mandanna members (Tempelman-Kluit, 1984). The Povoas formation consists of basalt, volcanic breccia, tuff and agglomerate; the Casca member consists of mudstone, sandstone and limestone with minor conglomerate; the Hancock member consists of limestone; and the Mandanna member consists of sandstone, limestone, volcaniclastic rocks and minor conglomerate. The Tantalus Formation (Middle Jurassic-Lower Cretaceous) is a formal unit consisting of conglomerate and coal-bearing sandstone and mudstone (Long, 1986; Lowey and Hills, 1988; Lowey, 2004).

HISTORICAL BACKGROUND

Cairnes (1910) first described and named the Laberge strata in the Lewes and Nordenskiold coal district as the "Laberge series" and "Nordenskiold dacites". Lees (1934), working in the Laberge map area, and Bostock (1936) working in the Carmacks map area, adopted this nomenclature. Bostock and Lees (1938) subsequently described the Nordenskiold unit as the Nordenskiold formation. Wheeler (1961) mapped the Whitehorse area and renamed the Laberge series the "Laberge group". Souther (1971), working in northern British Columbia, subdivided the Laberge Group into the relatively coarser grained Takwahoni Formation and the relatively finer grained Inklin Formation. Tempelman-Kluit (1984) remapped the Carmacks and Laberge areas and subdivided the Laberge Group (from oldest to youngest) into the Richthofen, Conglomerate, Nordenskiold Dacite and Tanglefoot formations. Hart (1997) remapped parts of the Whitehorse area and redefined the Laberge Group (and all strata in the Whitehorse trough) as "time-rock" units. However, the Glossary of Geology (Bates and Jackson, 1987, p. 688) states that a time-rock unit is an "undesirable term for chronostratigraphic unit", and both the North American Stratigraphic Code (North American Commission on Stratigraphic Nomenclature, 2005) and the International Stratigraphic Guide (International Subcommission on Stratigraphic Classification, 1994) refer to chronostratigraphic units, in order of decreasing rank, as eonothem, erathem, system, series and stage, whereas

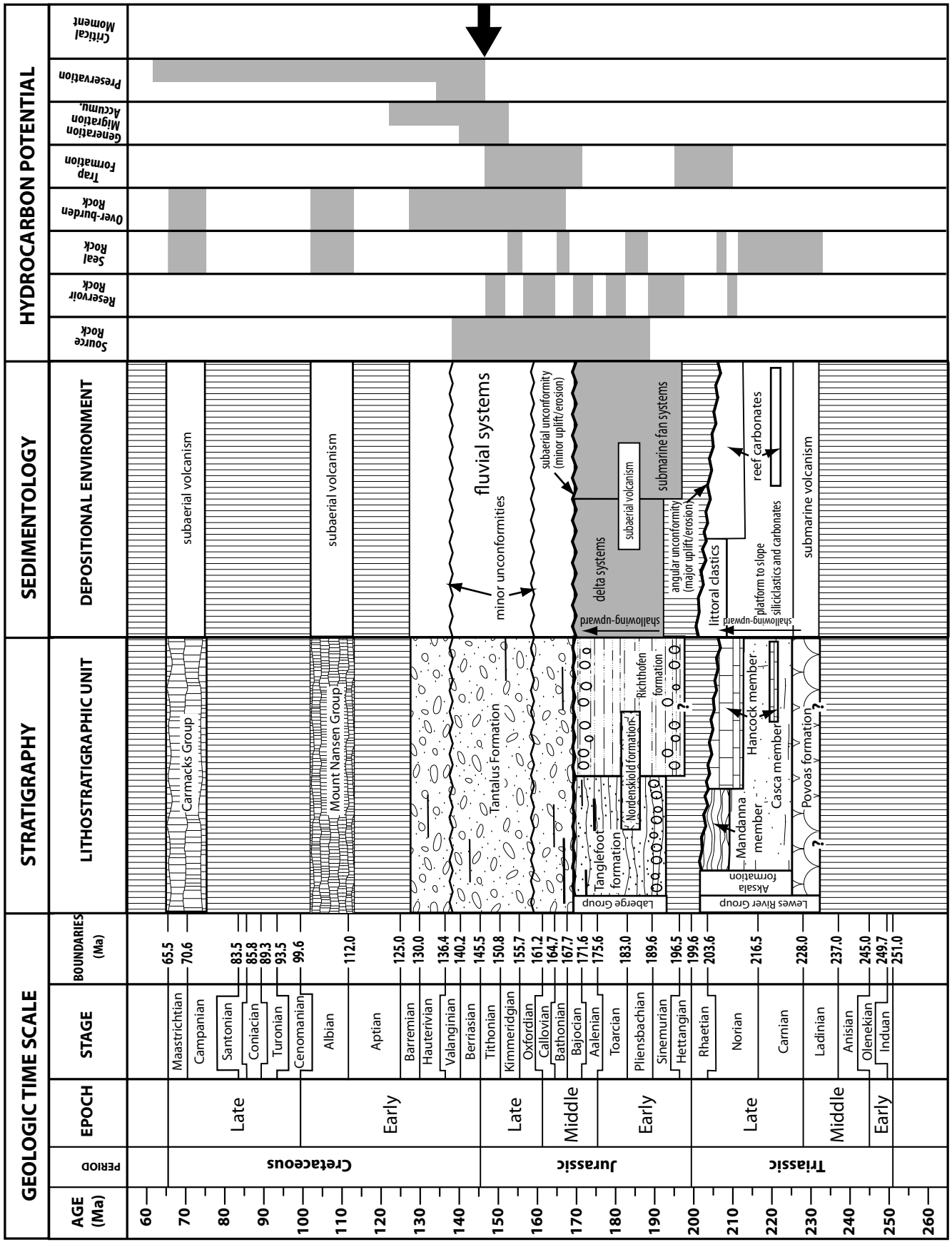


Figure 3. *Summary of the stratigraphy, sedimentology and hydrocarbon potential of the Laberge Group, Whitehorse trough, Yukon.*

lithostratigraphic units, in order of decreasing rank, include supergroup, group, formation, member and bed. Hence it was not appropriate for Hart (1997) to redefine formations (*i.e.*, lithostratigraphic units) as time-rock units (*i.e.*, chronostratigraphic units) based on collections of fossils (*i.e.*, biostratigraphic units). Lowey (2004, 2005) demonstrated that the Conglomerate formation was not a lithostratigraphic unit and reassigned strata in this unit to the Richthofen and Tanglefoot formations. The Laberge Group is herein informally subdivided into the Richthofen, Tanglefoot and Nordenskiold formations.

TYPE LOCALITY AND TYPE SECTION

No type sections, or stratotypes, have been described for the Richthofen, Tanglefoot and Nordenskiold formations. The type area for the Richthofen formation is the west shore of Lake Laberge, and the type area for the Tanglefoot formation is the Division Mountain area, northwest of Lake Laberge. The type area for the Nordenskiold formation is the Nordenskiold River valley near Montague Mountain and Conglomerate Mountain north of Lake Laberge.

LITHIC CHARACTERISTICS

The Richthofen formation is characterized by graded siltstone to very fine grained sandstone and mudstone couplets, or thin-bedded turbidites. Also occurring in the Richthofen formation and associated with the couplets are conglomerate, pebbly sandstone, massive sandstone, volcaniclastic rocks and minor amounts of limestone. The Tanglefoot formation is characterized by coal-bearing, interbedded sandstone and mudstone. Also occurring in the Tanglefoot formation and associated with the interbedded sandstone and mudstone are conglomerate, pebbly sandstone, volcaniclastic rocks and minor amounts of limestone. The Nordenskiold formation is characterized by bedded to massive crystal-rich volcaniclastic material. It is dominated by angular to subangular plagioclase feldspar, quartz and potassium feldspar, with minor amounts of lithic and vitric clasts (Fillmore, 2006).

CONTACT RELATIONS

Cairnes (1910) determined that the basal unit of the Laberge Group was conglomerate and that it unconformably overlies limestone of the Lewes River Group. Cockfield and Bell (1926) thought that the contact appeared to be an angular unconformity. However Bostock and Lees (1938) suggested that the Laberge Group appears to overlie the Lewes River Group conformably, but they were unable to establish with certainty the relations of the two units. Bostock and Lees (1938) also noted that conglomerate assigned to the Laberge Group appears to rest directly on the Lewes River Group, indicating that a period of erosion had preceded deposition of the conglomerate. Wheeler (1961) interpreted the contact between the Lewes River and Laberge groups as a disconformity along the western margin of the Whitehorse trough, and suggested that the contact may be conformable near the centre of the basin and angular along the eastern margin. Tempelman-Kluit (1984) thought that the Lewes River and Laberge groups were a single depositional sequence (*i.e.*, with no major unconformity separating the two units), and suggested that it was impractical to subdivide them. As a result, the Laberge Group is included with the Lewes River Group in the Lexicon of Canadian Stratigraphy (Hills *et al.*, 1981). Most subsequent workers (*e.g.,* Dickie and Hein, 1995; Hart, 1997) followed Tempelman-Kluit's (1984) practise, and interpreted the Lewes River-Laberge contact as a facies boundary.

A key criterion to recognizing unconformities is a basal conglomerate containing clasts from an underlying unit (Shanmugam, 1988). Both the Richthofen and Tanglefoot formations contain limestone clasts lithologically similar to the underlying Hancock member of the Lewes River Group, and several of these clasts reveal Carnian-Rhaetian conodonts identical to the Hancock member (Orchard, 2004, 2006, 2007). The Richthofen formation also contains rare clasts of maroon mudstone that are lithologically similar to the underlying Mandanna member of the Lewes River Group (Fig. 4). Furthermore, Lowey (2005) demonstrated that at two localities where Tempelman-Kluit (1984) mapped the Lewes River-Laberge contact as conformable, one locality was a fault contact and the other was an angular unconformity.

Hart and Pelletier (1989) mapped the Lewes River-Laberge contact exposed on Jackson Hill south of Whitehorse as conformable, and referred to the contact as a "transition" between the two units. At this locality (Fig. 5), conglomerate of the Richthofen formation has eroded the underlying limestone and pyroclastic units of the Mandanna member, and immediately west of the exposed contact, the Hancock member is folded into an anticline. The pyroclastic rocks, referred to by Hart and Pelletier (1989) as siltstone, reveal a zircon U-Pb age of 201.5 ± 0.6 Ma (Mortensen, 2005). This contact is herein reinterpreted as an angular unconformity. Hart (1997) also

mapped the contact between the Lewes River Group and Laberge Group in the Pilot Mountain subdivision area north of Whitehorse as a facies boundary (Fig. 6a). Conglomerate, sandstone and mudstone described as the Richthofen formation by Hart (1997), are reassigned to the Casca and Mandanna members in this study, and the contact re-interpreted as an angular unconformity (Fig. 6B). There is no compelling evidence to suggest that the Lewes River Group–Laberge Group contact is either conformable or a facies boundary, but rather it appears to be a major unconformity generally marked by a basal conglomerate in the Richthofen and Tanglefoot formations.

Figure 4. *Clast of the Mandanna member (Aksala formation), Lewes River Group, in conglomerate of the Richthofen formation, Takhini Crossing, Yukon (clast located above and to the left of the scale).*

The Richthofen-Tanglefoot contact is not exposed and it is uncertain if the two units overlap stratigraphically. Although the Nordenskiold formation occurs mainly as isolated outcrops near the centre and western margin of Whitehorse trough, lithologically similar strata are present locally as thin to thick beds in both the Richthofen and Tanglefoot formations (see comments under Distribution and Thickness).

The contact between the Laberge Group and Tantalus Formation is not exposed in outcrop, but both Cockfield and Bell (1926) and Bostock (1936) stated that it was apparently conformable. The contact is present in drill core in the Division Mountain area (*i.e.*, DDH 97-63, UTM E445122 N 6796798, NAD 83). The contact occurs at a depth of 58.8 m and is marked by the first occurrence of chert clasts. At the contact, coarse sand-sized to granule chert occurs in a 1.2-m-thick, rusty-weathering, massive sandstone bed. It is overlain by a 0.4-m rubble zone (consisting of rusty-weathering fragments of quartz- and

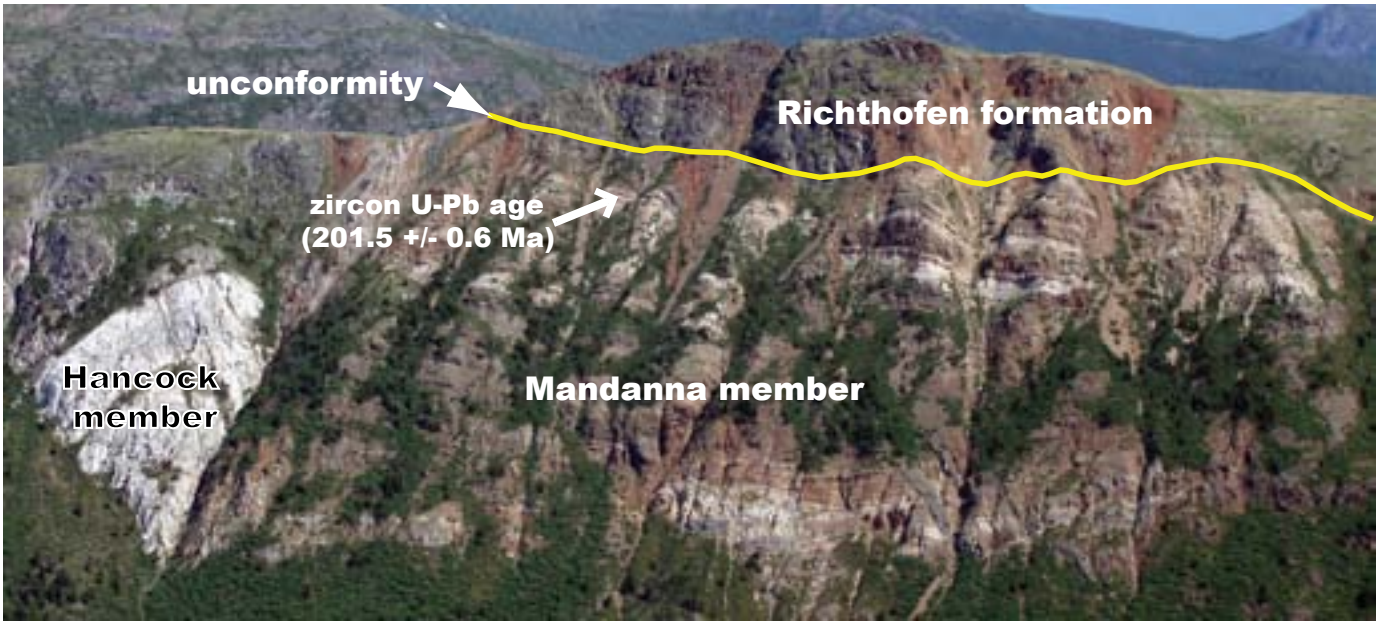


Figure 5. *Angular unconformity between the Hancock and Mandanna members (Aksala formation, Lewes River Group), and the overlying Richthofen formation (Laberge Group), Jackson Hill, Yukon. View looking north. The Hancock member consists of limestone, the Casca member consists of interbedded limestone and volcaniclastics (that reveal a zircon U-Pb age of 201.5 ± 0.6 Ma), and the Richthofen formation consists of conglomerate.*

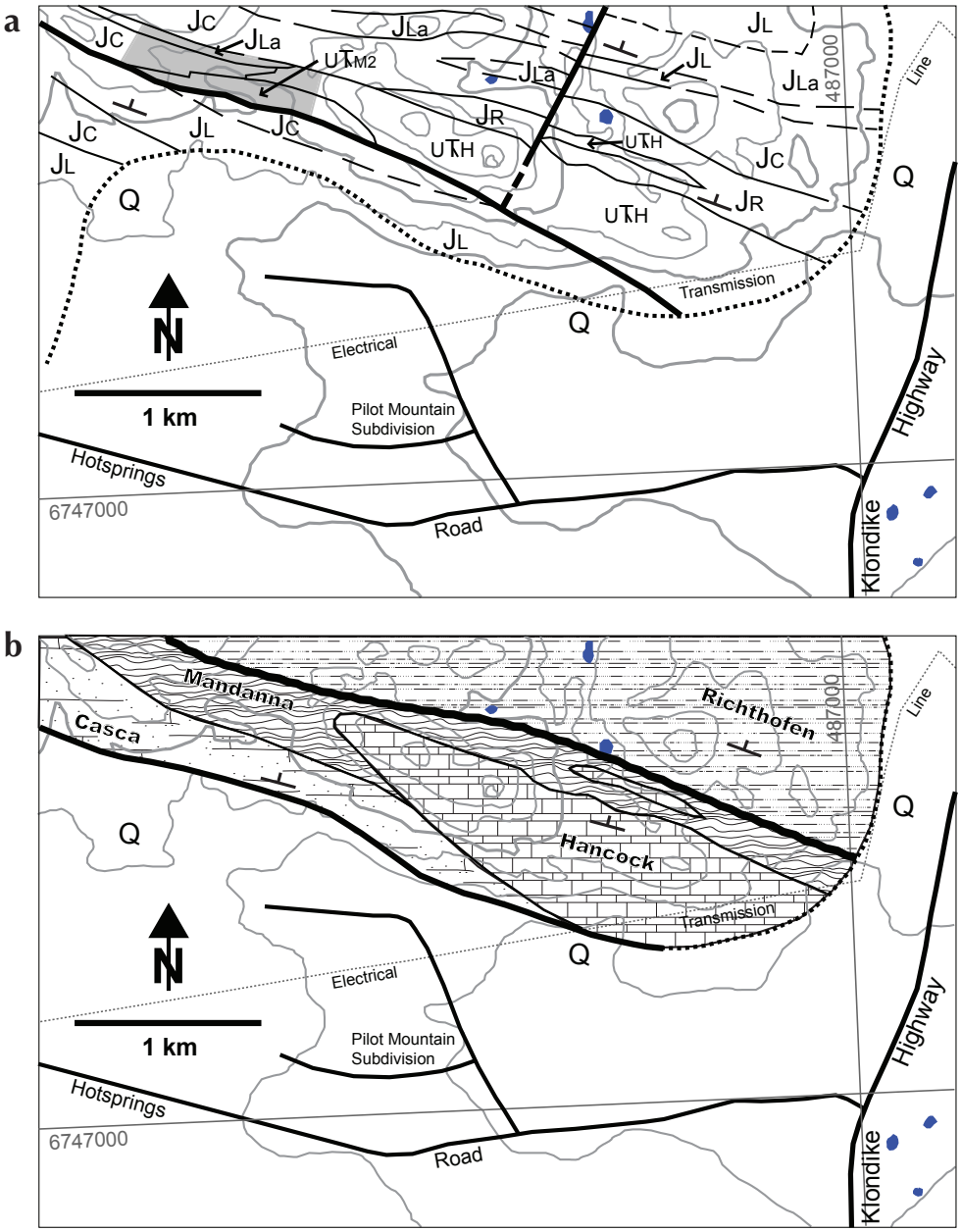


Figure 6. *General geology of the Pilot Mountain Subdivision area, Whitehorse trough, Yukon.* ***(a)*** *Interpretation based on Hart (1997). Shaded area highlights facies contacts between the Lewes River Group (units UTH and UTM2) and Richthofen formation (units JA, JC, JL, JLa and JR).* ***(b)*** *Interpretation based on this study. Heavy wavy line indicates an unconformity between the Lewes River Group (i.e., Casca, Hancock and Mandanna members) and the Richthofen formation. Upper Laberge map sheet, NTS 105 D/14, 1:50 000 scale. (Refer to Figure 3 for key.)*

feldspar-rich sandstone and conglomerate), which is overlain by a 0.75-m-thick granule to fine chert–pebble conglomerate bed. The contact is interpreted as a minor unconformity. Hill (1977) similarly placed the Laberge-Tantalus contact at the base of massive chert-pebble conglomerate observed in drill core from the Carmacks 'south' area (*i.e.*, south of Carmacks and the Yukon River). However, in the Carmacks 'north' area (*i.e.*, north of Carmacks and the Yukon River, including Tantalus Butte), the Laberge-Tantalus contact has been assumed to be at some unknown distance below the massive chert-pebble conglomerate exposed at Tantalus Butte (Cairnes, 1910; Bostock, 1936; Hills, 1977; Tempelman-Kluit, 1984). Lithostratigraphically, it would be more practical to place the contact at the base of the chert-pebble conglomerate, as it is in the Carmacks south and Division Mountain area.

DISTRIBUTION AND THICKNESS

The Richthofen formation is restricted to the southern half of the Whitehorse trough and the Tanglefoot formation occurs in the northern half. The two formations probably overlap in the vicinity north of Lake Laberge and Little Fox Lake (Fig. 7), but the strata have not been observed juxtaposed in outcrop. The Nordenskiold formation was

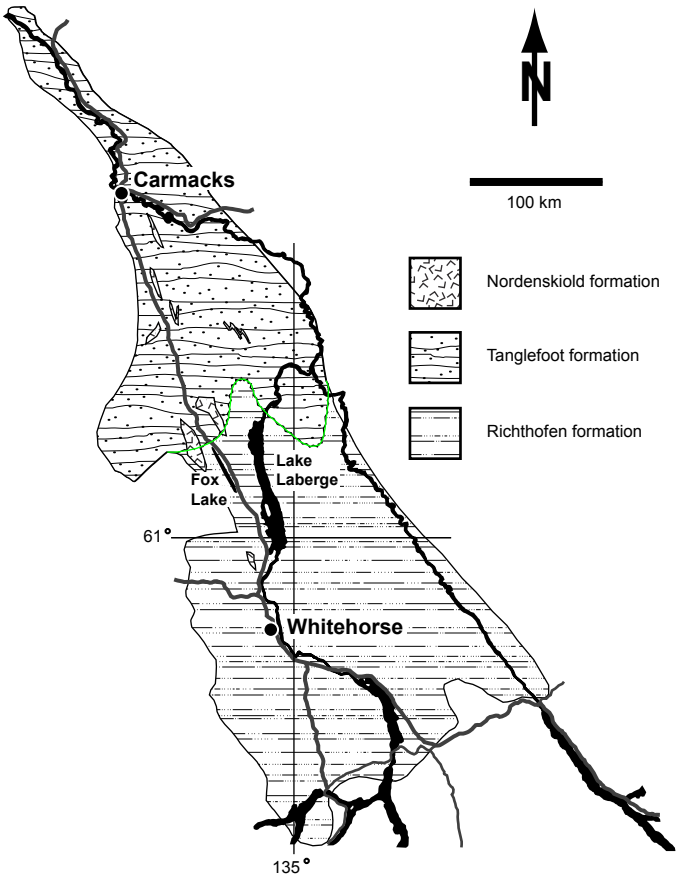


Figure 7. *General distribution of the Richthofen, Tanglefoot, and Nordenskiold formations (Laberge Group), Whitehorse trough, Yukon.*

subdivided by Tempelman-Kluit (1984) into a southern marine unit and a northern subaerial unit. However, at several localities in the south the volcaniclastics occur in sandstone-mudstone couplets belonging to the Richthofen formation; and at several localities in the north the volcaniclastics occur in coal-bearing sandstone and mudstone beds belonging to the Tanglefoot formation. Hence where the volcaniclastics represent a minor component of the strata, these rocks are reassigned either to the Richthofen or Tanglefoot formations. Therefore, the Nordenskiold formation occurs mainly as isolated, massive outcrops near the centre and western margin of Whitehorse trough, but also occurs as thin to thick beds in both the Richthofen and Tanglefoot formations (that are more properly referred to as lithostratigraphic members, lenses, or beds; *c.f.,* North American Commission on Stratigraphic Nomenclature, 2005).

Precise determinations of the thickness of these units are not possible due to the scattered nature of the exposures. Previously reported thicknesses (*e.g.,* Cairnes, 1910; Cockfield and Bell, 1926; Bostock, 1936; Bostock and Lees, 1938; Wheeler, 1961; Hart, 1997) are probably overestimates, because they are based mainly on calculations from a map and not from measured stratigraphic sections. Only relatively short (~200 m), continuous sedimentologic sections have been measured, which indicate that the Richthofen formation is at least 500 m thick in the Lake Laberge area near the central part of the basin (Lowey, 2005), at least 1000 m thick in the Carcross area near the southern part of the basin, and possibly 2000 m thick farther south (Eisbacher, 1974). Based on a deep seismic survey, White *et al.* (2006) interpreted the Tanglefoot formation to be ~3000 m thick in the Carmacks area near the northern part of the basin. However, this too is probably an overestimate, because the Tanglefoot formation is depicted as maintaining a constant thickness in both the east-west (line 1) and north-south (line 2) seismic sections through to the margins of the basin (White *et al.*, 2006). Drill holes at Tantalus Butte near Carmacks penetrated up to 300 m of strata before stopping, and drill holes in the Division Mountain area near the west-central part of the basin penetrated approximately 300 m of continuous Tanglefoot strata before stopping at what was mistakenly thought to be the Tanglefoot-Richthofen contact (Carne and Gish, 1996).

AGE AND CORRELATION

Lowey (2004) demonstrated that by re-assigning previously misidentified units to other formations (particularly the now obsolete 'Conglomerate formation' to the Richthofen and Tanglefoot formations), the Richthofen and Tanglefoot formations span almost the same age. Additional re-assignment of misidentified strata to these units, together with a review of previous data (*e.g.,* Hart, 1997 and references therein; Clapham *et al.*, 2002), indicates that the Richthofen and Tanglefoot formations are at least Sinemurian to Bajocian in age (Early-Middle Jurassic). The reported occurrence of Hettangian strata in the Richthofen formation is contentious (Frebold and Poulton, 1977; Taylor *et al.*, 1984; Jakobs, 1994; Palfy and Hart, 1995; Clapham *et al.*, 2002). U-Pb zircon ages from the Nordenskiold formation range from 188.5-182.5 Ma (Pliensbachian, or Early Jurassic; Hart, 1997; M. Colpron, pers. comm., 2007).

Souther (1971), working in the Whitehorse trough in northwestern British Columbia, redefined the Inklin and

Takwahoni formations of Kerr (1948) to the Laberge Group. The Inklin Formation (Lower-Middle Jurassic) consists of an estimated 3000 m of interbedded sandstone, sandstone-mudstone couplets, clast- and matrix-supported conglomerate and minor amounts of limestone interpreted as deepwater marine deposits (Souther, 1971). It is correlative with the Richthofen formation. The Takwahoni Formation (Lower-Middle Jurassic) consists of an estimated 3300 m of clast-supported conglomerate, sandstone and mudstone interpreted as shallow-water marine and fluvial deposits (Souther, 1971). It is correlative with the Tanglefoot formation. Johannson and McNicoll (1997) reported a U-Pb age of 186.6 ± 0.1 Ma from a rhyodacitic lithic-crystal tuff from the Whitehorse trough in northwestern British Columbia, which is similar in age to the Nordenskiold formation.

SEDIMENTOLOGY

A major unconformity (spanning ~5 million years) separates the Laberge Group from the Lewes River Group (Fig. 3): Lewes River Group strata are at an angle to the unconformity and are locally truncated by the unconformity. According to Embry (1997, 2006), uplift and tilting of strata (*i.e.*, his 'tectonic tilt test') is evidence for the influence of tectonism on sedimentation. In addition, the interpretation of the Laberge basin as a collapsing fore-arc basin, in which the Lewes River arc was undergoing uplift and erosion, also suggests that tectonics was a major control of sedimentation of the Laberge Group.

LITHOFACIES TYPES

Lithological characteristics of the Laberge Group strata are provided by Lowey (2004, 2005). The Richthofen formation is characterized by sediment-gravity-flow deposits, whereas the Tanglefoot formation is characterized by traction deposits (Table 1). The sixteen lithofacies types recognized in the Richthofen formation include conglomerate, sandstone, sandstone-mudstone couplets, siltstone, and siltstone-mudstone couplets (interpreted as debris flows and high- to low-concentration turbidity currents), folded and contorted strata (interpreted as submarine slides), lime mudstone (interpreted as biogenic ooze), and volcaniclastic rocks

Table 1. *Comparison of lithofacies types in the Richthofen and Tanglefoot formations (Laberge Group), Whitehorse trough, Yukon (lithofacies codes modified from Pickering et al., 1989, and Miall, 1996).*

Richthofen formation	
A1.1	Disorganized conglomerate
A1.2	Disorganized muddy conglomerate
A1.3	Disorganized gravelly mudstone
A1.4	Disorganized pebbly sandstone
A2.6	Inversely graded pebbly sandstone
A2.8	Graded-stratified pebbly sandstone
B1.1	Thick/medium-bedded, disorganized sandstone
B2.1	Parallel-stratified sandstone
C2.2	Medium-bedded sandstone-mudstone couplets
C2.3	Thin-bedded sandstone-mudstone couplets
D1.1	Structureless siltstone
D2.2	Thick irregular siltstone-mudstone laminae
D2.3	Thin regular siltstone-mudstone laminae
F2.1	Coherent folded and contorted strata
G1.1	Lime mudstone
V	Volcaniclastic sandstone

Tanglefoot formation	
Gcm	Clast-supported massive conglomerate
Gh	Clast-supported horizontally stratified conglomerate
Sm	Massive fine to coarse-grained sandstone
Sh	Horizontally laminated very fine to coarse-grained sandstone
Sl	Low-angle, cross-bedded fine-grained sandstone
St	Trough cross-bedded fine-grained sandstone
Fm	Massive siltstone and mudstone
Fl	Interlaminated very fine grained sandstone and mudstone
C	Coal
L	Coral wackstone to floatstone
O	Oyster rudstone
V	Volcaniclastic sandstone

(interpreted as resedimented syn-eruptive pyroclastic material). The twelve lithofacies types recognized in the Tanglefoot formation include conglomerate (interpreted as debris flow and river channel deposits), sandstone (interpreted as river channel and marine shoreface deposits), mudstone (interpreted as overbank, abandoned channel and waning flood deposits), coal (interpreted as vegetated swamp deposits), carbonate wackstone/floatstone/rudstone (interpreted as marine bar and offshore deposits), and volcaniclastic rocks (interpreted as resedimented syn-eruptive pyroclastic material).

FOSSILS

The Richthofen formation contains sparse and limited macrofossil, microfossil and trace fossil assemblages (Table 2). Marine macrofossils include only planktonic forms (*i.e.*, ammonites and belemnites). Rare fossilized wood fragments are present locally. Microfossils include degraded and blackened spores and pollen. The trace fossil assemblage (*i.e.*, *Helminthopsis, Phycosiphon, Planolites* and *Zoophycos*, in order of decreasing abundance) is similar to the distal *Cruziana* ichnofacies and proximal *Zoophycos* ichnofacies, typical of lower offshore to shelf marine environments (Pemberton *et al.*, 2001). In contrast, the Tanglefoot formation contains rich and varied macrofossil, microfossil and trace fossil assemblages (Table 2). Macrofossils include planktonic and benthonic forms (*i.e.*, ammonites, belemnites, pelecypods, brachiopods, corals, gastropods and crinoids). Trigonoiid bivalves identified by Poulton (1979) indicate shoreline to shallow marine environments, as do most of the other benthonic fauna. Fossilized wood fragments are locally abundant. Microfossils include spores, pollen and fungi/algae that indicate a well drained (semi-arid) alluvial plain and costal plain environment (Sweet, 2007). The trace fossil assemblage (*i.e.*, *Scolicia, Asterosoma, Thalassinoides, Skolithos* and *Zoophycos*, in order of decreasing abundance) is similar to the distal *Skolithos* and proximal *Cruziana* ichnofacies, typical of middle to lower shoreface and upper offshore marine environments (Pemberton *et al.*, 2001).

Table 2. *Comparison of fossils in the Richthofen and Tanglefoot formations (Laberge Group), Whitehorse trough, Yukon.*

	Richthofen formation	Tanglefoot formation
Macrofossils	ammonite	wood
	belemnite	ammonite
	(wood)[1]	pelecypod
		brachiopod
		coral
		gastropod
		crinoid
		(belemnite)
Microfossils	(spore)	spore
	(pollen)	pollen
		(fungi/algae)
Trace fossils	*Helminthopsis*	Rooting
	Phycosiphon	*Scolicia*
	Planolites	*Asterosoma*
	(Zoophycos)	*Thalassinoides*
		Skolithos
		(Chondrites)

[1]*Parentheses indicate a minor component.*

ENVIRONMENT OF DEPOSITION

Wheeler (1961) suggested that the Laberge Group (*i.e.*, Richthofen formation) in the Whitehorse map-area was deposited partly in a marine environment, but thought that some conglomerate was deposited on an alluvial fan or delta because it was well rounded (implying a transport distance of ~16-32 km), and one bed displayed a channel-shaped cross-section. However, it is now recognized that coarse-grained clastic deposits like gravel can be 'resedimented' into a deepwater environment (Walker, 1975). Eisbacher (1974) recognized the deepwater character of what is now referred to as the Richthofen formation, and concluded that it was deposited in submarine fan systems. The lithofacies types and the fossil assemblages in the Richthofen formation support the interpretation of submarine fan systems. Based on the distribution of the Richthofen formation and the correlative Inklin Formation, these were probably partly coalescing submarine fans systems similar to the multiple-source mud/sand-rich ramp model of Reading and Richards (1994). Limited paleoflow directions indicate an overall southeast transport direction (Lowey, 2005).

Long (1986) interpreted the upper Laberge Group (now referred to as the Tanglefoot formation) as a broad coastal zone characterized by tidal marshes and high constructive river-dominated deltas. The lithofacies types and the fossil assemblages in the Tanglefoot formation support the interpretation of deposition on a coastal plain dominated by delta systems. The presence of coral wackestone to floatstone and oyster rudstone suggest the accumulation of bioclastic bars in a shallow marine environment.

Alternatively, the unique occurrence of the oyster rudstone may be interpreted as a supratidal storm deposit (*c.f.,* Boyajian and Thayer, 1995).

The Nordenskiold formation represents mainly subaerially erupted pyroclastic deposits. The occurrence of volcaniclastic rocks in the Richthofen and Tanglefoot formations (*i.e.,* as Nordenskiold members, lenses, or beds) is interpreted as reworked syn-eruptive pyroclastic material.

As stated previously the Richthofen and Tanglefoot formations probably overlap in the vicinity north of Lake Laberge and Little Fox Lake, and represent, in part a facies change. This 'transition' zone is characterized by very thin to thin-bedded graded siltstone and mudstone couplets, and it is difficult to distinguish pro-delta turbidites of the Tanglefoot formation from thin-bedded turbidites of the Richthofen formation. Some of these graded beds may represent distal storm deposits that accumulated on a shelf environment (*c.f.,* Davis *et al.,* 1989; Walker and Plint, 1992). Figure 8 summarizes the paleogeography of the Whitehorse trough during Pliensbachian time (late Early Jurassic, or ~185 Ma).

TECTONIC PROVENANCE

Lowey and Hills (1988) determined that sandstone compositions from the Laberge Group indicate a dissected arc provenance. Conglomerate compositions are also used to infer tectonic provenance, but due to the preferential weathering of carbonate clasts, the decomposition of igneous clasts into sand-sized mineral grains, and the ambiguous provenance of some chert clasts, they provide only a rough estimate (Cox and Lowe, 1995a,b; Veizer and Mackenzie, 2004). Approximately 3000 clasts from the Laberge Group were identified at 34 stratigraphic sections throughout the Whitehorse trough (Appendix 1). Clast compositions from the Richthofen formation plot entirely within the volcanic arc field, whereas clast compositions from the Tanglefoot formation plot mainly in the volcanic arc field with a few plotting in the basement uplift field (Fig. 9). Cox and Lowe (1995a) note that dissected-arc-derived conglomerates tend to plot between the P+M+Q and V poles. Hence

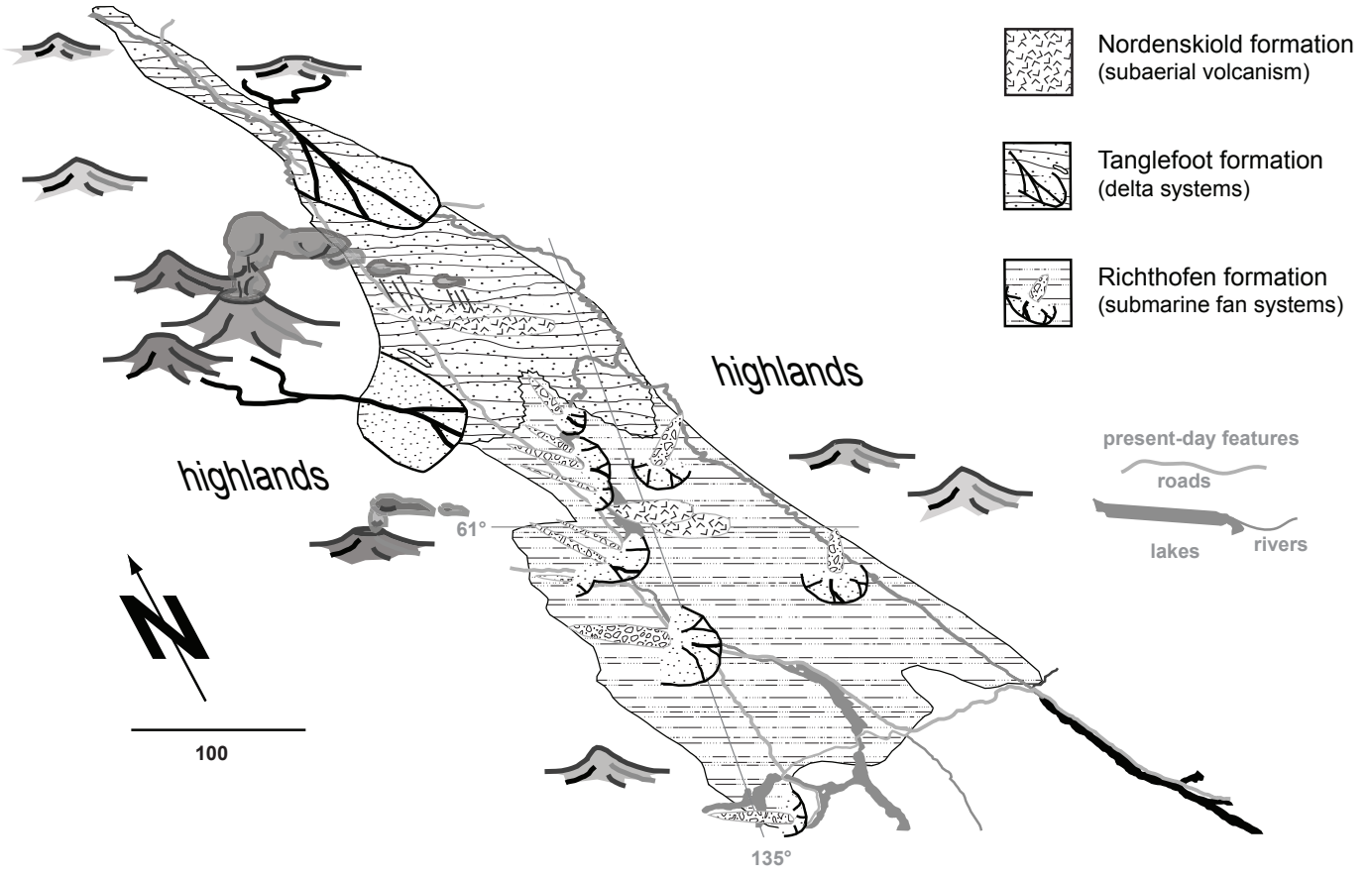


Figure 8. *Paleogeography of the Whitehorse trough during Pliensbachian time (Early Jurassic, or ~ 185 Ma) (oblique view).*

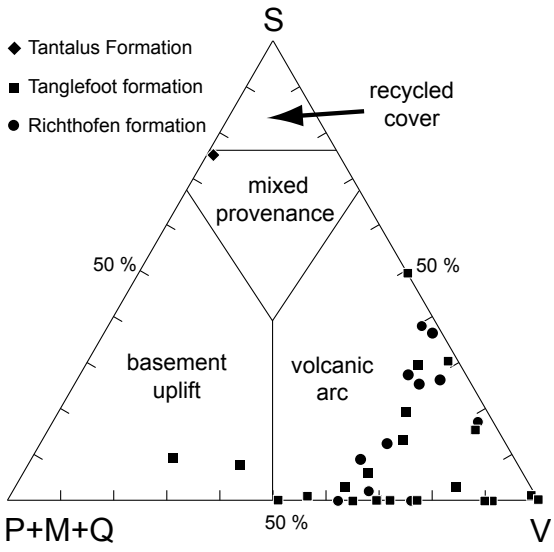


Figure 9. *Conglomerate clast compositions of the Richthofen and Tanglefoot formations (Laberge Group), Whitehorse trough, Yukon. P+M+Q=sum of plutonic, metamorphic and quartz clasts; V=sum of volcanic clasts; and S=sum of sedimentary clasts. Conglomerate composition of the Tantalus Formation is shown for comparison (from Bultman, 1979). Compositional fields for conglomerate clast populations of differing tectonic provenance from Cox and Lowe (1995a, b).*

conglomerate compositions from the Richthofen and Tanglefoot formations also indicate a dissected arc provenance, in agreement with the sandstone compositions from the Laberge Group. Fillmore (2006) determined that the geochemical composition of the Nordenskiold formation is characteristic of high-potassium arc volcanism.

HYDROCARBON POTENTIAL

The hydrocarbon potential of the Laberge Group is summarized in a petroleum system 'events chart' (Fig. 3). This chart shows the chronology of the four essential elements (*i.e.*, source rock, reservoir rock, seal rock and overburden rock) and two processes (*i.e.*, trap formation and generation-migration-accumulation) of a petroleum system (Magoon and Dow, 1994). A petroleum system is a natural system that encompasses a pod, or potential pod, of source rock, related oil and gas, and the geological elements and processes essential for petroleum accumulation to take place (Magoon and Dow, 1994).

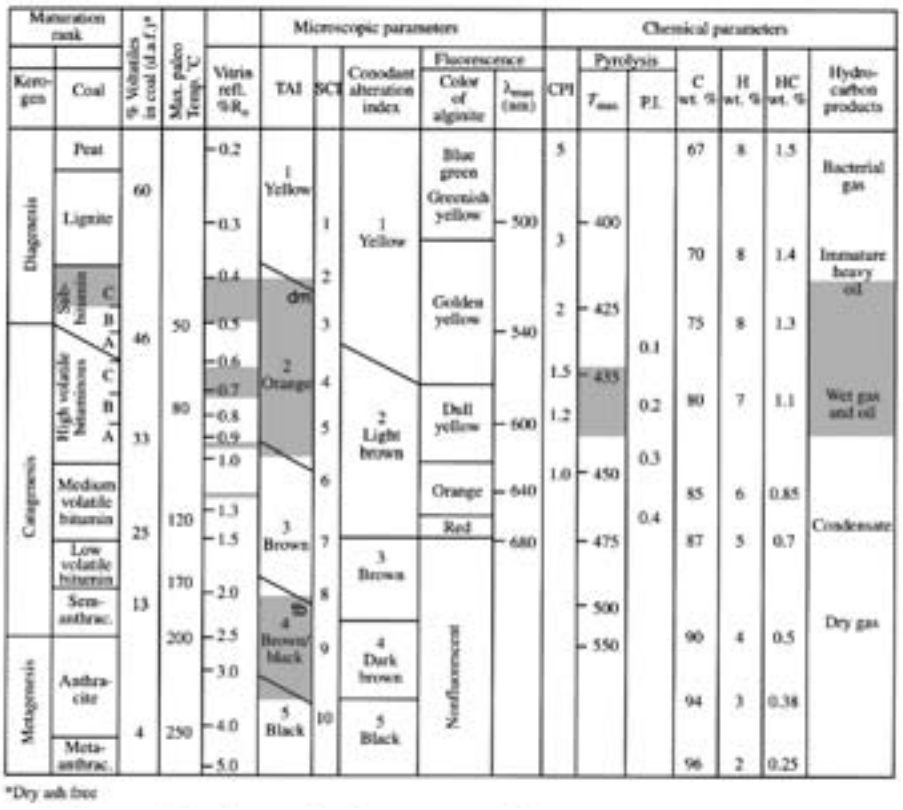
The events chart also shows the major rock units of the petroleum system, and the critical moment, or that point in time best depicting the generation-migration-accumulation of most of the hydrocarbons in a petroleum system (Magoon and Dow, 1994).

SOURCE ROCK

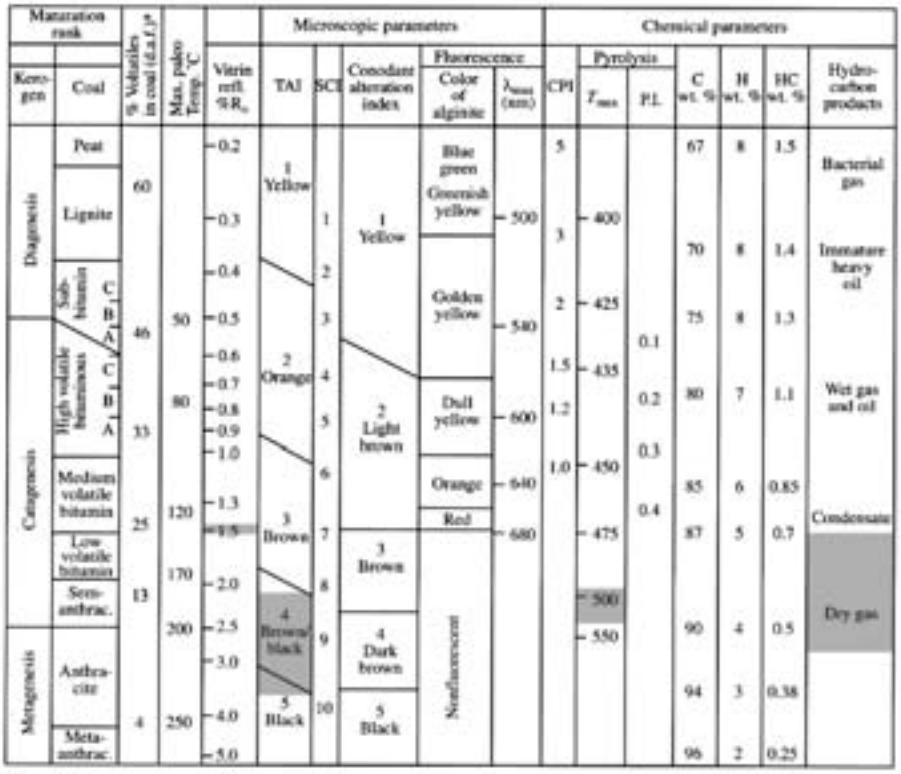
Lowey and Long (2006) provide a detailed report on the source rock potential of the Whitehorse trough. Source rock potential is generally based on maturation levels determined by programmed pyrolysis and combustion, coal rank, vitrinite reflectance, and the colour of microfossils (Fig. 10). The Richthofen formation is a poor to fair source rock, gas-prone and postmature, and the Tanglefoot formation is a good to very good source rock, mainly oil-prone with a possibility of gas, and mature. The Nordenskiold formation has no source rock potential. Petroleum fluid inclusions consisting of medium and light oils (*i.e.*, mainly 23°- 32° and 40°- 44° API gravity*) [*API gravity=American Petroleum Institute degrees, which are inversely proportional to density] are present locally in the Tanglefoot formation, and indicate a minimum trapping temperature of 110-115°C (Fluid Inclusions Technologies, Inc., 2007). The Richthofen formation is interpreted as a spent source rock, whereas the Tanglefoot formation is interpreted as a potential source rock and possibly an effective source rock. The northern part of Whitehorse trough is the most prospective area for hydrocarbon exploration (particularly the Division Mountain, Tantalus Butte and Five Finger Rapids areas). The Tantalus is also a potential source rock (Lowey and Long, 2006).

RESERVOIR ROCK

Potential reservoir rocks exposed at the surface were used to estimate subsurface reservoir quality (Tobin, 1997). All lithologies in the Richthofen and Nordenskiold formations exhibit tight depositional facies and are interpreted as a high risk for reservoir quality. Medium- to thick-bedded feldspathic sandstone in the Tanglefoot formation range from porous, with minimal weathering, to exhibiting abundant secondary porosity of uncertain origin, and is interpreted as a low and moderate to high risk for reservoir quality. The Lewes River Group is also interpreted as a high risk for reservoir quality (although limestone in the Mandanna member is locally fractured and may be a potential reservoir), whereas massive to thick-bedded lithic sandstone in the Tantalus Formation is tightly compacted, but porous and weathered, and is



Tanglefoot formation



Richthofen formation

Figure 10. Summary of thermal maturation levels (shaded areas) in the Richthofen and Tanglefoot formations (Laberge Group), Whitehorse trough, Yukon (dm=samples from Division Mountain area; tb=samples from Tantalus Butte area). Correlation of maturation parameters is from Hunt (1996).

interpreted as a moderate to high risk for reservoir quality.

SEAL ROCK

Interbedded conglomerate, sandstone and mudstone beds in the Richthofen formation and volcaniclastic beds in the Nordenskiold formation represent potential regional seals. Mudstone beds in the Tanglefoot formation are potential local seals. In addition, rocks lacking porosity and permeability occur throughout the Lewes River Group (and include basalt and volcaniclastics in the Povoas formation and interbedded sandstone and mudstone in the Aksala formation), whereas massive conglomerate in the Tantalus Formation is a potential regional seal and mudstone beds are potential local seals. The overlying volcanic flows of the Carmacks Group and Mount Nansen Formation are also potential regional seals.

OVERBURDEN ROCK

Overburden rock for the Tanglefoot formation includes the Tantalus Formation (~1500 m thick), Carmacks Group (~1000 m thick) and Mount Nansen Formation (~500 m thick). The Carmacks Group and Mount Nansen Formation are also an overburden rock for the Tantalus Formation.

TRAP FORMATION

Potential stratigraphic traps in the Laberge Group include unconformities and pinchouts in the Tanglefoot formation. Potential stratigraphic straps in the Lewes River Group include reefs in the Aksala formation (*i.e.*, Hancock member). Unconformities and pinchouts may also be potential stratigraphic traps in the Tantalus Formation. Structural traps include anticlines and high-angle faults that probably formed in Middle Jurassic time (~170 million years ago (mya)) and affected all strata in the Whitehorse trough.

GENERATION-MIGRATION-ACCUMULATION

The generation-migration-accumulation of potential hydrocarbons is difficult to estimate without adequate subsurface data and a proper burial history chart. However, burial of potential source rocks is thought to have started in Late Jurassic time (~150 mya).

PRESERVATION

The preservation, modification or destruction of any possible hydrocarbons probably began in Early Cretaceous time (~140 mya) and may be continuing today.

CRITICAL MOMENT

The critical moment, or point in time that best depicts the generation-migration-accumulation of possible hydrocarbons in the Whitehorse trough, is estimated to be Early Cretaceous time (~145 mya).

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APPENDIX 1: Results of pebble count analysis of the Richthofen and Tanglefoot formations (Laberge Group), Whitehorse Trough, Yukon

SAMPLE	UNIT	Syenite	Monzonite	Quartz Monzonite	Granite	Granodiorite	Diorite	Gabbro	Gneiss	Schist	Argillite	Quartz	Basalt
GL03-4	Tanglefoot	0	0	0	0	1	2	5	0	0	0	0	55
GL03-7	Tanglefoot	0	0	0	43	15	8	0	0	0	0	0	0
GL03-11B	Ttanglefoot	0	0	0	2	2	3	0	0	0	0	1	25
GL03-21	Tanglefoot	0	3	0	4	10	11	1	0	0	0	0	30
GL03-26A	Tanglefoot	0	0	0	1	12	19	0	2	0	0	0	7
GL03-28	Tanglefoot	0	0	0	7	10	19	0	3	0	0	0	26
GL03-34B	Tanglefoot	0	0	0	2	7	5	0	0	1	1	8	9
GL03-35A	Tanglefoot	0	0	0	0	4	3	0	0	0	0	0	24
GL03-36A	Tanglefoot	0	0	0	0	0	1	0	0	0	0	1	45
GL03-42	Tanglefoot	0	15	0	0	0	1	0	0	0	0	18	18
GL03-52A	Tanglefoot	0	0	7	6	26	7	0	0	0	0	5	74
GL03-54A	Tanglefoot	0	0	0	0	0	0	0	0	0	0	1	0
GL03-55A	Tanglefoot	1	1	0	0	10	2	0	0	0	0	0	10
GL03-55B	Tanglefoot	2	0	0	0	17	0	0	0	0	0	0	19
GL03-56	Tanglefoot	1	0	0	0	1	0	0	0	0	0	0	6
GL03-76	Tanglefoot	0	0	0	0	10	14	0	0	0	0	0	27
GL03-76AA	Tanglefoot	0	14	0	0	4	2	0	0	0	0	0	31
GL03-76AAA	Tanglefoot	0	1	0	0	0	0	0	0	0	0	0	57
GL03-76H	Tanglefoot	0	2	0	1	7	2	0	0	0	0	0	25
GL03-80	Richthofen	0	2	0	0	0	0	0	0	0	0	0	10
GL03-87	Richthofen	0	9	0	0	0	3	0	0	0	0	0	12
GL04-3A	Richthofen	0	0	0	0	22	14	2	0	0	0	0	32
GL04-3B	Richthofen	0	0	1	0	8	19	0	0	0	0	0	25
GL04-6	Richthofen	0	0	0	0	4	3	0	0	0	0	0	25
GL04-14	Richthofen	3	0	0	0	0	0	0	0	0	0	0	26
GL04-46	Richthofen	0	0	4	0	5	5	0	0	0	0	0	31
GL04-67	Richthofen	0	9	0	0	14	2	0	0	0	0	7	39
GL04-88	Richthofen	0	0	0	0	23	53	0	0	0	0	0	56
GL04-91	Richthofen	1	0	0	0	35	12	0	0	0	0	1	26
GL04-99	Richthofen	0	0	0	0	0	5	0	0	0	0	0	12
GL04-103	Tanglefoot	0	0	0	0	0	0	0	0	0	0	0	7
GL04-106	Richthofen	0	0	0	0	0	1	0	0	0	0	1	13
GL05-18	Tanglefoot	0	0	0	0	0	2	0	0	0	0	0	7
GL07-100	Tantalus	0	0	0	0	0	0	0	0	0	0	0	0

APPENDIX 1 continued

SAMPLE	UNIT	Andesite	Rhyolite	Dacite	Porphyry	Felsite	Agglomerate	Sandstone	Siltstone	Mudstone	Chert	Limestone	TOTAL
GL03-4	Tanglefoot	0	0	1	3	8	2	0	0	0	0	0	77
GL03-7	Tanglefoot	0	0	0	5	23	0	5	0	1	3	0	103
GL03-11B	Ttanglefoot	0	0	1	18	4	0	0	1	1	0	0	58
GL03-21	Tanglefoot	0	0	0	18	16	0	3	0	3	0	1	99
GL03-26A	Tanglefoot	0	0	0	18	12	0	0	0	0	0	0	69
GL03-28	Tanglefoot	0	0	0	19	5	0	0	0	1	0	0	90
GL03-34B	Tanglefoot	0	0	0	8	26	0	0	0	2	0	0	69
GL03-35A	Tanglefoot	0	0	0	40	4	0	0	0	0	0	0	75
GL03-36A	Tanglefoot	0	0	0	18	0	0	0	0	0	0	28	93
GL03-42	Tanglefoot	0	0	0	6	2	0	0	0	5	0	0	65
GL03-52A	Tanglefoot	0	0	0	18	2	0	0	0	0	0	0	145
GL03-54A	Tanglefoot	0	0	97	0	2	0	0	0	0	0	0	100
GL03-55A	Tanglefoot	0	0	0	41	0	0	0	0	0	0	10	75
GL03-55B	Tanglefoot	0	0	0	61	0	0	0	0	0	0	23	122
GL03-56	Tanglefoot	0	0	0	29	2	0	0	0	0	0	7	46
GL03-76	Tanglefoot	0	0	0	34	1	0	0	0	0	0	0	86
GL03-76AA	Tanglefoot	0	0	0	17	2	0	0	0	0	0	0	72
GL03-76AAA	Tanglefoot	0	0	0	47	1	0	0	0	0	1	0	107
GL03-76H	Tanglefoot	0	0	0	11	2	0	0	0	0	0	0	50
GL03-80	Richthofen	0	0	0	48	1	1	0	1	0	0	33	97
GL03-87	Richthofen	0	0	0	54	0	0	0	0	7	0	22	107
GL04-3A	Richthofen	0	0	0	48	0	0	0	0	3	2	6	129
GL04-3B	Richthofen	0	0	0	36	0	0	0	0	0	1	1	91
GL04-6	Richthofen	0	0	0	23	0	0	0	0	0	0	1	73
GL04-14	Richthofen	0	0	0	48	0	0	0	0	0	0	16	93
GL04-46	Richthofen	0	8	0	5	0	0	0	0	0	0	0	58
GL04-67	Richthofen	19	5	0	31	0	0	0	18	0	0	0	144
GL04-88	Richthofen	2	0	0	55	9	0	0	0	0	0	0	198
GL04-91	Richthofen	13	1	0	14	0	0	0	0	0	0	0	103
GL04-99	Richthofen	3	2	0	45	0	1	0	16	0	0	8	92
GL04-103	Tanglefoot	3	0	0	5	5	0	0	1	0	3	15	39
GL04-106	Richthofen	8	0	0	12	2	0	0	0	0	12	10	59
GL05-18	Tanglefoot	0	0	0	8	0	0	0	0	0	0	7	24
GL07-100	Tantalus	0	0	0	0	0	0	0	0	0	100	0	100
													3008

Thrust slices and associated deformation in the Klondike goldfields, Yukon

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ABSTRACT

Regional-scale thrust faults in the Klondike District separate major lithologic units that include medium-grade metamorphic rocks of the Upper Permian Klondike Schist and middle to late Paleozoic Finlayson (Nasina) assemblage, as well as relatively low-grade greenstone and ultramafic rocks of the Slide Mountain terrane. These units were emplaced in the Jurassic as a series of kilometre-scale stacked thrust slices that are locally separated by additional ultramafic slices. A distinctive set of post-metamorphic compressional structures related to thrusting, particularly a set of ductile recumbent folds and associated spaced cleavage, is preserved in all thrust slices and is well developed near bounding faults. In carbonaceous units within the Klondike Schist, spatially associated with some thrusts, carbonaceous material is locally concentrated along the thrust-related spaced cleavage. Thrust-related fabrics are overprinted by kink-folding that locally affects the Finlayson assemblage, but is mainly developed in Klondike Schist. Gold-bearing veins appear confined to Klondike Schist and were emplaced in local sites of extension controlled principally by axial surfaces of these kink folds.

RÉSUMÉ

Dans le district du Klondike, des failles de chevauchement d'échelle régionale séparent d'importantes unités lithologiques, y compris des roches de métamorphisme moyen du Schiste de Klondike datant du Permien tardif, un assemblage de Finlayson du Paléozoïque tardif, ainsi que des roches ultramafiques et des roches vertes de métamorphisme relativement faible du terrane de Slide Mountain. Ces unités, mises en place pendant le Jurassique, consistent en une série de lambeaux de chevauchement empilés d'échelle kilométrique séparés par endroits par d'autres lambeaux ultramafiques. Un ensemble distinct de structures de compression post métamorphiques liées au chevauchement, plus particulièrement un ensemble de plis couchés ductiles avec un clivage espacé connexe, a été conservé dans tous les lambeaux de chevauchement et est bien formé près de failles limitrophes. Dans les unités carbonées du Schiste de Klondike, que l'on trouve associé à certains chevauchements, le carbone semble être concentrés par endroits le long du clivage espacé asoocié aux failles de chevauchements. Les fabriques de chevauchement sont soumises à la surimpression de plis en kink qui sont développé par endroits dans l'assemblage de Finlayson, mais qui se retrouvent surtout dans le Schiste de Klondike. Des filons aurifères vraisemblablement circonscrits au Schiste de Klondike ont été mis en place dans des zones de distension localisées principalement délimitées par les surfaces axiales des plis en kink.

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INTRODUCTION

The Klondike goldfields have produced at least 20 million ounces (600 million grams) of alluvial gold that was ultimately derived from orogenic (mesothermal) veins contained within the underlying Klondike Schist (Tyrell, 1907; Rushton *et al.*, 1993; Knight *et al.*, 1999; Lowey, 2005; Lebarge, 2007). The structural controls on the emplacement of these gold-bearing veins has been the focus of ongoing research (MacKenzie *et al.*, in press) and the relative timing of gold mineralization has now been placed in a framework of the main structural events that occurred during the evolution of the Klondike Schist (MacKenzie *et al.*, 2007, 2008 (this volume)). This study further contributes to our understanding of the structural context in which the gold-bearing Klondike Schist has evolved.

Much of the preserved structural fabric within the Klondike Schist and within the other major lithologic units in the Klondike District is directly linked to their emplacement as a series of stacked thrust slices. Individual thrust slices are bounded by major regional-scale faults that separate the main lithologic packages. The nature and characteristics of these faults and their preserved deformational structures have not been previously described in detail. The main reason is that exposure of the bounding faults is generally poor and identification of the faults within individual lithologic units, such as the Klondike Schist, is very difficult because of the lack of contrasting rock types across faults. This investigation examines several of the major bounding thrust faults that separate the main basement lithologic units in the Klondike District, as well as some of the thrust faults which occur within the Klondike Schist.

This paper outlines results of a detailed structural investigation of regional-scale faults in the northern and central Klondike District during the 2007 field season. Due to the generally poor exposure in the area, this study focuses on a few key exposures in lower Bonanza Creek in the northern Klondike District, and some recent exploration trenches and road cuts in the central Klondike District. This work has been carried out as part of a regional study of the entire Klondike District and adjacent Indian River area (J. Mortensen, D. MacKenzie and D. Craw, work in progress) that is being funded by Klondike Star Mineral Corporation.

REGIONAL GEOLOGY

The main basement lithologic units of the Klondike District form part of the Yukon-Tanana terrane and include medium-grade metamorphic rocks of the Upper Permian Klondike Schist, carbonaceous schist of the Devonian–Mississippian Finlayson assemblage (Nasina facies), and little-metamorphosed Late Paleozoic greenstone and ultramafic rocks of the Slide Mountain terrane (Fig 1.; Mortensen, 1990, 1996; Mortensen *et al.*, 2007). These units were thrust-imbricated in the Early Jurassic (Mortensen, 1996) resulting in a series of stacked thrust slices that are locally separated by lenses of ultramafic rocks. The uppermost slices are Klondike Schist and consist of complexly interleaved (1- to 100-m-scale) greenschist-facies quartzofeldspathic, chloritic, micaceous and minor carbonaceous schists. The two upper slices of Klondike Schist host significant orogenic gold and are the focus of current research into the structural controls on gold-bearing veins (MacKenzie *et al.*, in press).

The thrust stack was uplifted through the brittle-ductile transition in the Jurassic and unconformably overlain by locally derived sedimentary and volcanic rocks in the Late Cretaceous (Mortensen, 1996). Regional extension and normal faulting continued from Late Cretaceous to early Eocene with initiation of the strike-slip Tintina fault, along which rocks of the Klondike District were offset ~450 km from the rest of the Yukon-Tanana terrane (Gabrielse *et al.*, 2006). Minor regional uplift continued in the late Tertiary when erosion produced the Pliocene White Channel Gravels and the world-famous Klondike gold placer deposits (Lowey, 2005). Exposure of basement rocks in the Klondike District is generally poor due to extensive colluvium and permafrost on the tree-covered slopes (Bond and Sanborn, 2006).

THRUST FAULTS

Regional-scale thrust faults form the boundaries between the major lithologic units of the Klondike District (Figs. 1 and 2). The Klondike Schist occurs at the top of the thrust stack, in at least three different thrust slices separated by major thrust faults (Figs. 1 and 3). In lower Bonanza Creek, an additional thrust fault cuts the northern Klondike Schist slice at Cripple Hill (Fig. 3; see below), indicating that there may be other, still unrecognized, thrust slices within the unit. Two thrust slices of Finlayson assemblage (Nasina facies) rocks underlie the Klondike Schist and these Finlayson slices are separated by a thrust slice of greenstone and discontinuous lenses of serpentinite.

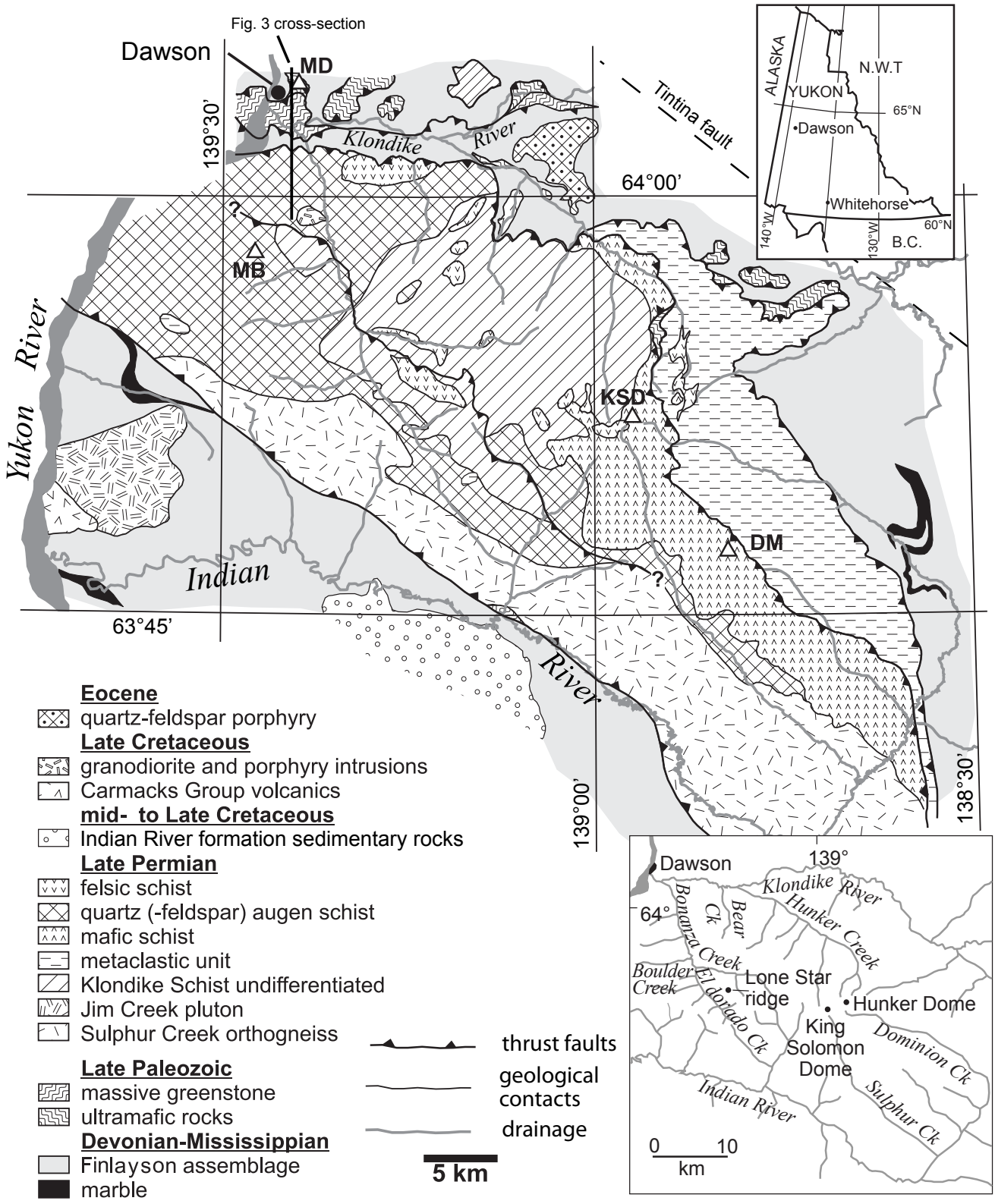

Figure 1. *Geological map of the Klondike District, central western Yukon (after MacKenzie et al., in press). KSD = King Solomon Dome; MD = Midnight Dome; DM = Dominion Mountain; MB = Mount Bronson. Top right inset map outlines the study area within Yukon, while bottom right inset map depicts the major drainages and physiographic features in the study area.*

At a regional scale, the faults bounding the slices are observed to be low-angle thrusts that separate the major lithologic units along widely spaced outcrops. At an outcrop scale, these faults are locally steepened and overprinted by later crosscutting structures. In a few places, the thrust faults are marked by lenses of sheared ultramafic rocks (Fig. 1) that typically pinch out along strike. Small isolated occurrences of sheared ultramafic rocks (serpentinite and/or talc schist) also occur locally within the Klondike Schist and are commonly associated with layers of strongly deformed carbonaceous schist (*e.g.,* Lone Star ridge, Fig. 1; Boulder Creek and Cripple Hill; Fig. 2).

All thrust slices are affected by a similar set of structures related to thrust emplacement. This set of structures comprises primarily post-metamorphic ductile folds and locally, a spatially associated late-stage phacoidal cleavage. In the Klondike Schist, these folds are designated F_3 (MacKenzie *et al.*, 2007) because they demonstrably overprint and deform the pervasive metamorphic foliation and F_1 and F_2 folds transposed along it.

In this study, we use standard structural notation correlated for structures in the Klondike Schist, as these schists are the principal focus of our study. We project the same nomenclature and structural designator into the underlying structural slices for convenience, although we accept that this projection may turn out to be an oversimplification. For example, the metamorphic foliation in the Finlayson assemblage carbonaceous schists is similar to that of the Klondike Schist (designated S_2), but is defined by much finer grained micas (<100 μm) than in Klondike carbonaceous schists. Thus it may have formed under a relatively lower grade of metamorphism and not correspond to the second phase of deformation in the Finlayson assemblage. As a further example, the greenstone thrust slice and serpentinite lenses of the Slide Mountain terrane are locally foliated over several metres near the thrust, but are generally unfoliated further away. The foliation in these units is a thrust-related fabric that corresponds to F_3 and S_3 in Klondike Schist. The F_1 and F_2 events that produced the dominant ductile recrystallization fabrics within the Klondike Schist and Finlayson assemblage are interpreted to have formed in latest Permian time, considerably before the thrust faulting that imbricated the entire package. It is uncertain whether the Slide Mountain terrane experienced these two earlier deformation events. Hence, although the thrust-related ductile folds are designated F_3 in the Klondike Schist and all of the other slices, folds designated as 'F_3' in the Slide Mountain units may actually result from the first or second phase of deformation that affected the Slide Mountain terrane.

Post-metamorphic F_3 folds affect all the thrust slices and are best developed near thrust faults (within 100 m). The folds typically have rounded hinges, and in schist, form crenulations in the metamorphic segregations. Where the folding is most intense, in the hinges of macroscopic folds

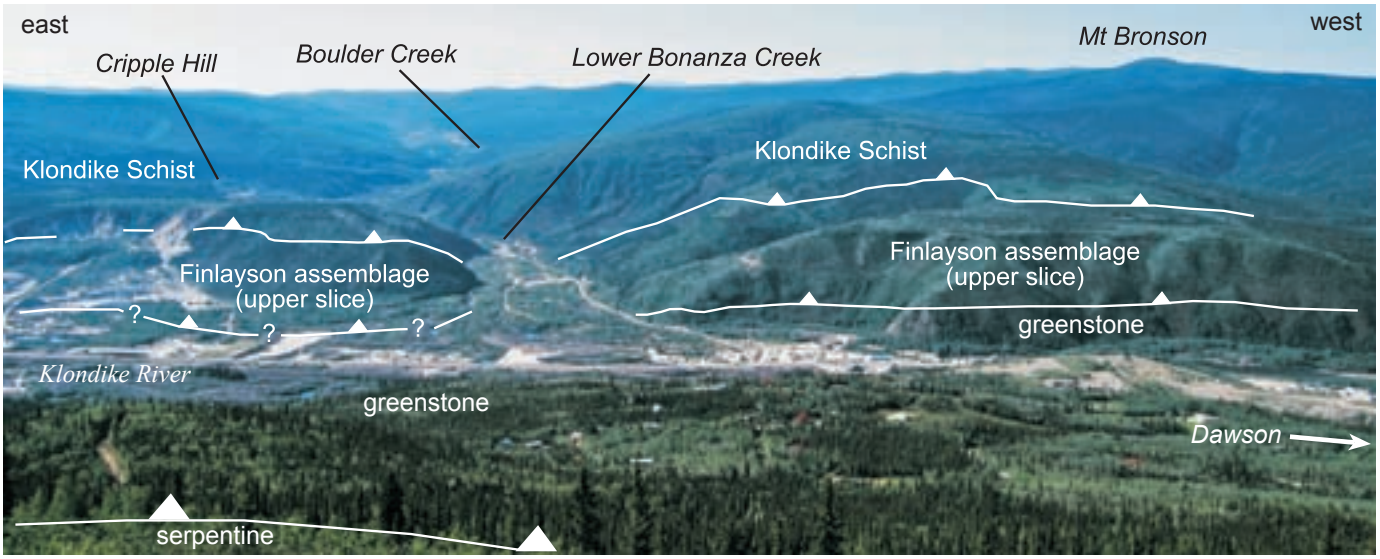

Figure 2. *Photograph of Bonanza Creek looking south from Midnight Dome (Fig. 1). The main thrust-fault contacts separating Klondike Schist, Finlayson assemblage, and greenstone and serpentinite of the Slide Mountain terrane are indicated by white lines with ticks on the upthrown side.*

and in foliated zones next to thrust faults, F_3 folds are associated with a variably developed spaced cleavage (S_3) parallel to fold axial surfaces. In the Klondike Schist, Finlayson assemblage, and greenstone thrust slices, S_3 and F_3 axial surfaces are generally shallowly dipping and lie subparallel to the main lithological contacts and thrust faults (Fig. 3g-k). Some of the more steeply dipping S_3 surfaces (Fig. 3j) are the result of local steepening next to later brittle faults and overprinting deformation. In the Finlayson and greenstone slice (Fig. 1), and in the Klondike Schist north of Boulder Creek (Fig. 2), F_3 fold axes plunge gently northeast-southwest (Fig. 3 c-f). To the south of Boulder Creek, the F_3 fold axes plunge in a different orientation, generally northwest-southeast (Fig. 3b). This may represent a rotation of the uppermost (southern) Klondike Schist thrust slices relative to underlying slices.

F_3 folds in Klondike Schist and Finlayson assemblage thrust slices are locally crosscut by a set of angular kink folds (F_4 in the Klondike Schist) with steeply dipping fold axial surface fractures. These kink folds affect all the thrust slices except the greenstone slice and serpentinite lenses, and are only rarely observed in the Finlayson assemblage slices. The kink folding is most intensely developed in the Klondike Schist where kink fold axial surface fractures control the emplacement of gold-bearing mesothermal veins (MacKenzie *et al.*, 2007, in press).

F_4 structures and gold-bearing quartz veins are crosscut by normal faults and associated zones of gouge that are correlated with Late Cretaceous regional extension (Mortensen, 1996). Many of these normal faults were localized by zones of pre-existing structural weakness, and metre-wide zones of steeply dipping normal fault gouge commonly overprint thrust exposures. Similarly,

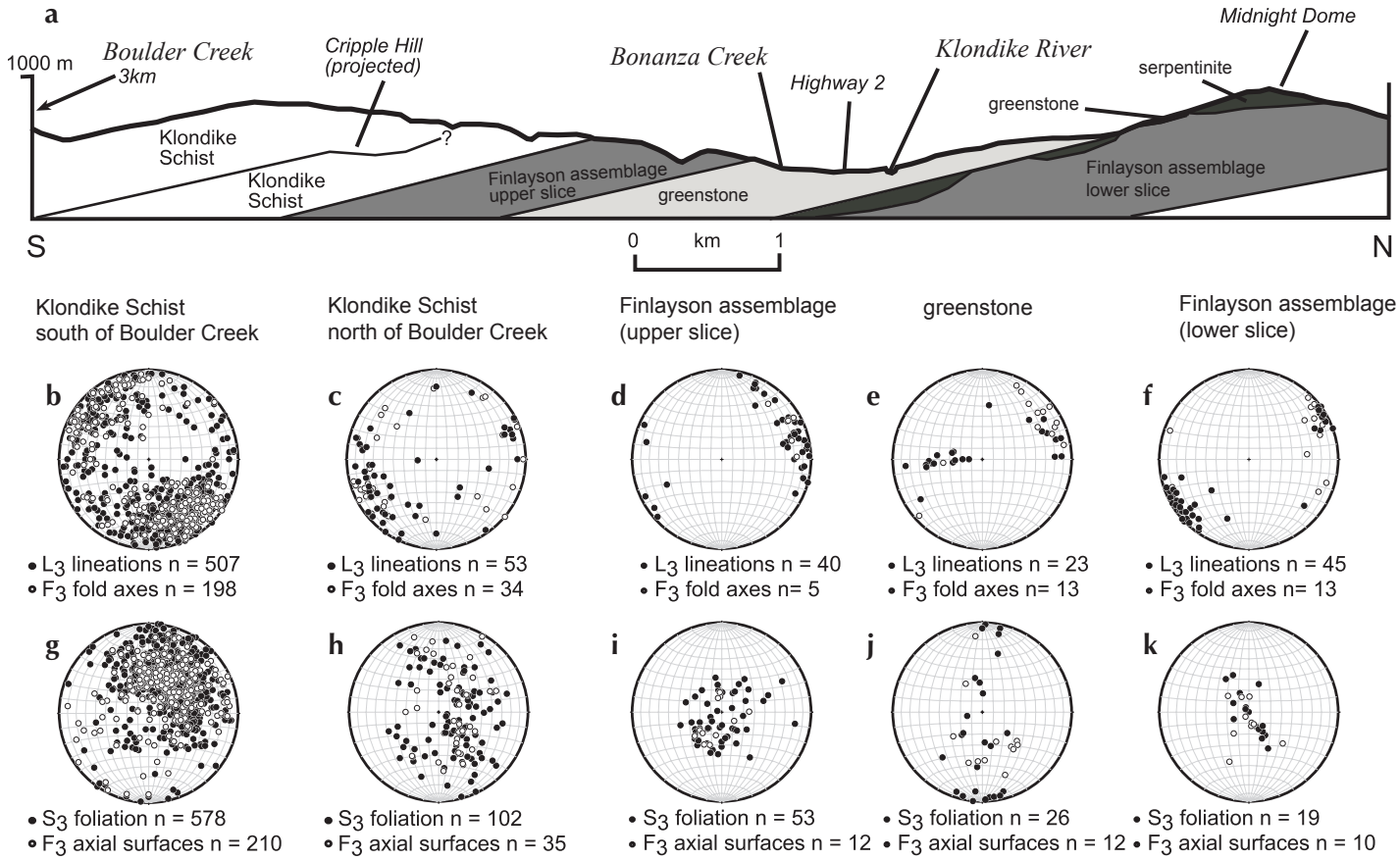

Figure 3. ***(a)*** *North-south cross-section through the northern Klondike District as located in Fig. 1.* ***(b-k)*** *Lower hemisphere equal-area stereonets for regional structural data depicting F_3 fold axes and L_3 crenulation lineations and poles to S_3 foliation and F_3 axial surfaces;* ***(b)*** *and* ***(g)*** *Klondike Schist south of Boulder Creek;* ***(c)*** *and* ***(h)*** *Klondike Schist north of Boulder Creek;* ***(d)*** *and* ***(i)*** *upper slice of Finlayson assemblage;* ***(e)*** *and* ***(j)*** *greenstone-ultramafic thrust slice;* ***(f)*** *and* ***(k)*** *lower slice of Finlayson assemblage.*

Late Cretaceous and Eocene dykes (Mortensen, 1996) have intruded fault zones and commonly obscure the thrusts on an outcrop scale. Hence, clear exposures of the thrusts, without these later overprints, are rare.

GREENSTONE–UPPER FINLAYSON ASSEMBLAGE THRUST

The thrust fault that separates the greenstone slice from the overlying upper Finlayson thrust slice is well exposed in a line of bluffs on the northwest side of lower Bonanza Creek (Fig. 1). Here, a large outcrop of variably foliated greenstone underlies carbonaceous and minor interlayered felsic schists of the Finlayson assemblage (Fig. 4). Greenstone is characterized by a weak, generally shallowly dipping metamorphic layering (designated S_2, Fig. 4e) which becomes more steeply dipping near the top of the bluff and crenulated about northeast-plunging F_3 axes (Fig. 4f). The S_2 metamorphic foliation in Finlayson assemblage schists (Fig. 4b) is steeply north and south-dipping about northeast-plunging F_3 fold axes (Fig. 4c).

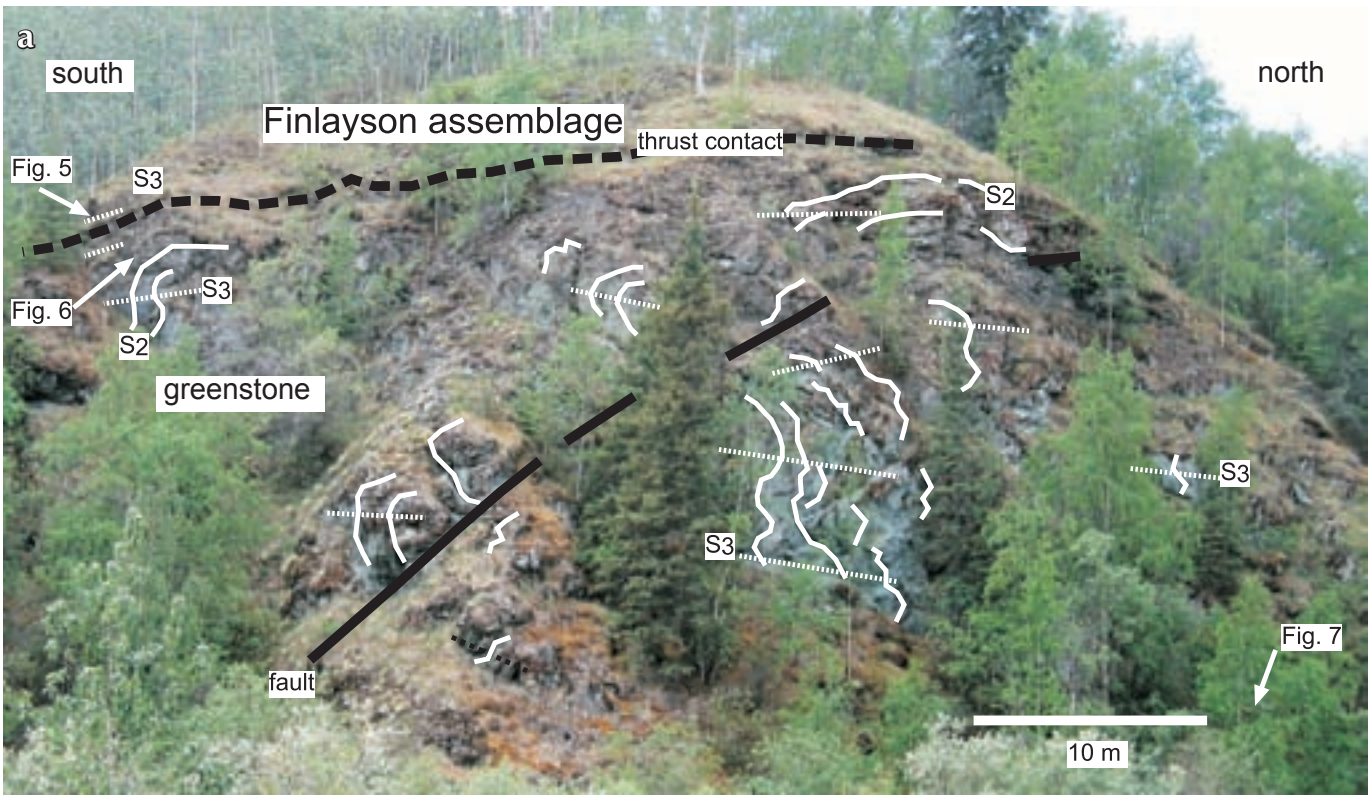

Figure 4. *Thrust contact between upper slice of Finlayson assemblage and greenstone-ultramafic slice, exposed in lower Bonanza Creek.* ***(a)*** *Steeply dipping S_2 foliation surfaces in greenstone (solid white lines) are crenulated about northeast-plunging fold axes (L_3). The S_3 spaced cleavage in greenstone (dashed white lines), is generally shallow, northeast-dipping (especially near the bottom), but is more gently dipping near the top of the bluff and dips to the southwest along the thrust (black dashed line). More steeply dipping faults and fractures locally cut the rocks along the contact. Lower hemisphere equal-area stereonets* ***(b-f)*** *of structural data from exposures on lower Bonanza Creek; (b), (d) and (e) are poles to planes.*

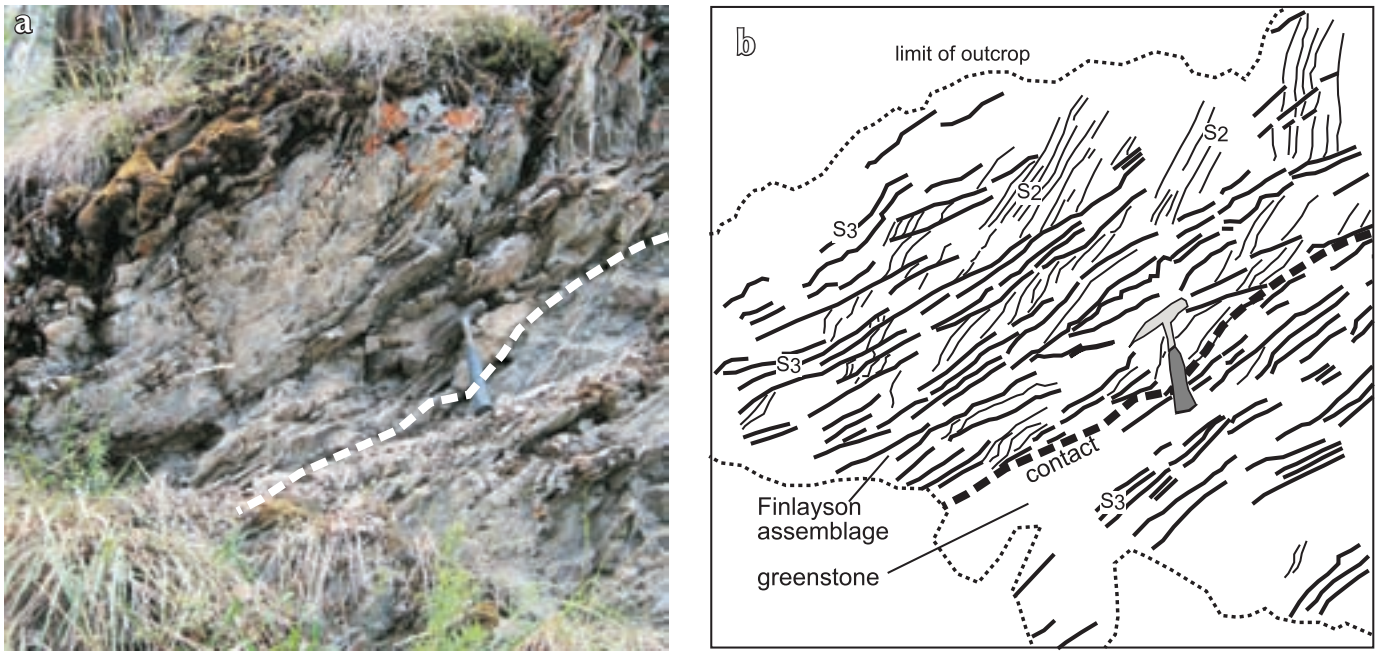

Figure 5. *Photograph* ***(a)*** *and sketch* ***(b)*** *of the thrust contact between the upper slice of Finlayson assemblage and greenstone near the top of the greenstone bluff (Fig. 4). A well developed S_3 spaced cleavage (thick black lines) crosscuts the steeper S_2 foliation (thin black lines) in the Finlayson assemblage, and in both units, S_3 is subparallel to the thrust contact (heavy dashed line).*

This metamorphic foliation has been tightly folded next to the thrust fault and is overprinted by a strong S_3 spaced cleavage (Figs. 4b, 5). The spaced cleavage crosscuts the metamorphic foliation and comprises a set of discrete millimetre-scale zones, oriented parallel to the axial surfaces of F_3 folds, in which metamorphic micas have been rotated into parallelism. Overall, the thrust fault separating the two lithological packages is gently southwest-dipping, and the S_3 spaced cleavage in Finlayson assemblage schist (Fig. 4b) and underlying greenstone (Fig. 4e) is subparallel to it. Locally, along the fault surface, higher angle faults and fractures (Fig. 4d) crosscut the fault plane and obscure the thrust fault's overall gentle dip.

Figure 6. *Outcrop of greenstone just below the thrust fault contact with the upper slice of Finlayson assemblage in Figure 4. The greenstone is well foliated and crenulated with a shallow-dipping spaced cleavage (dashed lines) with little or no recrystallization of micas. The spaced cleavage and folds are axial planar parallel to the contact in Figure 5.*

Greenstone next to the thrust fault is highly folded (Fig. 6), and thrust-related, fault-parallel spaced cleavage is well developed across several metres (Fig. 5). The spaced cleavage in the greenstone is defined by zones of deflection and rotation of metamorphic chlorite, and some recrystallized fine-grained (<100 µm) chlorite that is aligned along S_3 cleavage surfaces. Further from the fault contact, the spaced cleavage gives way to tight folds, and at the base of the cliff, the greenstone is massive with only subtle banding defined by alternating chlorite-rich and epidote-rich layers (Fig. 7).

UPPER FINLAYSON ASSEMBLAGE – KLONDIKE SCHIST THRUST

The upper contact of the slice of Finlayson assemblage with the Klondike Schist is poorly exposed and is best observed in lower Bear Creek (Fig. 1). Here, the contact between the two units consists of sheared schist dipping 50-60° to the southeast. On either side of the contact, the S_3 spaced cleavage is strongly developed and dips moderately to the south, subparallel to the contact. In other outcrops along the Klondike River valley, and near the inferred fault contact (Fig. 3i), S_3 spaced cleavage remains strongly developed, with a variable dip between outcrops (locally steep) that may reflect local overprinting of the thrust by steeper structures. In outcrop, the generally gently dipping metamorphic foliation is crosscut by a prominent, finely spaced (centimetre-scale) S_3 cleavage (Fig. 8). Large (10-m scale) recumbent F_3 folds in Finlayson assemblage schist occur in lower Bonanza Creek, close to outcropping Klondike Schist, but the thrust contact is not exposed. Soft gouge that is possibly related to a later normal fault, and highly folded and deformed carbonaceous Klondike Schist, crop out near the inferred thrust contact.

THRUSTS WITHIN KLONDIKE SCHIST

In the overlying Klondike Schist south of the upper slice of Finlayson assemblage, S_3 spaced cleavage and F_3 fold axial surfaces dip variably to the northwest and southeast (Fig. 3h). The L_3 crenulation lineations and F_3 fold axes plunge generally northeast-southwest (Fig. 3c). Thrust-related structures in this northern Klondike Schist thrust slice have the same general orientation as those in the underlying Finlayson assemblage and greenstone thrust slices (Figs. 3d-f and 3i-k).

F_3 folds and S_3 spaced cleavage increase in intensity near Cripple Hill (Figs. 2 and 3) where a thrust fault in Klondike Schist is locally exposed. The fault zone is delineated by

Figure 7. *Outcrop of greenstone near the base of the greenstone bluff in Figure 4. The greenstone is fairly massive with a subtle banding of light (epidote-rich) and dark (chlorite-rich) layers.*

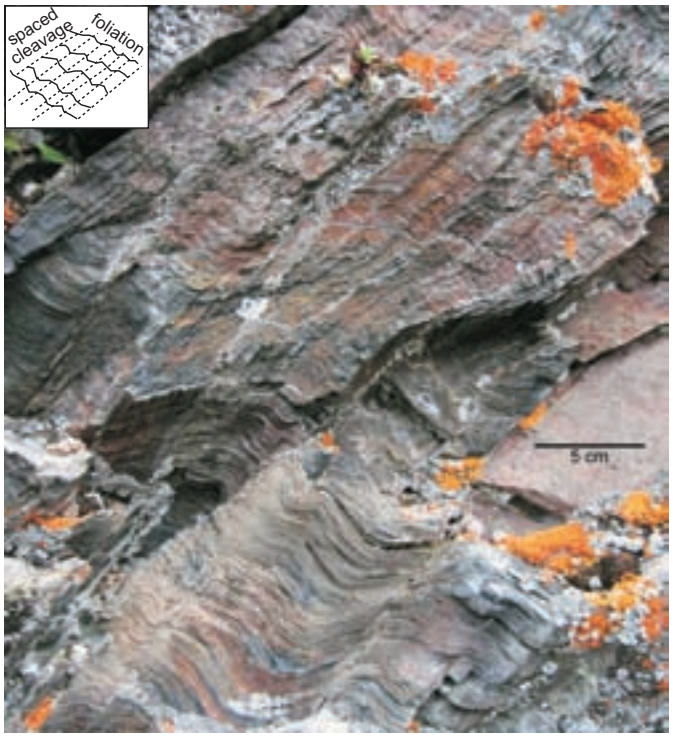

Figure 8. *Outcrop of the upper slice of Finlayson assemblage near (<100 m) the unexposed contact with Klondike Schist in lower Bonanza Creek. The fine wavy metamorphic laminations (left to right) are crosscut by a well developed S_3 spaced cleavage (bottom left to upper right).*

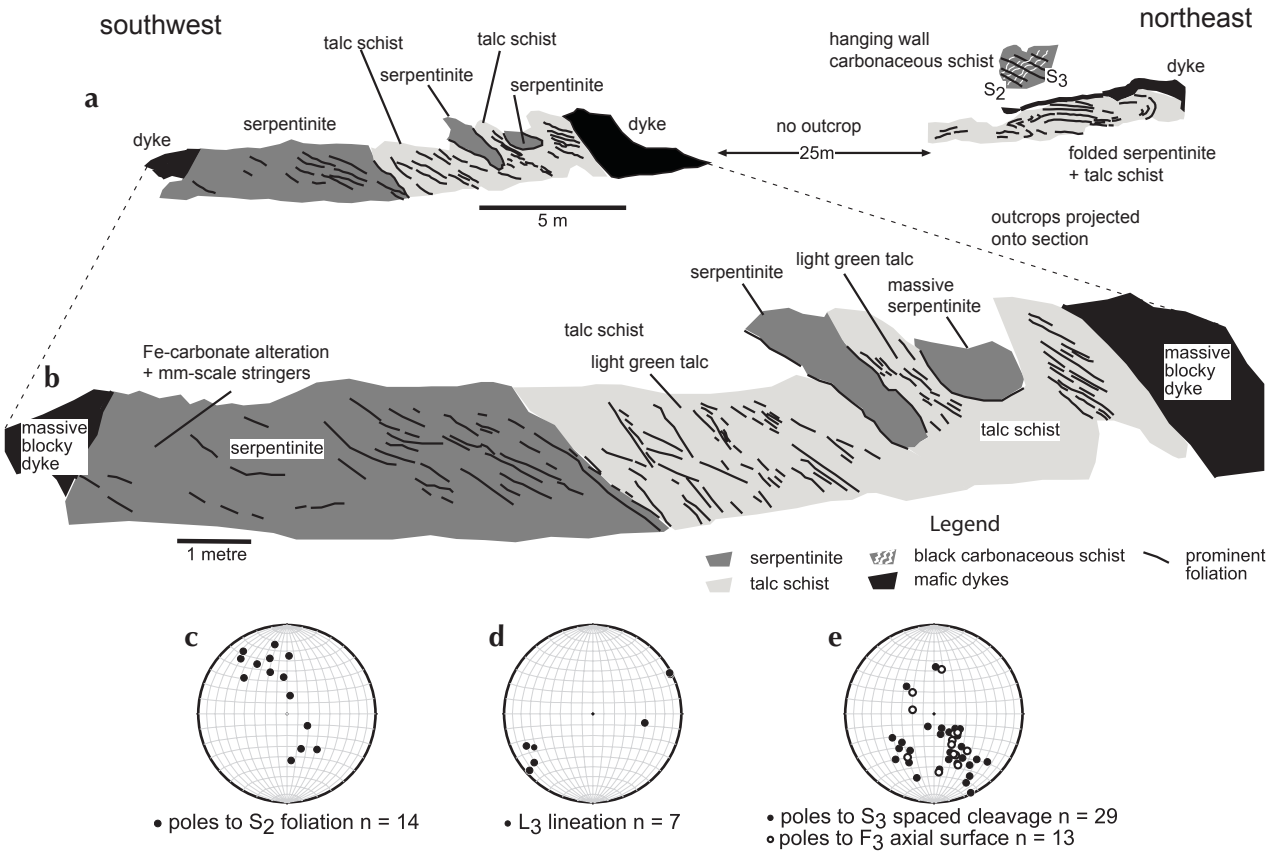

Figure 9. *Sketch of road cut in placer workings at Cripple Hill* ***(a)*** *and detailed section* ***(b)*** *through the Cripple Hill thrust based on field sketches and photographs. Outcrops on the northeast end are projected onto section from an opposite face along an adjacent road cut. The zone is composed primarily of folded serpentine and talc schist intruded by several igneous dykes. Black carbonaceous schist in the hanging wall (locally interlayered with more quartzofeldspathic schist) delineates the relationship between S_2 metamorphic foliation (white lines) and S_3 spaced cleavage (black lines). Lower hemisphere equal-area stereonets for the area depict* ***(c)*** *poles to S_2 foliation in host schist,* ***(d)*** *L_3 crenulation lineations and* ***(e)*** *poles to F_3 axial surfaces and S_3 spaced cleavage.*

sheared lenses of talc schist and serpentinite (Fig. 9). Discontinuous horizons of black carbonaceous schist and interlayered quartzofeldspathic schist show strong S_3 cleavage next to the fault. These carbonaceous layers are unlike the Nasina facies carbonaceous schist of the Finlayson assemblage to the north. Carbonaceous units in Klondike Schist (see below) are distinguishable from those in the Finlayson assemblage by their coarser micas (>100 µm) and typically thicker (millimetre- to centimetre-scale) quartz segregations. The S_3 spaced cleavage is generally more strongly developed in Klondike Schist than in Finlayson assemblage schist, and is characterized by new growth of post-metamorphic muscovite and chlorite along S_3 cleavage surfaces. At Cripple Hill, the S_2 metamorphic foliation (Fig. 9a) is overprinted by a generally north-dipping S_3 spaced cleavage that parallels the thrust fault in this area (Fig. 9e). Structurally above the

Figure 10. *Quartz augen schist in the hanging wall of the Cripple Hill thrust. Simplified sketch illustrates the interpreted relationship between S_2 foliation (solid lines) and S_3 spaced cleavage (dashed lines).*

carbonaceous schist, outcrops of quartz augen schist (Fig. 10) have strong S_3 spaced cleavage up to several hundred metres from the thrust fault zone. The fault zone dips variably north, as defined by northward-dipping shears in serpentinite and talc schist. The contacts are obscured by the intrusion of several small intrusive bodies.

South of Cripple Hill, several other zones of intense F_3 folding and strongly developed S_3 spaced cleavage occur within the Klondike Schist (*e.g.,* Boulder Creek and Lone Star ridge; Fig. 1). The deformation zone at Boulder Creek is marked by highly folded carbonaceous schist and rare boulders of serpentinite partially altered by iron-bearing carbonate. Exposure here is poor, and apart from the strong F_3 folding and the presence of ultramafic boulders, evidence for any fault structure is lacking. To the south of this zone however, F_3 fold axes and L_3 crenulation lineations in Klondike Schist have a markedly different orientation than those in Klondike Schist and the upper slice of Finlayson assemblage to the north (Fig. 11). South of Boulder Creek, F_3 fold axes and L_3 lineations plunge predominantly northwest-southeast (Fig. 11a); north of Boulder Creek F_3 fold axes and L_3 lineations plunge northeast-southwest (Fig. 11b,c).

Within the southern Klondike Schist slice, another major thrust is exposed at Lone Star ridge (Fig. 1), where lenses of sheared serpentinite and talc schist outcrop in several exploration trenches (Fig. 12). At one exposure, the southwest-dipping hanging wall contact of the fault (Fig. 12c) is well preserved and displays a zone of strongly foliated talc separating highly crenulated carbonaceous schist and serpentinite. The serpentinite consists locally of massive pods, but is generally highly sheared with a phacoidal cleavage parallel to the contact. The footwall serpentinite-schist contact (Fig. 12b) is overprinted by several metres of steeply dipping fault gouge. At a different exposure of the same fault zone (>100 m to the southeast), the footwall contact between serpentinite and carbonaceous schist dips approximately 20° to the southwest, and the hanging wall contact dips gently northwest. Hence the dip of the thrust fault is somewhat irregular and variable along strike.

F_3 DEFORMATION IN CARBONACEOUS SCHIST

Carbonaceous schist is the dominant lithology of the Finlayson assemblage, and a similar lithology also occurs within the Klondike Schist where it is distinctly coarser grained and more coarsely segregated. Carbonaceous schist in the Klondike Schist is commonly spatially associated with thrust faults (Figs. 9 and 12) but also occurs in many other localities interlayered with felsic schist (Fig. 13). In Klondike Schist, individual bands of carbonaceous schist can be up to 10 m thick, but layers are typically only a few metres thick. Carbonaceous units are typically highly folded, with a well developed S_3 spaced cleavage especially near thrusts, and appear to be discontinuous and lens-like. The carbonaceous schist is typically highly fissile in all localities and appears to be much more strongly folded and have a more highly developed S_3 spaced cleavage than the surrounding more massive quartzofeldspathic schist.

In hand sample, carbonaceous schist consists of dark grey to black micaceous layers interlayered with millimetre- to centimetre-scale quartz and feldspar segregations (Fig. 14a-e). Carbonaceous schist typically contains up to 2-3% disseminated pyrite cubes which weather readily to limonite. In many samples (Fig. 14a, c, d, e) a prominent S_3 spaced cleavage is developed parallel to F_3 crenulation fold axial surfaces, and this has been accentuated by the relative concentration of black micaceous material along S_3 surfaces. The S_2 metamorphic foliation is typically truncated by seams of rotated metamorphic micas, newly

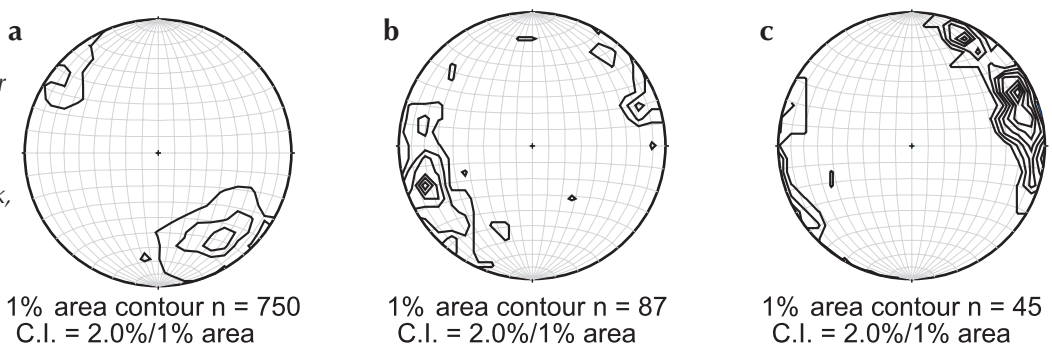

Figure 11. *Lower hemisphere equal-area stereonets of contoured L_3 crenulation lineations and F_3 fold axes for* ***(a)*** *Klondike Schist south of Boulder Creek,* ***(b)*** *Klondike Schist north of Boulder Creek, and* ***(c)*** *upper slice of Finlayson assemblage in lower Bonanza Creek. C.I. = contour interval.*

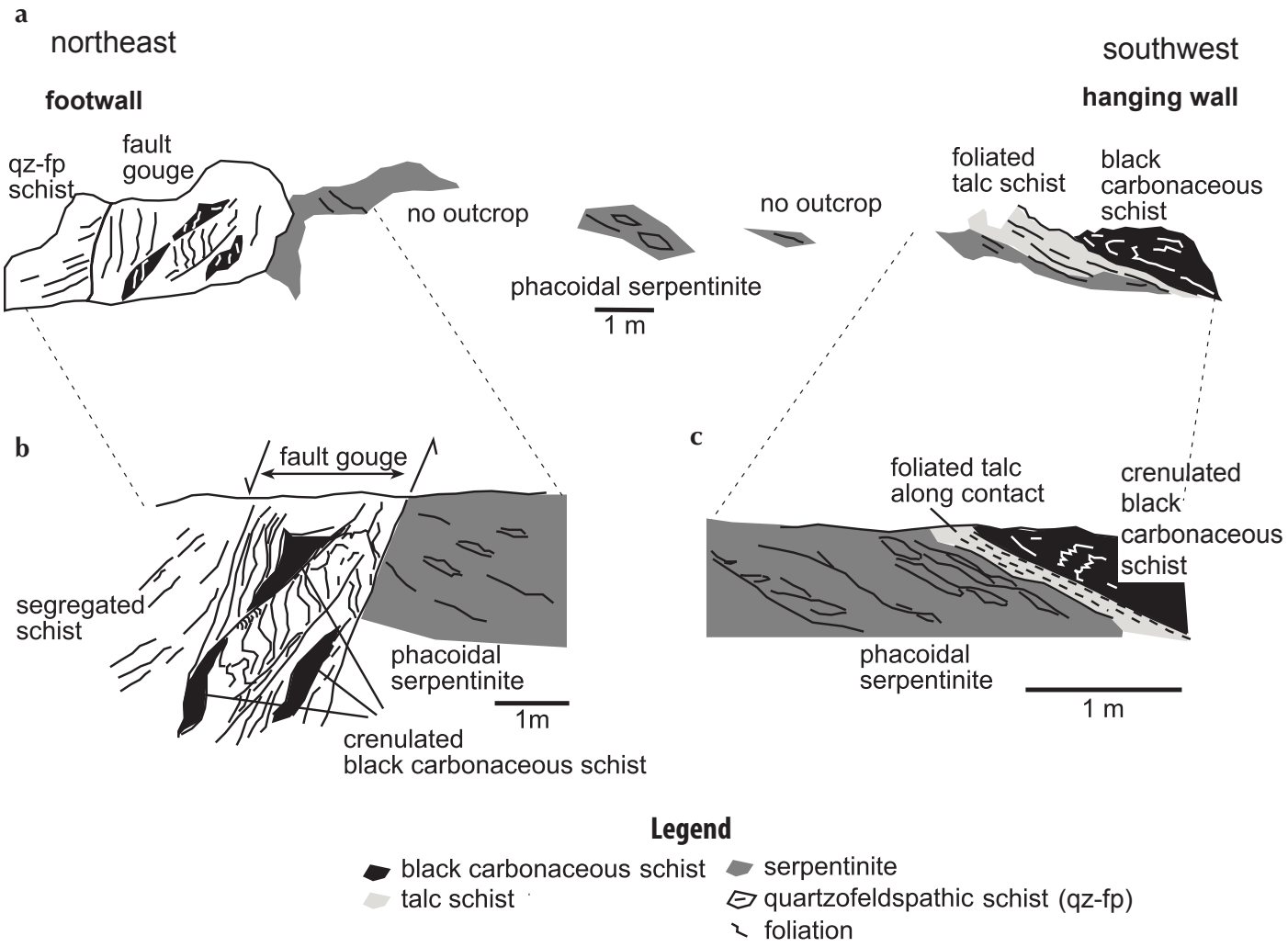

Figure 12. ***(a)*** *Composite section through the thrust at Lone Star ridge based on photographs and field sketches.* ***(b)*** *Detailed sketch of high-angle fault gouge that cuts across the contact between serpentinite and footwall schist.* ***(c)*** *Detailed sketch of the hanging wall contact between serpentinite and black carbonaceous schist.*

Figure 13. *Annotated photograph of interbedded black carbonaceous schist and brown quartzofeldspathic schist in O'Neill Gulch, a tributary of upper Bonanza Creek, on Lone Star ridge.*

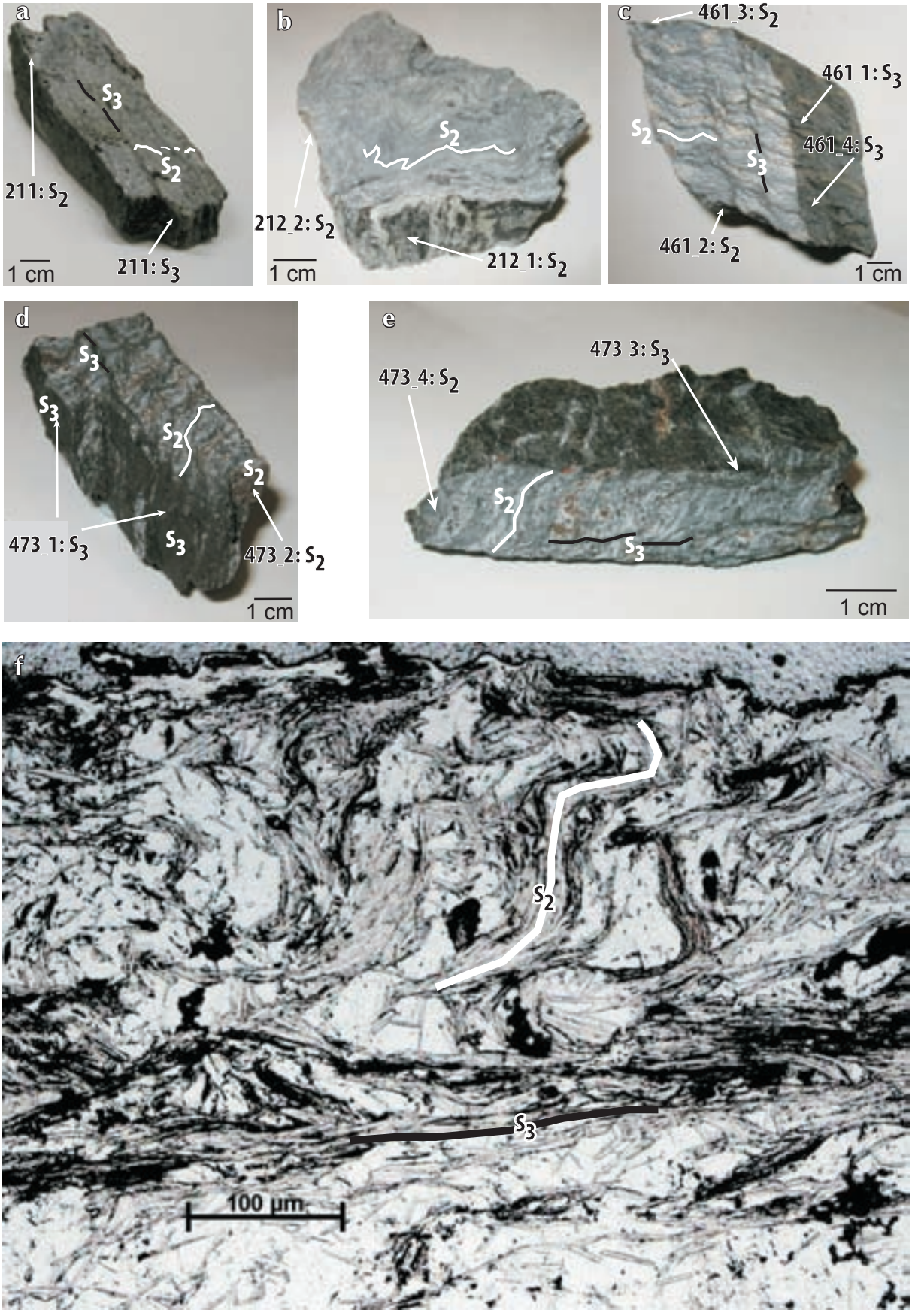

Figure 14. *Caption on next page.*

crystallized muscovite, and black carbonaceous material concentrated along S_3 cleavage surfaces (Fig. 14f).

Some of the black micaceous material on S_3 surfaces in the carbonaceous schist was analysed for carbon and compared with the micaceous layers on S_2 foliation surfaces. Samples of this material weighing ~300-500 mg were flaked off by knife. Approximately 3 mg portions were powdered and treated with hot (80°C) HCl (10%) for 8 to 12 hours to dissolve carbonates, then washed and dried. The treated powders were then analysed for carbon in a Carlo Erber CHNS Elemental Analyser, which has a detection limit of 0.1 wt%. The carbon analyses (Fig. 15) are a measure of the amount of non-carbonate carbon contained in the sample, but this method cannot distinguish between organic and non-organic origins for that carbon.

Figure 14. *(previous page) Samples of black carbonaceous schist* ***(a-e)*** *analysed for total non-carbonate carbon. Sample locations and the foliation surface that was sampled are indicated by the sample numbers. Samples 211, 212 and 473 are from different localities on Lone Star ridge and sample 461 is from Klondike Schist close to the Finlayson assemblage contact near lower Bonanza Creek. Sample numbers correspond to the values plotted in Figure 15. The orientation of S_2 metamorphic foliation is indicated by white lines and S_3 spaced cleavage by black lines.* ***(f)*** *Photomicrograph of sample in (a) illustrating black carbonaceous material and opaques (black) concentrated along S_3 surfaces (black lines).*

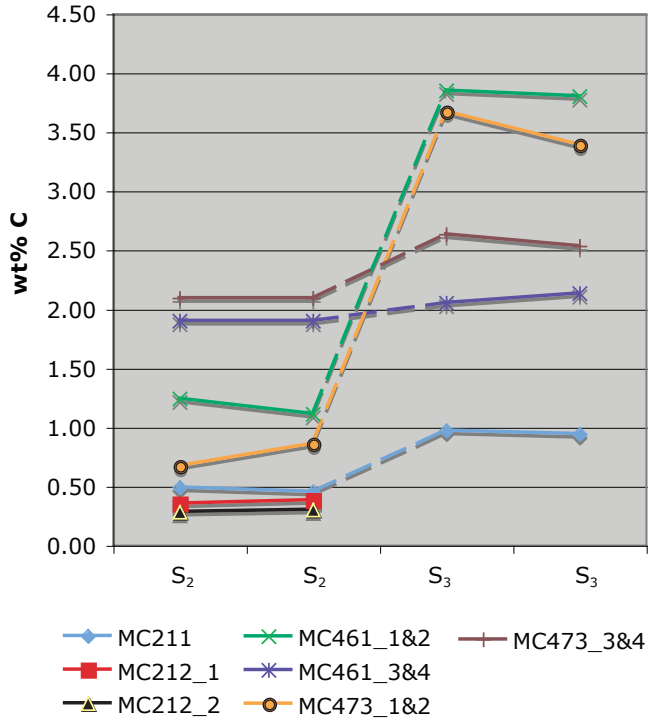

Figure 15. *Plot of non-carbonate carbon for carbonaceous schist samples in Figure 14. In each of the specimens, the S_2 metamorphic foliation and S_3 spaced cleavage surface was sampled, except for specimen 212 which had two different S_2 surfaces sampled. Each of the samples was then analysed twice.*

The results illustrate that for each of the samples, except 212, the total non-carbonate carbon was generally significantly higher in S_3 spaced cleavage surfaces than in the corresponding S_2 foliation surfaces of the same samples. Hence, development of F_3 has been accompanied by recrystallization and relative enrichment of graphitic material in the S_3 spaced cleavage. Localized graphitic enrichment may have resulted from centimetre-scale remobilization of graphite from S_2 foliation or loss of silica by pressure solution. This localized graphite enrichment may have facilitated the more intense deformation that characterizes these carbonaceous schists. Despite being highly crenulated, sample 212 did not contain any S_3 surfaces and its total non-carbonate carbon was very low (<0.5 %).

DISCUSSION AND CONCLUSIONS

The main lithological units in the Klondike district form a pile of stacked thrust sheets that were emplaced in the Jurassic in the latter stages of metamorphism as the rocks were uplifted through the brittle-ductile transition. Post-metamorphic ductile F_3 folds and an associated S_3 spaced cleavage affect all the major thrust sheets and are related to displacement on regional-scale thrust faults that form the boundaries between fault slices. In a few places (*e.g.,* lower Bonanza Creek, Fig. 4; and Lone Star ridge, Fig. 12c), the thrust faults are well exposed and dip gently southwest. These dips can vary along strike (*e.g.,* Lone Star ridge) and in some exposures, thrust faults dip locally northwest (*e.g.,* Cripple Hill). Exposure over most of the region is generally poor, however, and thrust faults are commonly overprinted by normal faults and dykes (Figs. 9 and 12b). On an outcrop scale, thrusts are locally crosscut by high-angle faults and fractures that locally disrupt and steepen the fault surfaces.

Thrust faults are typically marked by F_3 folds and well developed S_3 cleavage. Zones of intense F_3 folding and

strongly developed S_3 cleavage are observed in several other outcrops in Klondike Schist away from the main thrusts mapped in Fig. 1 (*e.g.,* the headwaters of Bear Creek, inset Fig. 1). The differences between the schist on either side of these zones are not evident, so these zones may not necessarily indicate relative displacement by thrust faulting. Nevertheless, these zones represent significant localized semi-ductile deformation subparallel to the foliation. Where strong F_3 folding is associated with sheared ultramafics, major displacement along faults is suggested. The presence of sheared serpentinite and talc schist at Cripple Hill for example, indicates that the Klondike Schist is more imbricated than previously thought. Likewise, the differing orientations of L_3 to the north and south of Boulder Creek (Fig. 11) support relative movement between these schist slices.

Although a relatively minor constituent, carbonaceous schist is widely distributed throughout the Klondike Schist. It is distinguished from Nasina facies carbonaceous units in the Finlayson assemblage by its generally wider millimetre-scale quartz segregations and coarser mica grain size of >100 µm. Many of the mapped thrust faults and F_3 deformed zones in Klondike Schist are associated with discontinuous lenses of carbonaceous schist (Figs. 9 and 12). Non-carbonate carbon in these units is concentrated along S_3 cleavage surfaces and may act to focus strain along these surfaces in a process of deformation weakening.

Thrust-related structures are locally overprinted by a set of F_4 kink folds with a more brittle style than F_3 folds. The kink folds occur locally in the Finlayson assemblage, but are most prominent in Klondike Schist. Kink fold axial surface fractures crosscut the metamorphic foliation at high angles and are locally filled by quartz. Quartz veins in Finlayson assemblage sampled at lower Bonanza Creek assayed below detection level (<5 ppb) for Au, but gold-bearing veins hosted in similar structures are widely dispersed in the Klondike Schist. The main stage of gold mineralization occurred during, or after F_4 kink folding and therefore after major regional compression and thrust stacking. Normal faults offset gold-bearing veins and crosscut F_3 and F_4 structures. The main phase of gold mineralization was localized into post-metamorphic compressional structures in the Klondike Schist after the rocks were uplifted through the brittle-ductile transition and before extensional normal faulting.

ACKNOWLEDGEMENTS

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Disseminated gold mineralization associated with orogenic veins in the Klondike Schist, Yukon

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ABSTRACT

Disseminated gold, without quartz veins, occurs in some types of Klondike Schist, typically near mineralized orogenic veins. The disseminated gold and sulphide minerals (mainly pyrite) are associated with a distinctive chlorite alteration and weak silicification of host rock. In drill core sections that contain mineralized discordant quartz veins there is a crude association between gold and arsenic. In sections that contain disseminated sulphide minerals and gold without quartz veins there is no apparent association between gold and arsenic. Compared to the Otago Schist, New Zealand, a similar orogenic belt that has gold mineralization without coeval magmatism, the Klondike Schist has much lower levels of arsenic in mineralized schist (up to 1000 times less) and in unmineralized host schist (typically 10 times less). The disseminated sulphide minerals associated with Klondike veins are important as they extend the exploration target for these veins.

RÉUMÉ

On trouve de l'or disséminé, en l'absence de filons de quartz, dans certains types de Schiste de Klondike, généralement près de filons mésothermaux minéralisés. L'or disséminé et des minéraux sulfurés (surtout de la pyrite) sont associés à une chloritisation distincte et à une silicification faible de la roche encaissante. Des carottes contenant des filons de quartz discordants minéralisés présentent une association grossière entre l'or et l'arsenic. Des carottes contenant de l'or et des minéraux sulfurés disséminés, en l'absence de filons de quartz, ne présentent aucune association apparente entre l'or et l'arsenic. Comparativement au Schiste d'Otago de la Nouvelle Zélande, qui constitue une ceinture orogénique similaire renfermant des minéralisations en or sans aucun magmatisme contemporain, le Schiste de Klondike présente des concentrations d'arsenic beaucoup plus faibles dans le schiste minéralisé (jusqu'à 1000 fois inférieures) et dans le schiste encaissant non minéralisé (généralement dix fois inférieures). Les minéraux sulfurés disséminés associés aux filons de Klondike sont importants, car ils élargissent le cadre d'exploration ciblant ces filons.

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INTRODUCTION

The placer gold deposits of the Klondike goldfield (Fig. 1) have produced approximately 20 million ounces (600 million grams) since their discovery in 1896 (Government of Yukon, 2007). The ultimate source of these extremely rich deposits is presumed to be orogenic (mesothermal) quartz veins hosted in the underlying Klondike Schist (Tyrell, 1907; Rushton *et al.*, 1993; Knight *et al.*, 1999; Lowey, 2005). The relationship between placer gold and gold-bearing quartz veins is well established on an individual catchment scale, and placer-gold compositions correspond closely to gold in nearby schist-hosted discordant quartz veins (Knight *et al.*, 1999; Mortensen *et al.*, 2005). These quartz veins have mesothermal characteristics (Rushton *et al.*, 1993) and are hosted in local sites of extension, controlled principally by post-metamorphic compressional structures (MacKenzie *et al.*, 2007). The relative timing of the veins has now been placed in a structural framework coincident with the evolution of the Klondike Schist (MacKenzie *et al.*, 2007, 2008 (this volume)). The timing of vein emplacement is not associated with any igneous activity. Since their discovery in the late 1890s, gold-bearing quartz veins in the Klondike have been the target of many exploration programs, and for the past four years they have constituted the main focus of an extensive drilling program by Klondike Star Mineral Corporation.

The Otago Schist in South Island, New Zealand, has a similar geological history to the Klondike and hosts hydrothermal gold mineralization that formed during the latter stages of metamorphism as rocks were uplifted through the brittle-ductile transition. Like the Klondike, gold mineralization in Otago is not associated with any coeval magmatism. Both metamorphic belts share a similar history of early placer mining followed by the discovery of gold-bearing quartz veins. For over a hundred years the principal source of mined hardrock gold in Otago was schist-hosted gold-bearing quartz veins (Williams, 1974). Hardrock miners typically handpicked high-grade quartz veins and ignored the softer (commonly uneconomic) host schist. This changed in the 1990s with the development of the currently active Macraes mine, an approximately 6-million-ounce (200-million-g) deposit that is dominated by low-grade disseminated gold with subordinate small (typically metre-scale) gold-bearing quartz veins (Mitchell *et al.*, 2006). The bulk of mined material at Macraes, the largest gold mine in New Zealand, is auriferous sulphide-mineral-impregnated schist with only minor gold-bearing quartz veins. Hence the current focus of gold exploration in Otago is this newly recognized disseminated style of mineralization.

Due to its many similarities with Otago, the Klondike Schist is highly prospective for this style of mineralization and large-volume, low-grade gold deposits. This paper outlines the results of an ongoing investigation by the authors into the association of disseminated gold without quartz veins in the Klondike Schist. This research is supported by Klondike Star Mineral Corporation.

REGIONAL GEOLOGY

The Klondike goldfield is underlain by highly deformed, greenschist-facies, Paleozoic metasedimentary and meta-igneous rocks of the Klondike Schist and Finlayson assemblage that form part of the Yukon-Tanana terrane, and lesser amounts of little metamorphosed ultramafic rocks of the Slide Mountain terrane (Fig. 1; Mortensen, 1990, 1996). Regional-scale thrust faulting in the Early Jurassic (Mortensen, 1996) stacked these rocks into a series of thrust slices that are locally separated by lenses of sheared ultramafic rocks. They were then uplifted through the brittle-ductile transition in the Jurassic and unconformably overlain by locally derived sedimentary and volcanogenic rocks in the Late Cretaceous (Mortensen, 1996). The Klondike goldfield was then offset approximately 450 km along the Tintina fault (Fig. 1, Gabrielse *et al.*, 2006). Erosion and minor regional uplift continued in the late Tertiary and resulted in the deposition of the Pliocene White Channel Gravels and their contained placer gold deposits (Lowey, 2005).

STRUCTURAL CONTROLS ON VEIN FORMATION

Mesothermal gold vein formation occurred in the latter stages of Jurassic compressional deformation after the Klondike Schist was uplifted through the brittle-ductile transition and prior to the main stage of Cretaceous extension (MacKenzie *et al.*, 2007, in press; MacKenzie *et al.*, this volume). Gold-bearing veins are widely dispersed throughout the uppermost slices of Klondike Schist and are hosted in a wide variety of small extensional sites controlled by pre-existing structures in the schist. The veins crosscut metamorphic and thrust-related fabrics in the schist and are controlled principally by axial surface fractures associated with a phase of post-metamorphic kink-folding (MacKenzie *et al.*, 2007). Normal faults locally overprint and offset the veins.

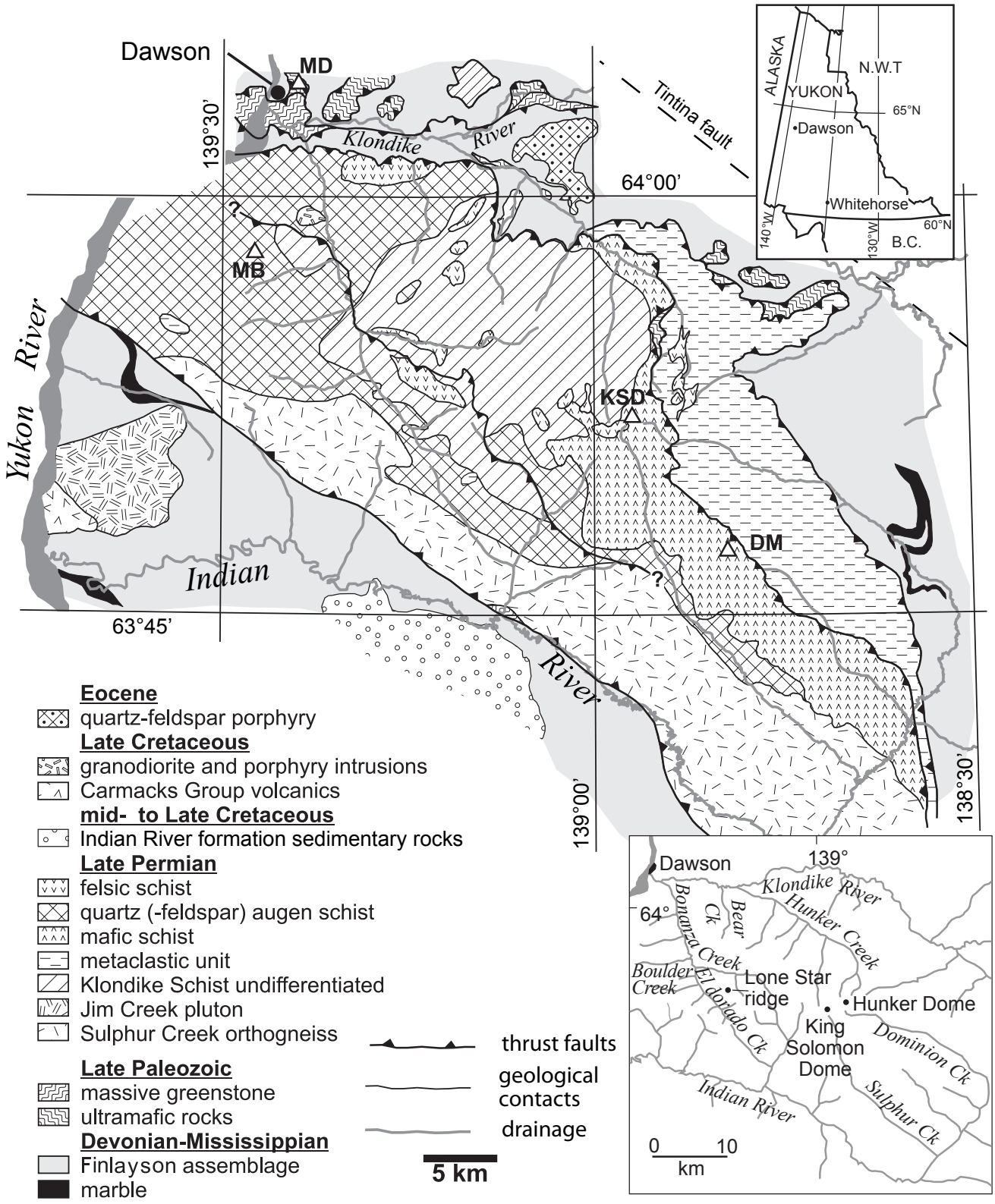

Figure 1. *Geological map of the Klondike District, central western Yukon (after MacKenzie et al., in press). KSD = King Solomon Dome; MD = Midnight Dome; DM = Dominion Mountain; MB = Mount Bronson. Top right inset map outlines the study area within Yukon, while bottom right inset map depicts the major drainages and physiographic features in the study area.*

QUARTZ VEINS IN KLONDIKE SCHIST

Gold-bearing quartz veins in the Klondike Schist are extension veins that infill a variety of pre-existing extensional structures (MacKenzie *et al.*, in press). The veins typically consist of massive milky quartz, with some clear euhedral crystals protruding into open-space cavities (Fig. 2). Calcite, galena, sphalerite and chalcopyrite are rare accessory minerals in some veins. Visible gold, up to millimetre-scale, is fairly common (Figs. 2 and 3). Some veins contain breccia fragments of schist wallrock, which can extend several centimetres from vein margins. These fragments are typically silicified and may contain fine-grained disseminated pyrite. Minor sericite alteration affects some fragments and host rock up to 1 cm from the veins (MacKenzie *et al.*, in press).

AURIFEROUS KLONDIKE SCHIST

Disseminated mineralization is associated with quartz veins and chloritic schist in the King Solomon Dome area (Fig. 1), where euhedral pyrite crystals up to several millimetres long extend tens of centimetres from vein margins. In the Lone Star ridge area (Fig. 1) extensive zones of disseminated euhedral pyrite and gold (up to several grams/tonne) extend out from mineralized quartz veins hosted in highly deformed micaceous schists. The schist-hosted disseminated sulphide minerals in both of these areas form an otherwise subtle alteration halo that extends centimetres to metres out from the auriferous veins.

Recent drilling by Klondike Star Corporation in the Lone Star ridge area (Lone Star and Victoria occurrences, Yukon MINFILE[1], 115O 072 and 115O 146) has intersected gold-mineralized intervals in drill core associated with spotty chlorite alteration and finely disseminated pyrite (*e.g.*,, Fig. 4a,c). This distinctive alteration occurs in segregated schist consisting of millimetre to centimetre-wide alternating layers of quartz and feldspar and micaceous layers composed of metamorphic muscovite and chlorite. Altered samples are weakly to moderately silicified along foliation surfaces with millimetre-scale clots of chlorite concentrated along micaceous layers. The pyrite is fine-grained (< 1 mm) and typically concentrated along foliation surfaces. Some samples contain minor amounts of iron-carbonate and trace amounts of magnetite.

DISSEMINATED GOLD AND THE ASSOCIATION WITH ARSENIC

The association between spotty chlorite alteration and gold is evident in drillholes 05LS02 and 05LS09 (Fig. 4a,c). Anomalous gold grades over 1 ppm occur in chlorite-altered intervals in the first 80 m of drillhole 05LS02 (Fig. 4a) and in several chlorite-altered zones in the first 100 m of drillhole 05LS09 (Fig. 4c). The chlorite-altered zones do not generally contain quartz veins but at different depths away from these zones there are crosscutting quartz veins in both drillholes with anomalous gold >0.1 ppm. Drillhole 05LS08, shown for

[1]*http://www.geology.gov.yk.ca/databases_gis.html*

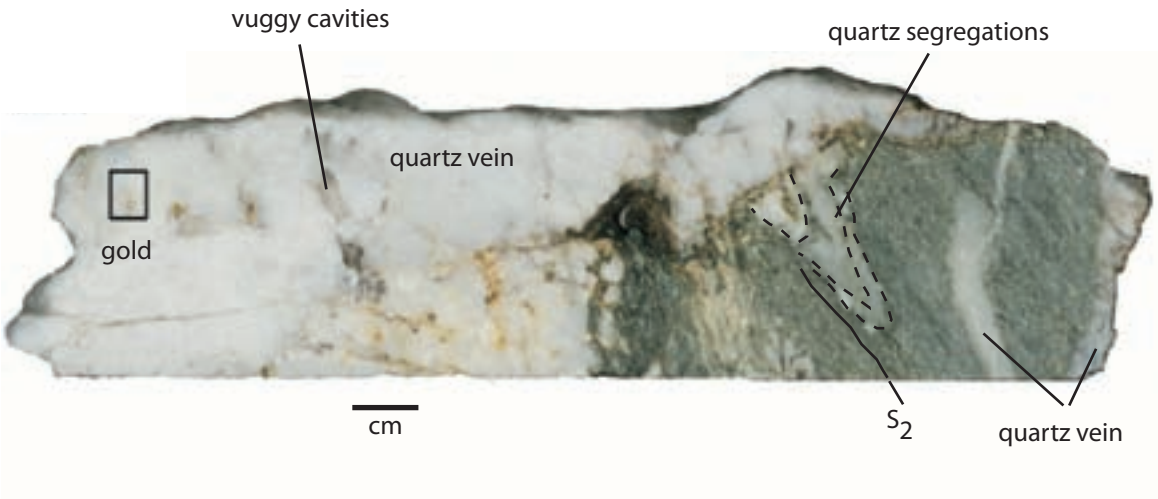

Figure 2. *Diamond drill core of quartzofeldspathic schist from Lone Star ridge. Metamorphic segregations (S_2) are crosscut by discordant quartz veins. The larger vein with euhedral quartz cavities contains visible gold outlined in black box.*

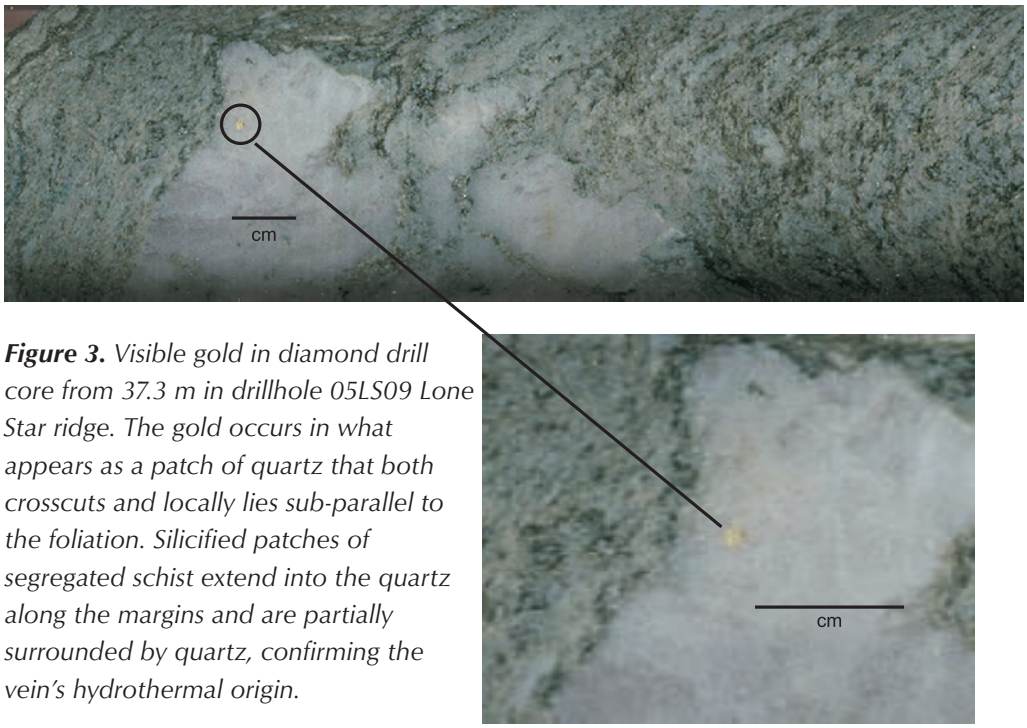

Figure 3. *Visible gold in diamond drill core from 37.3 m in drillhole 05LS09 Lone Star ridge. The gold occurs in what appears as a patch of quartz that both crosscuts and locally lies sub-parallel to the foliation. Silicified patches of segregated schist extend into the quartz along the margins and are partially surrounded by quartz, confirming the vein's hydrothermal origin.*

comparison (Fig. 4b), is a typical mineralized hole with millimetre to centimetre-scale quartz veins and without any logged chlorite alteration. The lower portion of this hole (>80 m) is generally barren and gives a good indication of background levels for gold (< 2 ppb) and arsenic (< 2 ppm).

The chlorite-altered zone from 69 to 70 m depth in hole 05LS02 returned an overall grade of 1.1986 ppm Au and 0.8 ppm As (fire assay, ICP finish with detection limits of 0.5 ppb Au and 0.5 ppm As). This 1-m interval was examined in detail to determine the distribution of gold on a centimetre-scale (Fig. 5). The interval was divided approximately every 2.5 cm down the hole into 39 separate samples that were then analysed at the ALS Chemex laboratory in Vancouver using procedure Au-AA25 with a detection limit of 10 ppb Au. The interval near 69.45 m (Fig. 5c) assayed >100 ppm Au and may be associated with a centimetre-scale quartz vein in this interval. Other intervals, however, *e.g.,* 69.58 to 69.71 m (Fig. 5d), contain alteration without quartz veins and gold up to >10 ppm. Overall the 69 to 70-m interval is consistently well mineralized with 20 of the 39 samples containing >0.5 ppm Au and 18 samples >1 ppm Au. Many of these mineralized samples are characterized by the distinctive spotty chlorite alteration and finely disseminated pyrite without quartz veins.

In Lone Star drillholes, arsenic is typical of many of the common anomalous trace elements (*e.g.,* copper, lead, zinc) and shows no obvious correlation with gold. For mineralized drillholes 05LS02 and 05LS09 containing chlorite alteration, the linear correlation between arsenic and gold is very poor (Fig. 6a, c) with $r^2 = 0.0002$ and $r^2 = 0.0001$ respectively (where r = coefficient of linear correlation and r^2 = proportion of the total variability of arsenic values that can be accounted for by gold values). Drillhole 05LS08 with mineralized quartz veins and no logged chlorite alteration shows a weak to moderate correlation between gold and arsenic (Fig. 6b) with $r^2 = 0.1369$. Arsenic values range from a high of 73.5 ppm to <0.05 ppm. The higher arsenic values >10 ppm are commonly associated with millimetre to centimetre-scale quartz veining in the core (Fig. 4) and not the chlorite-altered sections. The mean arsenic assay for all three holes (Fig. 4) is 4 ppm.

DISCUSSION AND CONCLUSIONS

Gold-bearing mesothermal veins in the Klondike Schist are controlled by post-metamorphic compressional structures and infill local extensional sites associated with a variety of pre-existing structures (MacKenzie *et al.*, in press). The veins are typically white milky quartz with some open-space cavities infilled with clear euhedral quartz crystals. Some veins contain breccia fragments of host schist that are silicified and impregnated with finely disseminated sulphide minerals (mainly pyrite). Local sericitic alteration affects some schist fragments and may extend into wall rock. This alteration and local silicification is generally not extensive however, and is confined to a few millimetres adjacent to vein margins. Metre-scale alteration in the form of disseminated sulphide minerals (mainly millimetre-scale euhedral cubes of pyrite) is associated with the gold-bearing veins and host chloritic schist at King Solomon Dome, and the mineralized veins and deformed mica schist at Lone Star ridge. This

disseminated pyrite alteration forms an otherwise subtle alteration halo around the quartz veins in these areas.

The spotty chlorite and disseminated pyrite alteration intersected in drill core at Lone Star ridge is easier to distinguish than that described above and is not associated with quartz veins. Gold grades >1 ppm are associated with this alteration in mineralized schist at Lone Star ridge (Fig. 4). In spotty chlorite-altered mineralized schist, gold is consistently elevated on a centimetre-scale throughout the altered zone (Fig. 5). No visible gold was noted in these sections but there was a crude association with gold and the amount of finely disseminated pyrite. Hence the gold in these altered sections may be locked in pyrite and other trace sulphide minerals. The mineralogical distribution of gold is the focus of ongoing research.

High gold values in the spotty chlorite altered sections are not directly correlated with high arsenic (Fig. 6 a, c), whereas in the veined sections of core, there is a weak correlation between the two elements (Fig. 6b). In general where quartz veins are logged, there is a crude association between gold and arsenic, but where there are no quartz veins only background levels of arsenic are observed. This relationship between arsenic and gold distinguishes the Klondike Schist from other comparable mineralized metamorphic belts like the Otago Schist, New Zealand. Gold deposits in Otago are characterized by high arsenic (up to 10 000 pm), where veins and mineralized schist commonly contain arsenopyrite (< 5%). Typical arsenic values in mineralized Otago Schist range from 1000 to 2000 ppm (Craw *et al.*, 2007) compared with 1 to 100 ppm in mineralized Klondike Schist samples (Fig. 7). Background arsenic values in unmineralized Otago Schist are much higher as well and range from 10

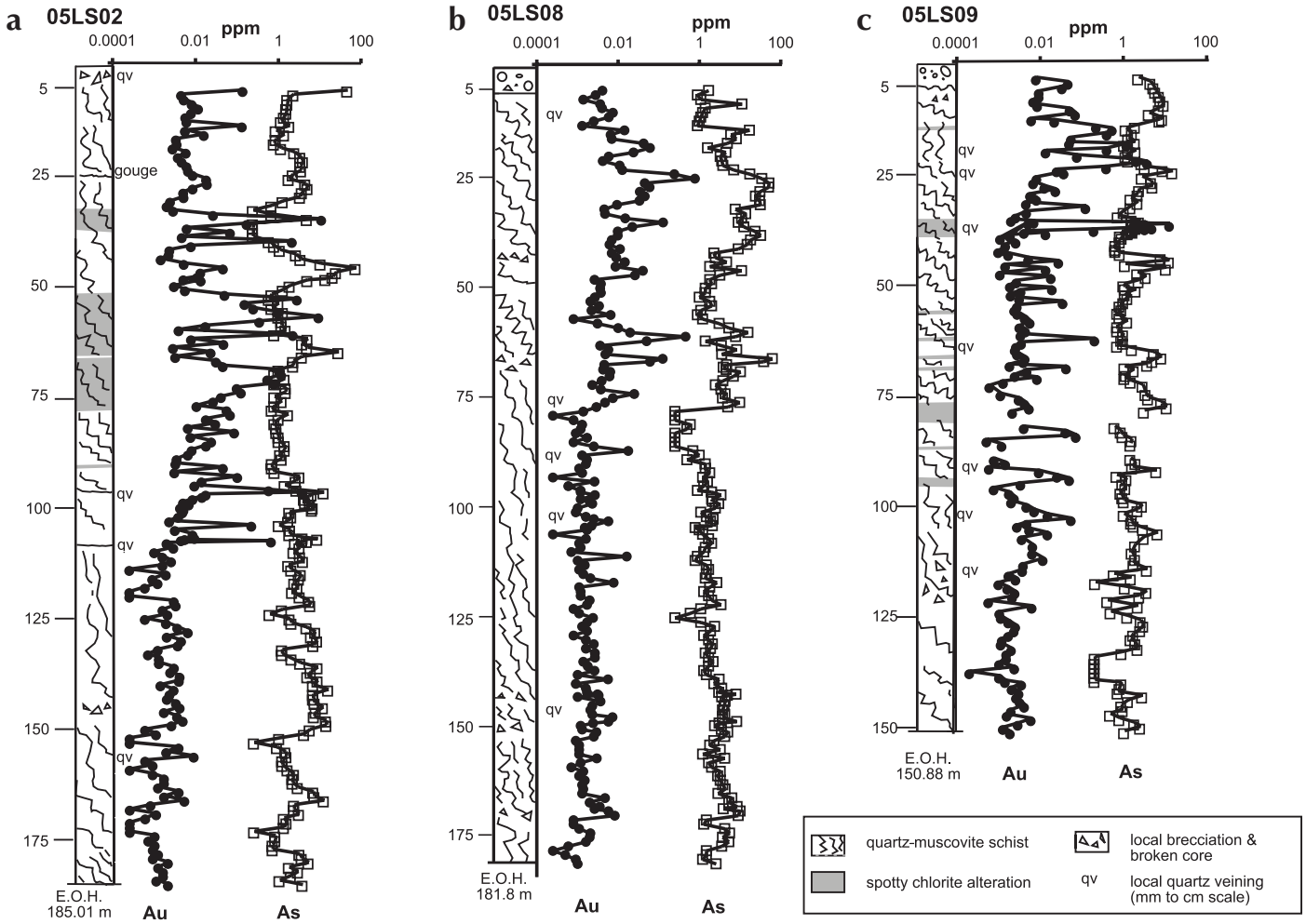

Figure 4. *Sketches of three diamond drillholes from Lone Star ridge showing variation of gold and arsenic assays with depth.* ***(a)*** *05LS02 (dip -70°).* ***(b)*** *05LS08 (dip -70°).* ***(c)*** *05LS09(dip -50°).*

to 20 ppm compared with 0.1 to 2 ppm for unmineralized Klondike Schist.

Higher arsenic levels in the Otago Schist may be the result of relatively enriched host rocks that released arsenic into mineralizing fluid reservoirs during greenschist facies metamorphism. This arsenic was then remobilized and deposited as arsenopyrite along with gold in late-metamorphic shear zones and post-metamorphic quartz veins. It is possible that Klondike host rocks did not have much arsenic in them and thus there was less arsenic available for later remobilization.

The importance of disseminated mineralization in Otago gold deposits has only recently been recognized. Prior to the late 1990s, with the opening of the currently active Macraes mine, exploration was directed solely at gold-bearing quartz veins. Mineralized schist with disseminated sulphide minerals forms the bulk of the material mined now at Macraes. Higher grade quartz veins are mined locally but these form a volumetrically small proportion of the ore. Ore-grade material is composed primarily of mineralized host schist.

Disseminated gold mineralization in the Otago Schist is interpreted to be epigenetic in origin. This may also be the case for disseminated gold described here from within the Klondike Schist, especially that contained within mafic schist hosts adjacent to gold-bearing quartz veins in the King Solomon Dome area. An alternative interpretation for disseminated gold contained within felsic schist in the Lone Star ridge area, however, is that at least some of it might be syngenetic in origin. Felsic schist on Lone Star ridge was derived from pyritic, submarine felsic tuff. Narrow bands of disseminated to semi-massive pyrite with minor galena, sphalerite and rare chalcopyrite have been recognized within schist on Lone Star ridge and in similar host rocks in several other localities in the Klondike. These sulphide bands are interpreted to represent small volcanogenic massive-sulphide (VMS) occurrences on the basis of both their geological setting and Pb isotopic

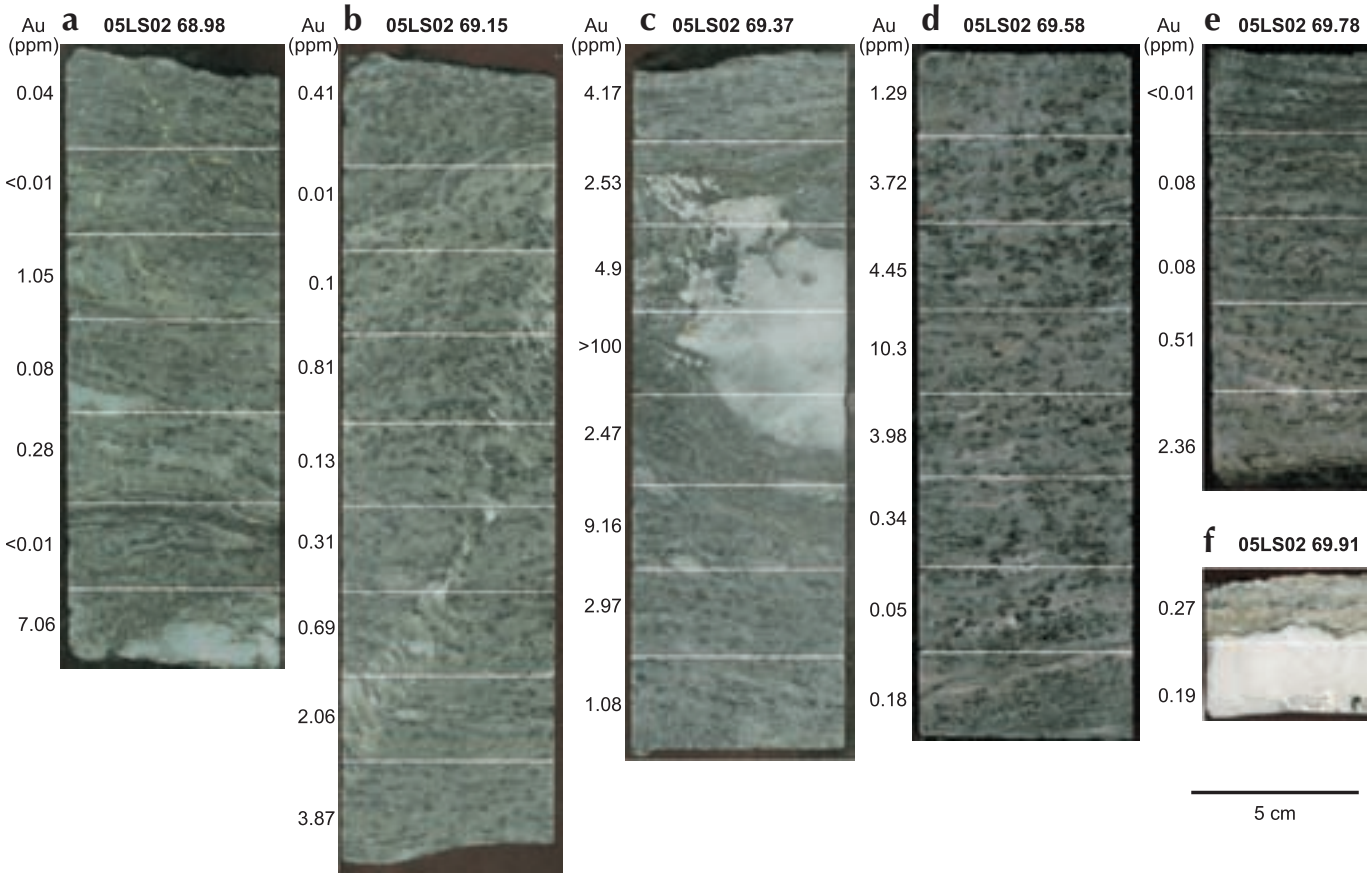

Figure 5. *A 1-m interval (69 to 70 m) of diamond drill core from hole 05LS02 on Lone Star ridge. This interval was sampled in detail and white lines delineate the boundaries between individual samples. Gold content in ppm is indicated to the left of each sample.*

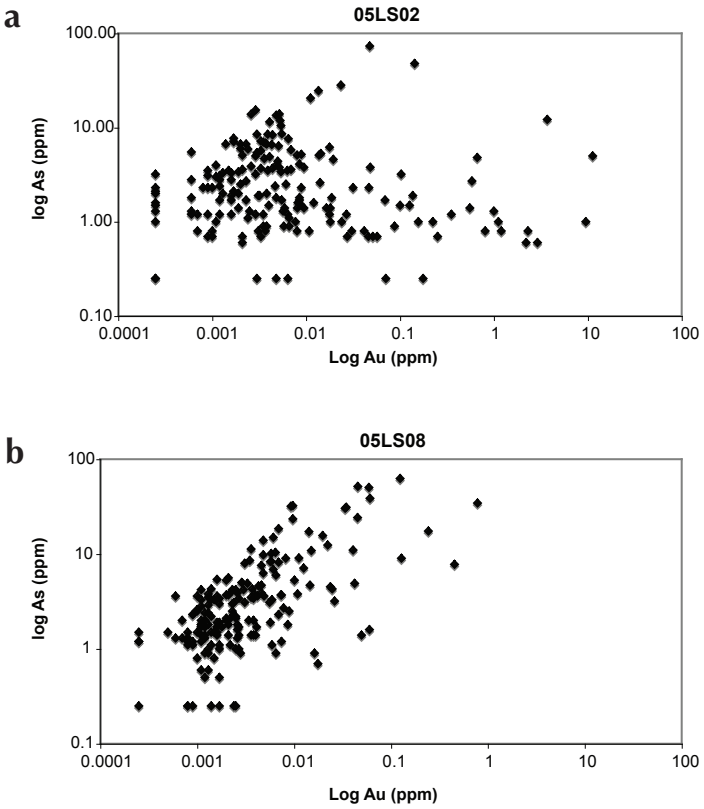

Figure 6. *Plots of log arsenic versus log gold for Lone Star ridge drillholes in Figure 4:* ***(a)*** *05LS02,* ***(b)*** *05LS08,* ***(c)*** *05LS09.*

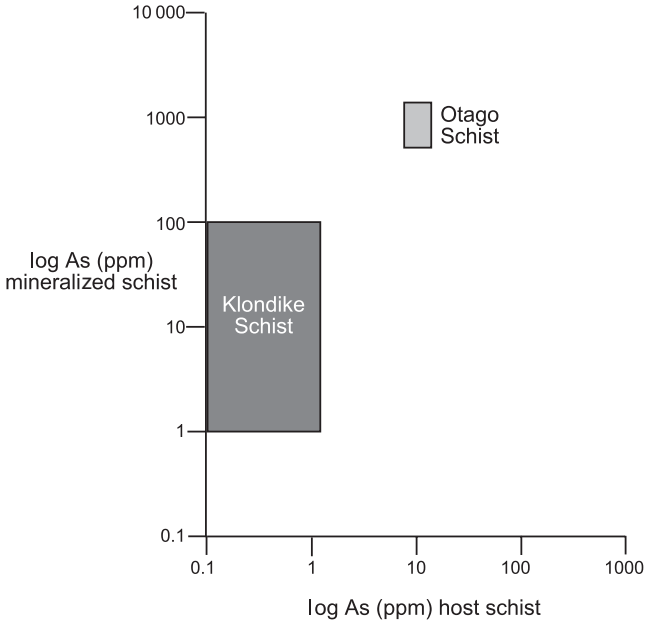

Figure 7. *The range of typical log arsenic values in mineralized schist plotted against log arsenic in umineralized schist to compare the Klondike Schist with the Otago Schist, New Zealand.*

compositions (Mortensen *et al.*, 2006). Thus gold-bearing quartz veins in the Lone Star ridge area are hosted by felsic metavolcanic rocks that at least locally contain elevated primary base and possibly precious metal values. We are still investigating possible linkages between the scattered syngenetic base metal occurrences and the disseminated gold (and gold-bearing quartz vein) mineralization.

Due to many similarities with the Otago Schist, the Klondike Schist is considered very prospective for disseminated mineralization. Recent drilling shows there is a strong association of gold with disseminated sulphide minerals without quartz veins at Lone Star ridge. The recognition of disseminated mineralization in Klondike Schist is encouraging and has expanded the exploration target and potential mineable width of gold-bearing quartz veins in this area.

ACKNOWLEDGEMENTS

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Windy McKinley terrane, Stevenson Ridge area (115JK), western Yukon: composition and proposed correlations, with implications for mineral potential

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Murphy, D.C., van Staal, C. and Mortensen, J.K., 2008. Windy McKinley terrane, Stevenson Ridge area (115JK), western Yukon: composition and proposed correlations, with implications for mineral potential. *In:* Yukon Exploration and Geology 2007, D.S. Emond, L.R., Blackburn, R.P. Hill and L.H. Weston (eds.), Yukon Geological Survey, p. 225-235.

ABSTRACT

Recent mapping in the 'Windy McKinley' terrane of Stevenson Ridge area of western Yukon defined two subdivisions of the terrane, an imbricated ophiolite and a succession of predominantly fine-grained, variably carbonaceous and calcareous clastic rocks extensively intruded by Middle Triassic gabbro. Further work in 2007 has revealed a third subdivision of felsic metavolcanic and carbonaceous clastic rocks, also spatially associated with voluminous gabbro. The two subdivisions of the terrane containing gabbro are reminiscent of the two subdivisions of the Delta district of Alaska, and gabbroic rocks from the two areas are coeval and geochemically similar. If the Stevenson Ridge successions correlate with those of the Alaska Range, the mineral potential of the Stevenson Ridge area would be appropriately increased.

RÉSUMÉ

Une récente cartographie du terrane de « Windy McKinley », dans la région de Stevenson Ridge, dans l'ouest du Yukon, a permis de le subdiviser en une ophiolite imbriquée et en une succession de roches clastiques à grain principalement fin, inégalement carbonées et calcaires, lesquelles sont pénétrées de manière importante par des gabbros du Trias moyen. D'autres travaux réalisés en 2007 ont permis d'en établir une troisième subdivision, celle-ci composée de roches clastiques carbonaées et métavolcaniques felsiques, qui sont elles aussi associées sur le plan spatial à un fort volume de gabbro. Les deux subdivisions du terrane renfermant du gabbro rappellent celles du district de Delta, en Alaska, et les roches gabbroïques de ces deux régions sont similaires sur le plan géochimique. Si les successions de Stevenson Ridge étaient corrélées avec celles de la chaîne de l'Alaska, leur potentiel minéral pourrait augmenter en conséquence.

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INTRODUCTION

Rocks underlying the poorly exposed western part of the Stevenson Ridge area (115JK) were thought to have similarities with both the Windy and McKinley terranes of Alaska on the basis of reconnaissance mapping in the early 1970s (Tempelman-Kluit, 1974), and have collectively been referred to as Windy McKinley terrane (Wheeler and McFeeley, 1991; Monger *et al.*, 1991; Silberling *et al.*, 1992; Gordey and Makepeace, 2001; Fig. 1). Until recently, owing to poor exposure and a lack of detailed information about these rocks, little could be concluded about either their role in the geological evolution of the Cordillera, or their potential to host economic mineralization. Since 2003, however, two new studies have been completed on rocks of Windy McKinley terrane (Canil and Johnston, 2003; Mortensen and Israel, 2006) and a new mapping program has been initiated by the Yukon Geological Survey (Murphy, 2007). This work has led to the recognition that none of the rocks in western Stevenson Ridge area resemble the type Windy and McKinley terranes of the Alaska Range, requiring a re-assessment of the terrane classification of the Stevenson Ridge rocks as a first step to better understanding their mineral potential and role in Cordilleran evolution. Murphy (2007) proposed that parts of what had been called Windy McKinley terrane correlate better with Pingston terrane of the Alaska Range, Yukon-Tanana terrane of western Yukon and eastern Alaska and the Chulitna terrane of the southern Alaska Range.

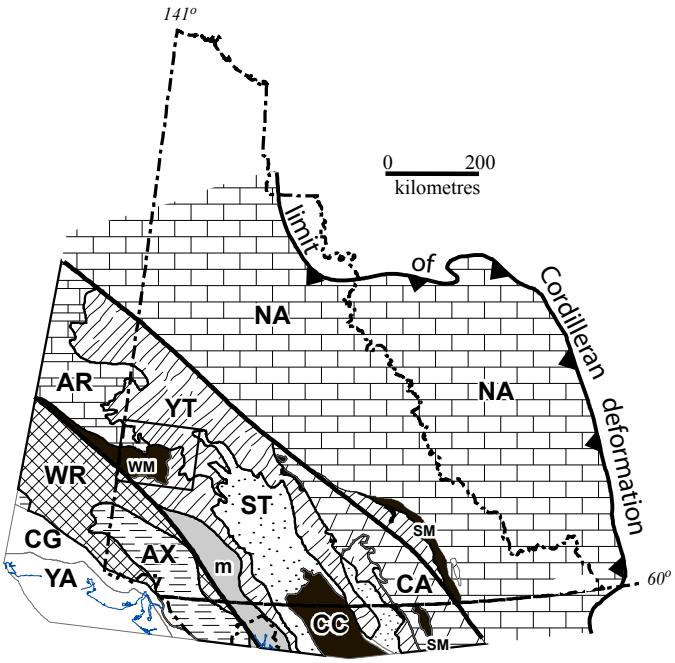
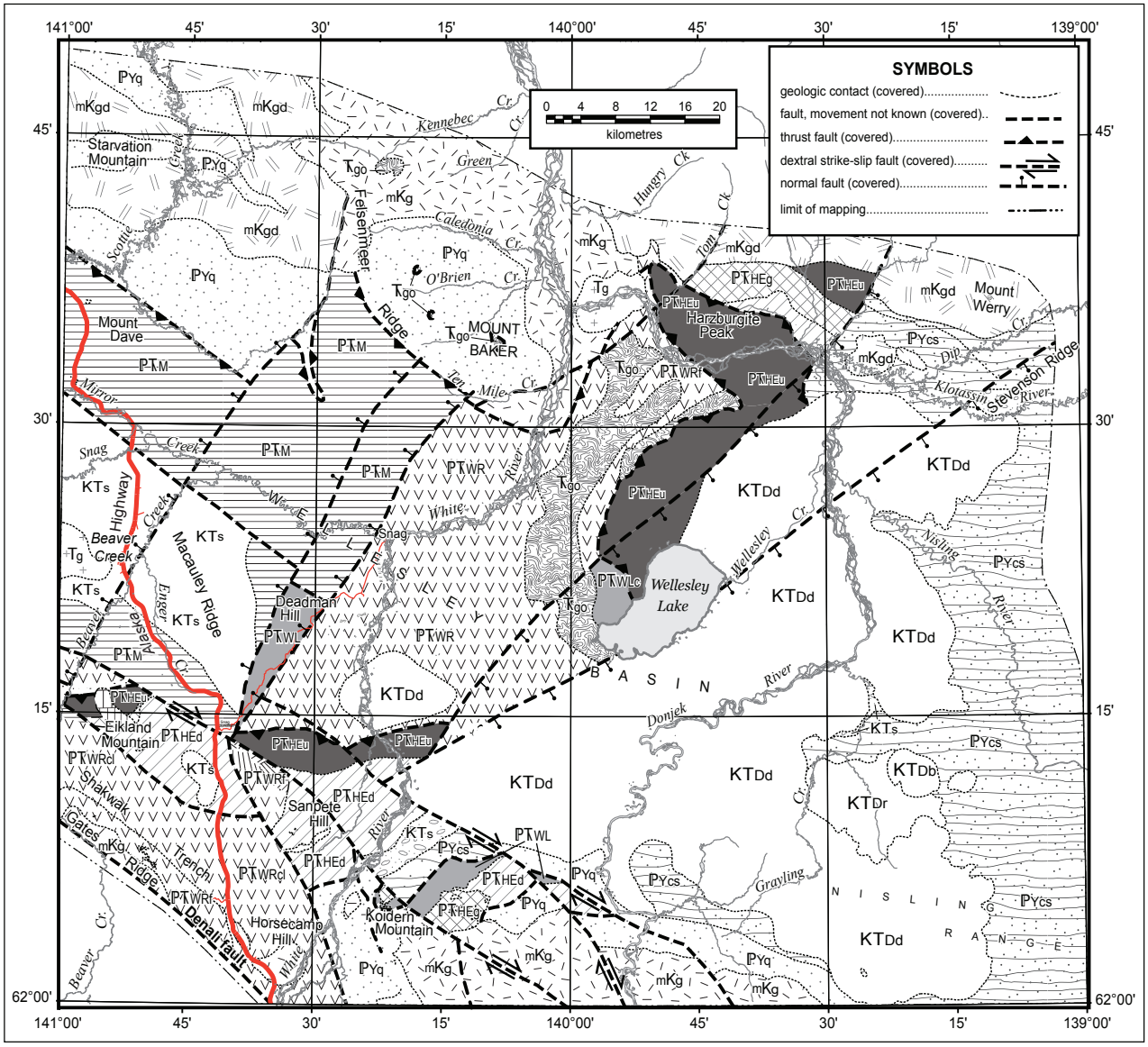


Figure 1. *Terrane map illustrating the distribution of Windy McKinley terrane in western Yukon and eastern Alaska (modified after Colpron et al., 2006). Stevenson Ridge map area is indicated by box. Laurentian elements: NA = Ancestral North American margin; CA = Cassiar terrane, North American continental margin displaced on Tintina fault; AR = Alaska Range, parautochthonous North American continental margin. Intermontane superterrane: SM = Slide Mountain terrane; YT = Yukon-Tanana terrane; ST = Stikinia; CC = Cache Creek terrane; WM = Windy McKinley terrane; m = undifferentiated metamorphic rocks. Insular superterrane: WR = Wrangellia; AX = Alexander terrane; CG = Chugach terrane; YA = Yakatat block.*

During the 2007 field season, nearly every accessible outcrop in western Stevenson Ridge area was visited, and these new data were combined with regional aeromagnetic data to produce a new bedrock geological compilation of the area (Murphy *et al.*, 2007). The purpose of this article is to present a status report on the nature and correlation of the rocks previously called Windy McKinley terrane, their role in Cordilleran evolution, and their potential to host economic mineralization.

GEOLOGY OF WESTERN STEVENSON RIDGE AREA

Fieldwork during 2007 documents that in addition to being underlain by rocks previously assigned to Windy McKinley terrane, western Stevenson Ridge area also includes rocks belonging to Yukon-Tanana terrane; a coarse-grained clastic succession of unknown age; extensive felsic to intermediate volcanic rocks of unknown age (the Donjek volcanics of Tempelman-Kluit, 1974); and several suites of foliated and unfoliated felsic to intermediate plutonic rocks (Fig. 2; Murphy, 2007; Murphy *et al.*, 2007). Rocks previously assigned to Windy McKinley terrane can be divided into three subdivisions (Fig. 3), the herein named White River and Mirror Creek formations, both of which are intruded or spatially associated with bodies of gabbro, and the Harzburgite Peak-Eikland Mountain ophiolite complex. These rock units are everywhere separated from surrounding rocks of Yukon-Tanana terrane by faults and shear zones. Two subdivisions of Yukon-Tanana terrane have been recognized, a lower, locally calcareous, quartz-rich metaclastic succession that resembles the regional



INTRUSIVE ROCKS

TERTIARY

Tg granite

LATE CRETACEOUS

lKd hornblende diorite and gabbro

EARLY CRETACEOUS

mKg biotite (± hornblende) granite

mKgd variably foliated biotite-hornblende granodiorite

'WINDY MCKINLEY' TERRANE

TRIASSIC

Tgo medium- to coarse-grained, unfoliated to strongly foliated gabbro

LAYERED ROCKS

CRETACEOUS - TERTIARY

'Donjek volcanics' (after Tempelman-Kluit, 1974)

KTDb olivine basalt

KTDd dacite

KTDr rhyolite

KTs sandstone and conglomerate

'WINDY MCKINLEY' TERRANE

MIDDLE TRIASSIC AND/OR OLDER

Mirror Creek formation

PTM phyllitic argillite with variable amounts of variably calcareous quartz siltstone, sandstone and pebbly sandstone, extensively intruded by Triassic gabbro

Contact relationships not exposed.

White River formation

PTWRf muscovite-quartz schist and quartz- and feldspar-augen schist (felsic metavolcanic rocks) and carbonaceous meta-pelitic schist

PTWRcl carbonaceous meta-pelitic and psammitic schist and quartzite

PTWR undifferentiated felsic metavolcanic rocks and carbonaceous metaclastic rocks; includes bodies of Triassic(?) gabbro

Contact relationships not exposed.

Harzburgite Peak - Eikland Mountain Ophiolite Complex

Wellesley Lake formation

PTWLc green, pink, tan and black chert, locally interbedded with or intruded by massive mafic volcanic or intrusive rock

PTWL undifferentiated mafic volcanic or intrusive rock, foliated pink and green chert, and Triassic(?) gabbro

Contact relationships not exposed.

PTHEd massive, locally feldspar porphyritic basalt or diabase; inferred to be sheeted dyke complex; overlies gabbro

PTHEg gabbro, coarse-grained, locally foliated and lineated; overlies ultramafic rocks; locally intrudes sheeted dyke complex

PTHEu harzburgite, dunite and lesser lherzolite, variably serpentinized

YUKON-TANANA TERRANE

DEVONIAN-MISSISSIPPIAN

PYcs carbonaceous muscovite-quartz phyllite or schist and quartzite, minor felsic meta-volcanic rock

PYq psammitic biotite-muscovite-quartz schist biotite schist and biotite-muscovite meta-pelitic schist, minor marble

Figure 2. *Simplified geology of western Stevenson Ridge area, after Murphy et al. (2007).*

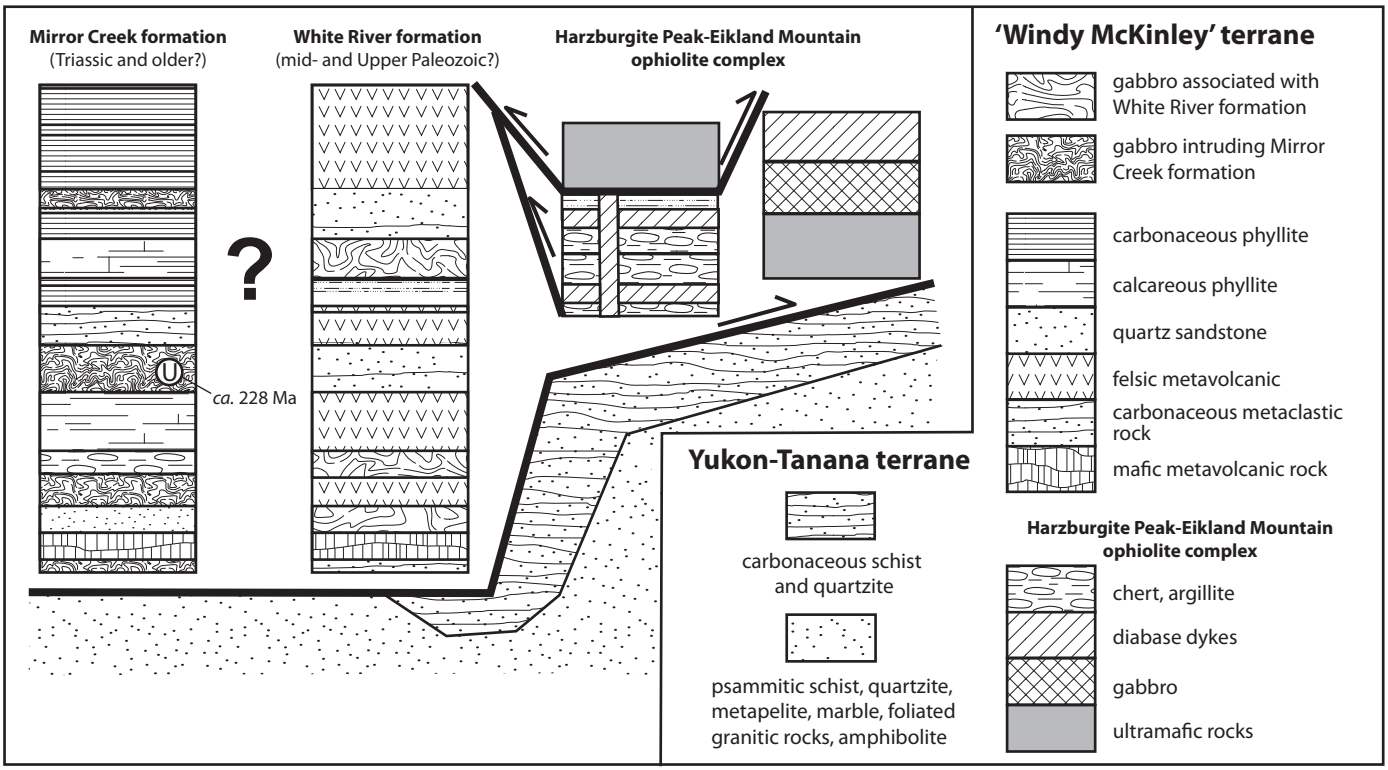


Figure 3. *Lithostratigraphic assemblages of western Stevenson Ridge area and their structural relationships.*

Snowcap assemblage (Colpron *et al.*, 2006) and an upper succession of siliceous, carbonaceous schist and quartzite interbedded with rare felsic and mafic metavolcanic rocks that resembles the regional Finlayson assemblage (*op. cit.*). The remaining map units are sedimentary or intrusive overlap assemblages onto or into the two basement terranes and as they are not the focus of this paper, they will be described in a subsequent publication.

THE FORMER WINDY MCKINLEY TERRANE

Harzburgite Peak-Eikland Mountain ophiolite complex

The prominent upland areas bordering the Wellesley Basin are underlain primarily by the fault-imbricated components of an ophiolite complex, herein named the Harzburgite Peak-Eikland Mountain ophiolite complex. The upper mantle (harzburgite) and lower crustal (cumulate dunite, peridotite and gabbro overlain by diabase and micro-gabbro sheeted dyke complexes) parts of the complex underlie two of the main mountainous massifs in the area: the massif surrounding Harzburgite Peak in the eastern part of the area, and in the west, the Eikland Mountain massif north of the Shakwak Trench. Geophysical data suggest that the highly magnetic ultramafic rocks of these two massifs continue through the poorly exposed ground intervening between them, and underlie younger rocks and unconsolidated sediments (Canil and Johnston, 2003). Massive diabase and micro-gabbro, inferred to be sheeted dykes, occur in these two massifs, but also in Sanpete Hill and the mountainous massif southeast of White River which includes Koidern Mountain (Fig. 2). Chert-bearing supracrustal sedimentary and possibly volcanic rocks, herein called the Wellesley Lake formation, occur west of Wellesley Lake, on Deadman Hill and in the Koidern mountain massif.

The Harzburgite Peak-Eikland Mountain ophiolite complex is internally imbricated and a continuous section of ophiolite, from the upper mantle to the sedimentary and volcanic supracrustal cover, has not been observed. Geological relationships near Harzburgite Peak suggest that mantle harzburgite and crustal cumulate peridotite and dunite are thrust to the northeast over crustal sheeted diabase and micro-gabbro dykes which lie at the top of what appears to be a continuous mantle-lower crustal section (Canil and Johnston, 2003). Near Wellesley Lake, mantle harzburgite is also inferred to be thrust to the southwest over the Wellesley Lake formation, the

supracrustal cover of the ophiolite. In the Koidern Mountain massif, the Wellesley Lake formation is directly in thrust fault contact above rocks of Yukon-Tanana terrane without the lower crustal and mantle portions of the ophiolite.

Preliminary geochemical data show that diabase and gabbro from the ophiolitic rocks are similar in composition to normal mid-ocean ridge basalt (NMORB; Fig. 4). Massive diabase from San Pete Hill, Eikland Mountain and Koidern Mountain, and coarse-grained gabbro from Koidern Mountain have REE element compositions similar to that of the NMORB reference composition (Fig. 4; Sun and McDonough, 1989), although diabase is slightly enriched and gabbro somewhat depleted relative to the NMORB composition.

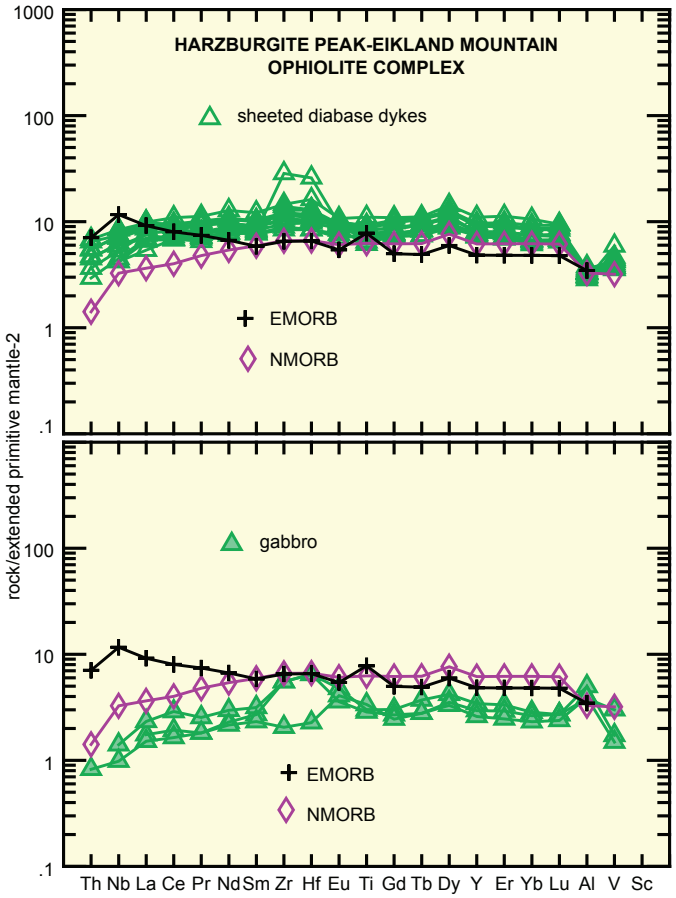


Figure 4. *Primitive mantle normalized trace element plot of data from diabase and gabbro of the Harzburgite Peak-Eikland Mountain ophiolite complex. The reference standards for normal (NMORB) and enriched (EMORB) mid-ocean ridge basalt from Sun and McDonough (1989) are also shown for comparison.*

The influence of subduction-related arc processes is not apparent in samples analysed to date. Data from a more comprehensive suite of samples is forthcoming.

The age of the Harzburgite Peak-Eikland Mountain ophiolite complex is not known. Dating studies are currently in progress to address this issue.

White River formation

The White River formation is a newly recognized unit of felsic metavolcanic and carbonaceous clastic rocks that occurs in two parts of the western Stevenson Ridge area (Fig. 2). Much of the upland region between Wellesley Lake and the White River (south of its confluence with the Donjek River) is underlain by the White River formation. In addition, it is found in the southwestern corner of the study area, northeast of the Denali fault, where it underlies part of Gates Ridge and Horsecamp Hill. Geophysical data suggest that the White River formation underlies the extensive lowland areas of the Shakwak Trench between Gates Ridge and the Eikland Mountain massif, and in the Wellesley Basin between Wellesley Lake and Macauley Ridge, in which there is virtually no bedrock exposure. The formation is spatially associated with extensive bodies of variably foliated gabbro (see below).

The White River formation comprises massive muscovite-quartz schist, strongly foliated quartz-muscovite schist, quartz and feldspar-augen schist and siliceous carbonaceous schist. Our interpretation of the varieties of felsic schist as metavolcanic rock is based on local preservation of primary features including fragmental and porphyritic textures. Massive, cherty, relatively weakly foliated siliceous schist is interpreted as coherent vent-facies flows or domes; siliceous schist with fragmental texture is inferred to represent autobreccia at the margins of flows/domes; and quartz-feldspar metaporphyry with lithic clasts is inferred to be crystal-lithic tuff.

The age of the White River formation is not known. Samples of felsic metavolcanic rock have been submitted for age determinations by U-Pb methods.

Mirror Creek formation (new)

Named after good exposures along the Alaska Highway north of Mirror Creek, the Mirror Creek formation is also exposed along the Alaska Highway northwest of Enger Lakes and in sporadic outcrops in the lowland areas of the Wellesley Basin along Snag Creek. Geophysical data and the occurrence of similar rocks directly across the border

in Alaska (Richter, 1976) suggest that the unit underlies the unexposed area northwest of Enger Lakes. A large part of the map extent of the Mirror Creek formation is actually underlain by bodies of gabbro which intrude the Mirror Creek formation as exhibited in exposures along the Alaska Highway (Murphy, 2007). The lack of exposure throughout much of the area precludes outlining individual bodies of gabbro.

The Mirror Creek formation consists of folded and foliated, medium to dark-grey phyllitic argillite with variable amounts of interbedded tan-brown, variably calcareous, quartz siltstone, sandstone and pebbly sandstone. In the northern part of northern outcrop exposures, tightly folded and strongly foliated dark grey calcareous phyllite and argillaceous limestone predominate. Extensive bodies of dark, brown-green gabbro occur in outcrops along the Alaska Highway, intruding and imparting a hornfels texture on the host argillaceous rocks. Cherty, cream-coloured, green and pink calc-silicate rock, and spotted porphyroblastic meta-pelite occur near intrusive contacts.

The age of the Mirror Creek formation is not known. Gabbro intruding the formation has been dated as late Middle Triassic constraining the formation to be Middle Triassic or older (Mortensen and Israel, 2006).

Gabbro

Extensive bodies of medium to coarse-grained gabbro occur throughout the outcrop extent of both the Mirror Creek and White River formations. Gabbro is observed to be intrusive into the Mirror Creek formation (Murphy, 2007); the relationship of gabbro to the White River formation is less clear as contacts were never observed and gabbro spatially associated with the White River formation is generally more highly foliated than that intruding the Mirror Creek formation. The only body of gabbro large enough to be portrayed at 1:50 000 or smaller scale occurs as a thick foliation-parallel slab above the White River formation in the area between the White and Donjek rivers, south of their confluence (Fig. 2).

Owing to the lack of local age determinations, it is unclear if gabbro intruding the Mirror Creek formation is coeval with gabbro spatially associated with the White River formation. The former has been dated by the U-Pb TIMS method as *ca.* 228 Ma (Mortensen and Israel, 2006). The latter is undated locally. Preliminary geochemical data from gabbro bodies from both settings are virtually identical, however, suggesting that they represent the same magmatic episode (Fig. 5).

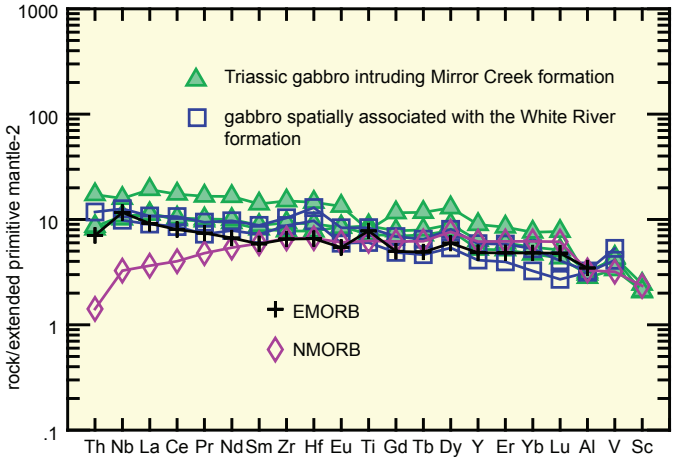


Figure 5. *Primitive-mantle-normalized trace-element plot of data from gabbro intruding the Mirror Creek formation and spatially associated with the White River formation. The similar geochemical fingerprints of gabbros from the two different settings affirm the possibility that they may be coeval. The reference standards for normal (NMORB) and enriched (EMORB) mid-ocean ridge basalt from Sun and McDonough (1989) are also shown for comparison.*

YUKON-TANANA TERRANE

Rocks of Yukon-Tanana terrane occur in fault contact to the north, east and south of rocks of the former Windy McKinley terrane. North and south of the rocks of the former Windy McKinley terrane, Yukon-Tanana terrane comprises strongly foliated, locally calcareous, siliceous schist and quartzite; meta-pelitic schist; and rare marble, amphibolite and biotite schist. Local domains of biotite-quartz-feldspar schist are inferred to be deformed intrusions. The siliceous schist of Yukon-Tanana terrane south of the rocks of the former Windy McKinley terrane passes to the east (upsection?) into an extensive region of siliceous carbonaceous schist and quartzite and rare light coloured pyritic muscovite-quartz schist inferred to be felsic metavolcanic rock. The siliceous schist unit resembles the regional Snowcap assemblage of Yukon-Tanana terrane and the carbonaceous unit resembles the regional Finlayson assemblage of the terrane. Dating studies are in process to better characterize the age and correlation of these units.

STRUCTURAL RELATIONSHIPS

The rocks of the former Windy McKinley terrane are separated from Yukon-Tanana terrane by a fault or faults

with different characteristics in different places (Figs. 2 and 3). Along the northern boundary of the former Windy McKinley terrane, the Mirror Creek and White River formations are juxtaposed with rocks of the Snowcap assemblage along the Scottie Creek fault and its associated several-km-wide shear zone. Based on its map pattern, the Scottie Creek fault appears to change from steeply dipping in the west, to shallowly dipping along strike to the east. Klippen of the rocks of the former Windy McKinley terrane overlie with shallow dip the Snowcap assemblage in at least three places (Fig. 2; Murphy *et al.*, 2007). Along the southern boundary of the former Windy McKinley terrane, on Koidern Mountain, the supracrustal Wellesley Lake formation of the Harzburgite Peak-Eikland Mountain ophiolite complex overlies rocks of the Snowcap assemblage of Yukon-Tanana terrane across a shallowly north-northwest-dipping, south-southeast-vergent thrust fault and shear zone (Murphy, 2007). These two sections of the faulted contact are separated by areas in which younger sedimentary and volcanic rocks overlie, and plutons intrude the contact; hence the two sections cannot be connected directly.

The rocks of the former Windy McKinley terrane were juxtaposed with those of Yukon-Tanana terrane prior to the mid-Cretaceous. A granitic pluton with a preliminary U-Pb LA-ICPMS (laser ablation - induced coupled plasma mass spectrometer) age of *ca.* 98 Ma intrudes the fault contact on Koidern Mountain (R. Friedman and D.C. Murphy, unpublished data, 2007), providing a lower age limit on displacement. Preliminary Ar^{40}-Ar^{39} age determinations on fuchsite from meta-gabbro and muscovite from meta-pelitic schist of the Mirror Creek formation caught up in the Scottie Creek shear zone are *ca.* 109 Ma and *ca.* 114 Ma, respectively (T. Ullrich and D. Murphy, pers. comm., 2007). Kinematic studies are currently underway to determine the nature of Cretaceous displacement across the shear zone.

Faults are either observed or inferred to separate the subdivisions of the former Windy McKinley terrane. In the Harzburgite Peak massif, the Harzburgite Peak-Eikland Mountain ophiolite complex is internally imbricated: harzburgite and cumulate peridotite is thrust over a sheeted dyke complex which lies at the top of what appears to be a near complete transition from mantle harzburgite upwards through cumulate gabbro and peridotite to the sheeted dyke complex (Canil and Johnston, 2003). The Harzburgite Peak mantle section is also thrust to the southwest over the White River formation and Triassic(?) gabbro along the Donjek River thrust fault (Figs. 2 and 3). This fault is inferred to merge at depth with the Scottie Creek fault. It has been traced to the south and west to Wellesley Lake and geophysical data suggest that it continues under cover and across strike-slip faults to the Eikland Mountain massif. In this area, a geophysically inferred dextral strike-slip fault separates the ophiolitic rocks from the Mirror Creek formation and Triassic gabbro to the northeast. The nature of the boundary of the ophiolitic rocks with the White River formation and Triassic gabbro on the west and southwest side of the massif is unconstrained. Finally, the contacts between the White River and Mirror Creek formations coincide with geophysical and/or topographic lineaments that are inferred to be strike-slip or normal faults. The spatial association with gabbro (White River formation), or intrusive contacts with gabbro (Mirror Creek formation) suggests a possible primary linkage between the two formations, but this has not been directly observed in the field.

The structural relationships outlined above suggest that the Harzburgite Peak-Eikland Mountain ophiolite complex is an internally imbricated slice of oceanic crust that overlies Yukon-Tanana terrane. The White River and Mirror Creek formations are also inferred to be part of the same thrust sheet, mapped to the west of the ophiolite and above Yukon-Tanana terrane. This geometry suggests that the ophiolite lay between the rocks of Yukon-Tanana terrane and the components of the former Windy McKinley terrane prior to thrust imbrication and emplacement above Yukon-Tanana terrane.

DISCUSSION

With these new data from the various components of the former Windy McKinley terrane, some tentative correlations can be proposed. The assemblage of fine-grained, variably calcareous clastic rocks, felsic metavolcanic rocks and Triassic gabbro is similar to what is found in the Delta District of Alaska, which is about 200 km to the northwest along strike (Fig. 6). In the Delta District, an older, felsic metavolcanic-bearing succession, the Jarvis Glacier belt, is overlain by fine-grained, variably carbonaceous and calcareous meta-clastic rocks of the Hayes Glacier belt, and both are intruded by Middle to Late Triassic gabbro (Dashevsky *et al.*, 2003; Dusel-Bacon *et al.*, 2006). Available trace-element data from Delta District gabbro is somewhat limited in range and quality, but compares favourably with that from the Mirror Creek and White River gabbros (Fig. 7). Felsic metavolcanic

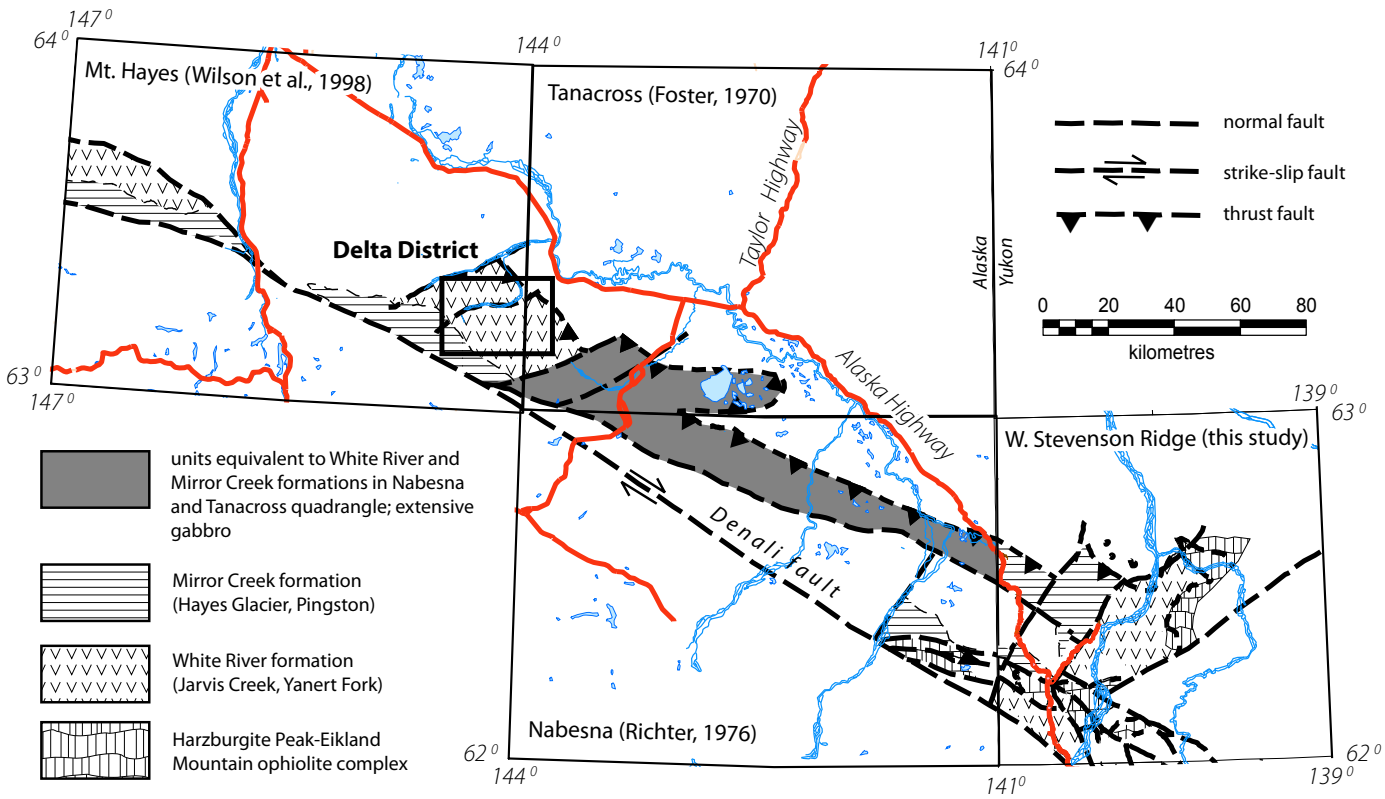


Figure 6. *Simplified geological compilation map of the region from Stevenson Ridge area, Yukon, to the Alaska Range, Alaska. Map units from Nabesna and Tanacross quadrangles, Alaska, have been interpreted from Richter (1976) and Foster (1970). The shaded map unit in these two areas comprises fine-grained schistose rocks associated with extensive bodies of gabbro that are herein correlated with the White River and Mirror Creek formations.*

rocks in the Jarvis Creek Belt are Late Devonian in age, with three U-Pb SHRIMP (Sensitive High Resolution Ion MicroProbe) age determinations of 358.6 ± 6.2 Ma, 364.2 ± 6.6 Ma and 372.0 ± 5.8 Ma (*op. cit.*). The age of the Hayes Glacier Belt has not been determined directly, but the upper part of the belt may correlate with rocks of the Pingston terrane, a lithologically similar succession in the Alaska Range from which Late Triassic fossils have been extracted (Till *et al.*, 2007). The Pingston terrane depositionally overlies the Yanert Fork sequence (Csejtey *et al.*, 1992), which has been correlated with the Jarvis Creek belt (Wilson *et al.*, 1998). If the rocks of the former Windy McKinley terrane correlate with those of the Delta District and Alaska Range, then they would range in age from Devonian to Late Triassic.

The Jarvis Creek and Hayes Glacier belts of the Delta District are considered to be part of Yukon-Tanana terrane (Dusel-Bacon *et al.*, 2006 and references therein). If the rocks of the former Windy McKinley terrane correlate with the Jarvis and Hayes Glacier belts of the Delta

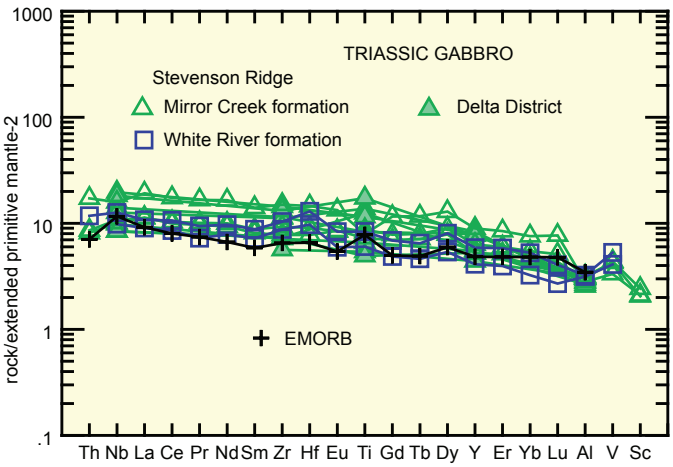


Figure 7. *Primitive-mantle-normalized trace-element plot of data from gabbro bodies in western Stevenson Ridge area (intruding the Mirror Creek formation and spatially associated with the White River formation) compared with more limited data from gabbro bodies intruding the Jarvis Creek and Hayes Glacier belts in the Delta District, Alaska (Dashevsky et al., 2003). The composition of primitive mantle is from Sun and McDonough (1989).*

District, then they too could potentially be part of Yukon-Tanana terrane. The presence of voluminous Triassic gabbro distinguishes the Stevenson Ridge and Delta District rocks from typical Yukon-Tanana terrane, however, and, in both areas, major faults and shear zones separate them from more typical rocks of Yukon-Tanana terrane (Elting Creek and Scottie Creek faults). If the Triassic gabbro-bearing Yukon-Tanana terrane was originally connected to the more typical Yukon-Tanana terrane, then it has experienced a different Early Mesozoic geological history.

The Harzburgite Peak-Eikland Mountain ophiolite complex eludes correlation. Murphy (2007) suggested that it may correlate with the mid-Paleozoic ophiolitic rocks of the Chulitna terrane in the southern Alaska Range, Alaska, on the opposite (south) side of the Denali fault. This correlation seems unlikely in light of the arc chemistry of basalt from the Chulitna terrane (Clautice *et al.*, 2001) and the apparent lack of arc influence in the trace element signatures of the Harzburgite Peak-Eikland Mountain diabase and gabbro.

Insufficient data are present to adequately constrain the nature of the original relationships between the three fault-bound components of Stevenson Ridge area ('normal' Yukon-Tanana terrane, Yukon-Tanana terrane with gabbro, and the Harzburgite Peak-Eikland Mountain ophiolite complex) and the geological evolution required for their juxtaposition. The presence of an imbricated ophiolite structurally between the two somewhat different assemblages of Yukon-Tanana terrane is difficult to reconcile without knowing the age of the ophiolitic rocks. One scenario being considered is that the ophiolitic rocks are coeval with the Triassic gabbro and both are manifestations of regional extension that culminated in the formation of oceanic crust between the two different blocks of Yukon-Tanana terrane. A viable tectonic setting for this extension could have been in the forearc of Stikinia/Quesnellia arc at its initiation during the Middle Triassic. These two blocks of Yukon-Tanana terrane were subsequently juxtaposed during mid-Cretaceous shortening, trapping the ophiolite between them. Other scenarios are also possible.

The observations presented in this study and in Murphy (2007) suggest that the name 'Windy McKinley terrane' should be discarded for the Stevenson Ridge area. Most of the rocks that had been assigned to Windy McKinley terrane in the past are now inferred to belong to Yukon-Tanana terrane, albeit with a distinct Early Mesozoic geological history. The only part of what had previously been called Windy McKinley terrane that can not be re-assigned to Yukon-Tanana terrane is the Harzburgite Peak-Eikland Mountain ophiolite complex. Although neither the age nor the correlation of the ophiolite is apparent, the ophiolite is unlike either Windy or McKinley terranes and therefore should not be labeled as such. It is also unlike any other terrane defined along the western margin of Yukon-Tanana terrane and may be unique to the area.

IMPLICATIONS FOR MINERAL POTENTIAL

The correlation with the Delta District proposed in this study has direct implications for mineral exploration in the area. Rocks of the Jarvis Creek belt in the Delta District host more than 40 volcanogenic massive sulphide (VMS) occurrences with similarities to Kuroko-style deposits (Dashevsky *et al.*, 2003). No mines have been developed in the Delta District, however, nine deposits have been outlined by drilling, ranging in size from the 0.3-million-ton (0.3-million-tonne) Nunatak deposit (0.3% Cu, 1.2% Pb, 2.8% Zn, 58 ppm Ag, 2.5 ppm Au), to the 7.2-million-ton (6.5-million tonne) MID deposit (0.4% Cu, 1.6% Pb, 4.5% Zn, 62 ppm Ag, 1.6 ppm Au; Dashevsky *et al.*, 2003). The recognition of the Delta District stratigraphy in Stevenson Ridge area increases the prospectivity of the area for VMS deposits. An area the approximate size of two 1:50 000-scale map sheets is underlain by felsic metavolcanic-bearing stratigraphy. Within this area, vent-facies metavolcanic rocks and fine-grained, carbonaceous schists have been observed, two key features of the geologic setting of Kuroko-style deposits. These observations further suggest that the appropriate environment for the formation of VMS deposits may exist in Stevenson Ridge area.

SUMMARY OF CONCLUSIONS

Rocks of the former Windy McKinley terrane comprise three subdivisions: the Harzburgite Peak-Eikland Mountain ophiolite complex of unknown age, the pre-Upper Triassic Mirror Creek formation, and the White River formation, possibly of Late Devonian to Early Mississippian age.

These three subdivisions are separated from surrounding rocks of Yukon-Tanana terrane by mid-Cretaceous, and possibly older, faults and shear zones.

The Harzburgite Peak-Eikland Mountain ophiolite complex does not appear to correlate with any other terrane in the region, and its role in Cordilleran evolution is therefore ambiguous.

The White River and Mirror Creek formations are lithologically similar to the two main subdivisions of the Delta District, Alaska, the Jarvis Creek and Hayes Glacier belts, respectively. Extensive gabbro in both areas is also geochronologically and geochemically identical. On this basis, we suggest that these two areas correlate.

The two subdivisions of the Delta District are considered to be part of Yukon-Tanana terrane; if so, then the correlative rocks of Stevenson Ridge area must also be part of Yukon-Tanana terrane. However, in both areas, the two subdivisions are separated from other parts of Yukon-Tanana terrane by faults and shear zones and, in addition, are associated with extensive bodies of Triassic gabbro, which do not occur in the other parts of Yukon-Tanana terrane. These two observations suggest that the correlative rocks of Stevenson Ridge area and the Delta District have a different Mesozoic history than that of the remainder of Yukon-Tanana terrane.

If the subdivisions of Stevenson Ridge area correlate with those of the Delta District, then the potential of the former to host mineral deposits is substantially increased.

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Preliminary bedrock geology for NTS 95D/6 (Otter Creek area), southeast Yukon

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Pigage, L.C., 2008. Preliminary bedrock geology for NTS 95D/6 (Otter Creek area), southeast Yukon. *In:* Yukon Exploration and Geology 2007, D.S. Emond, L.R. Blackburn, R.P. Hill and L.H. Weston (eds.), Yukon Geological Survey, p. 237-255.

ABSTRACT

The Otter Creek area contains sedimentary and volcanic strata of the ancient North American miogeocline: Neoproterozoic to Lower Cambrian shale (Narchilla Formation) and siltstone (Vampire Formation); Late Cambrian to Middle Ordovician argillaceous to massive limestone (Rabbitkettle Formation) and dolostone (Sunblood Formation); Cambrian to Ordovician basalt and associated diabase; Silurian to Devonian MacDonald carbonate platform strata (unit SDc-south) and Selwyn basin shale (Road River Group-north); and thinly bedded silty shale likely of the Devonian to Carboniferous Besa River Formation. The rocks are deformed by six mappable north-trending, east-verging, asymmetric, macroscopic folds with amplitudes of 500-2000 m. Argillaceous and silty units contain a pervasive, axial-planar slaty cleavage. Shortening caused by the folding is about 25%. The Narchilla Formation is structurally emplaced upon Upper Cambrian-Devonian sedimentary rocks on the western margin of the map area, along an east-verging thrust fault with unknown displacement. Late northeast-striking normal faults preserve younger stratigraphic units to the south. Deformation is poorly constrained to the Mesozoic-Cenozoic Cordilleran orogeny.

Four epigenetic(?), stratabound zinc±lead±barite deposits and showings occur at the stratigraphic contact between massive limestone and argillaceous limestone within the Rabbitkettle Formation. Two occurrences contain significant smithsonite, suggesting supergene enrichment of primary sulphide mineralization. Previous lead-isotope studies of galena from the Mel deposit suggest that the age of primary mineralization is Devonian. Primary mineralization cannot be definitively classified within existing genetic deposit models, but is most consistent with manto replacement or Mississippi Valley-type deposit models.

RÉSUMÉ

La région du ruisseau Otter recèle des strates sédimentaires et volcaniques du migéoclinal de l'Amérique du Nord. Elle compte des shales (Formation de Narchilla) et des siltstones (Formation de Vampire) datant du Néoprotérozoïque au Cambrien précoce, des grès (Formation de Rabbitkettle) et des dolomies (Formation de Sunblood) argileux à massifs datant du Cambrien tardif à l'Ordovicien moyen, des basaltes et des diabases connexes cambriens à ordoviciens, des shales du bassin de Selwyn (Groupe de Road River – nord) et des strates de carbonates (unité de carbonates siluriens à dévoniens – sud) de la plate-forme de MacDonald datant du Silurien au Dévonien, ainsi que des shales silteux finement interstratifiés qui sont probablement de la Formation de Besa River, qui date du Dévonien au Carbonifère. Ces roches ont été déformées en six plis macroscopiques asymétriques à vergence est et à direction nord, qui peuvent être cartographiés et dont l'amplitude va de 500 à 2000 m. Les unités argileuses et silteuses renferment un clivage ardoisier pénétratif dans le plan axial. Le raccourcissement attribuable au plissement totalise environ 25 %. À la limite ouest de la zone cartographique, la Formation de Narchilla repose structuralement sur des roches sédimentaires datant du Cambrien tardif au Dévonien le long d'une faille de chevauchement à vergence est dont le déplacement est inconnu. Des failles normales tardives orientées vers le nord est ont conservé des unités stratigraphiques plus jeunes vers le sud. La déformation est grossièrement circonscrite à l'orogenèse de la Cordillère, qui date du Mésozoïque au Cénozoïque.

Quatre indices et gisements de zinc±plomb±barite stratoïdes épigénétiques(?) se retrouvent le long du contact stratigraphique entre un calcaire massif et un calcaire argileux, dans la Formation de Rabbitkettle. Deux occurrences renferment d'importantes quantités de smithsonite, ce qui laisse supposer un enrichissement supergène de la minéralisation sulfurée primaire. Des analyses antérieures des isotopes du plomb de la galène du gisement Mel semblent indiquer que la minéralisation primaire date du Dévonien. Bien que cette dernière ne puisse être définitivement classée parmi les modèles de gisements existants, elle correspond davantage aux modèles de filons de barite, de remplacement ou de gisements de type Mississippi-Valley.

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INTRODUCTION

The Yukon Geological Survey has been involved with bedrock mapping projects in southeast Yukon since 2000 to provide better definition of the stratigraphy, structure, and mineral and hydrocarbon potential of the area. Recent geological mapping in NTS areas 95C/5 and 95D/8 has significantly revised the stratigraphy and facies relations of Neoproterozoic to Paleozoic strata (Pigage and Allen, 2001; Pigage, 2004b, 2006; Fallas *et al.*, 2004, 2005). Bedrock mapping in 95D/6 during 2006-2007 (Fig. 1) is a continuation of this earlier work to determine if bedrock geology identified further east extends westward into this area.

Seven weeks were spent doing fieldwork in NTS 95D/6 during 2006 and 2007. In 2006, fieldwork was curtailed by active fires immediately north of the map area. In 2007, challenges related to high water levels in streams and lakes were met through August.

This paper summarizes the bedrock geology documented by the fieldwork. It is a companion to the 1:50 000-scale geology map released by the Yukon Geological Survey as Open File 2007-4 (Pigage, 2007). Figure 2 summarizes the bedrock geology, and Figure 3 illustrates two east-west vertical cross-sections perpendicular to structural trend. These sections were not balanced for this interpretation. Lateral thickness variations in formations are probably related to a combination of poor field constraints on stratigraphic contacts, structural thickening related to uninterpreted faults and folds, and original sedimentary thickness variations. All rock descriptions are based on field observations. The geological map encompasses map sheet NTS 95D/6 and marginal parts of 95D/3, 5 and 7. These marginal areas are included to incorporate information from outcrops along the Coal River and Rock River.

LOCATION AND PHYSIOGRAPHY

NTS map sheet 95D/6 is located 90 km northeast of Watson Lake (Fig. 1) in the Hyland Plateau (Mathews, 1986). Topography consists of low rounded hills and broad open valleys with incised stream drainages. Elevations range from 660 m to 1380 m. The area is heavily forested with no ridges extending above tree line.

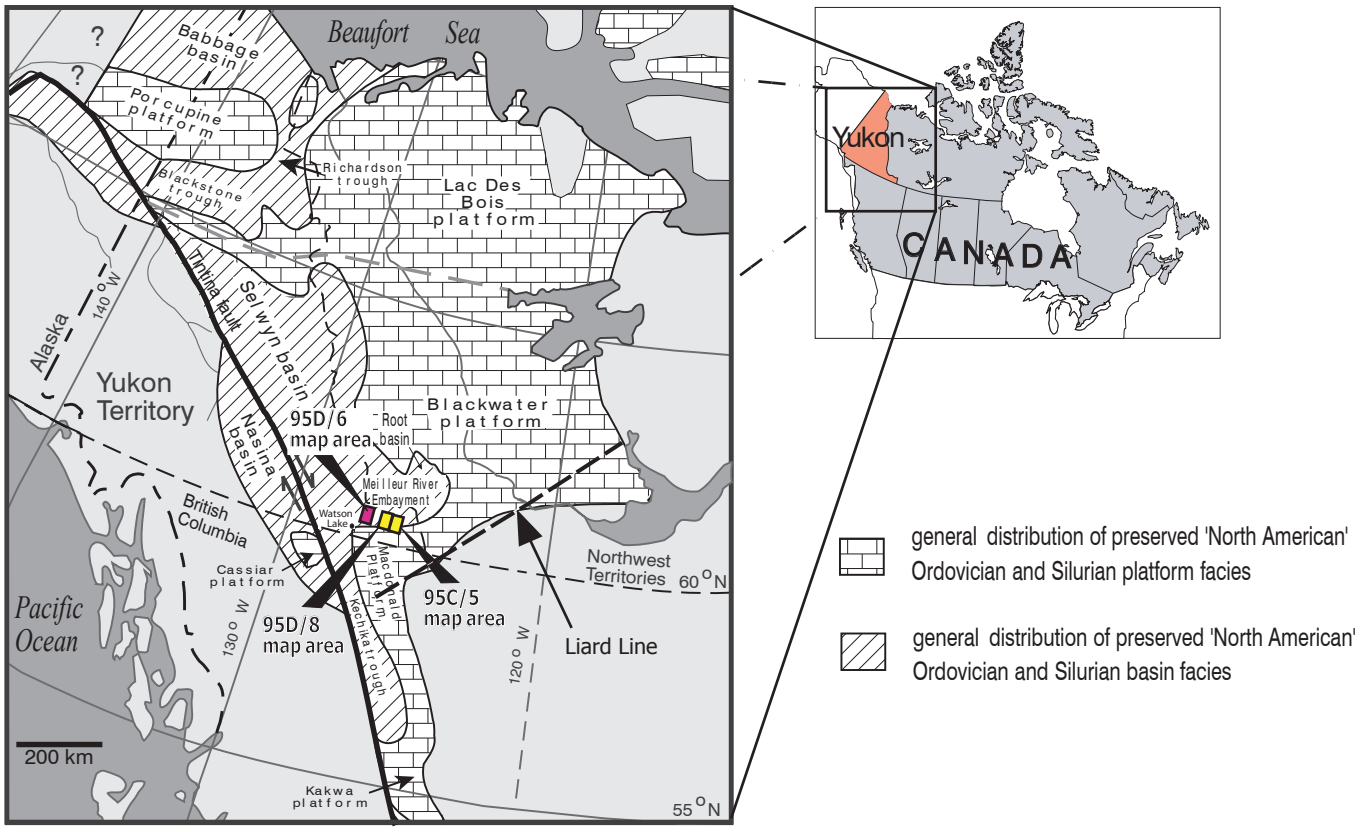


Figure 1. *Location of NTS map sheet 95D/6 in southeast Yukon. General distribution of Ordovician-Silurian platform carbonate and basinal shale facies for Canadian Cordillera and Alaska are indicated. Modified from Cecile et al. (1997).*

Much of the area has experienced major burns with extensive regrowth.

Coal River and Rock River flow south through the area into the Liard River. Scattered small lakes and marshy areas form abundant wetlands maintained by numerous beaver dams (Fig. 4). Bedrock exposure is less than 5% with most extensive exposures along streams, rivers and lakes (Fig. 5).

Fieldwork was completed primarily by foot and boat traverses from temporary base camps established by helicopter from Watson Lake. Exploration roads connecting the major mineralized properties in the west and central part of the map sheet were useful for walking and gaining access to selected ridge tops. Coal River and Rock River are suitable for navigation using an outboard jet with an inflatable boat; several traverses were completed on the Rock River in 2006 by this means. Spot checks and short traverses were completed in a few other areas where helicopter landings or 'toe-ins' were feasible.

PREVIOUS WORK

The Geological Survey of Canada completed 1:253 440-scale bedrock geological mapping of the Coal River map sheet (NTS 95D) in May and June of 1967 (Gabrielse and Blusson, 1969). Mineral exploration between 1967 and 1997 identified five Yukon MINFILE[1] occurrences. Three of these occurrences have detailed-scale bedrock geology maps and diamond drill reports (Miller, 1977, 1983, 1984, 1985; King, 1995; Senft, 1997).

REGIONAL GEOLOGY

Nelson and Colpron (2007) presented an excellent synopsis of tectonic history and metallogeny of the western North American margin which is summarized here. Rifting of the supercontinent Rodinia to form the passive margin of ancestral North America (Laurentia) began no later than about 750 Ma with deposition of the coarse clastic rocks of the Windermere Supergroup (Ross, 1991). The western margin of North America in Yukon subsequently showed clear west-deepening polarity with shallow marine sediments in the east, with a transition to deep marine sediments in the west during Neoproterozoic through Silurian time (Nelson and Colpron, 2007). NTS map area 95D/6 (Fig. 1) is located in the Cordilleran miogeocline, a depositional prism of sedimentary rocks of Precambrian to Middle Jurassic age along the relatively stable western continental margin of ancestral North America (Abbott *et al.*, 1986). It contains eight sedimentary units ranging in age from Late Neoproterozoic to Lower Carboniferous. The Silurian-Devonian transition from MacDonald platform carbonates (south) to Selwyn basin marine shales (north) (Figs. 1, 2) occurs within the map area.

All layered units have been deformed, predominantly by east-verging, asymmetric, north-trending folds. Argillaceous units contain a pervasive axial-planar slaty cleavage. Deformation is considered to result from the accretion of pericratonic and oceanic terranes to ancestral North America from Middle Jurassic through Tertiary time; it initiated development of the transpressional/transtensional orogenic belt broadly referred to as the Cordilleran orogen.

STRATIGRAPHY

INTRODUCTION

Figure 2 illustrates the map distribution of Late Neoproterozoic through Carboniferous layered units in the map area. Field descriptions for these units are presented in this section.

NARCHILLA FORMATION (HYLAND GROUP) (ℙЄN)

Several exposures along the Coal River and on the ridge immediately west of the MEL property (Yukon MINFILE 095D 005) have been assigned to the upper Narchilla Formation in the Hyland Group (Gordey and Anderson, 1993). The lower contact is structural and consists of an east-verging thrust fault placing Narchilla sediments on Cambrian-Devonian strata. The upper contact is not exposed in the map area.

The Narchilla Formation in NTS 95D/6 consists predominantly of medium green, silvery-tan-weathering, soft, thin-bedded, noncalcareous phyllite. Bedding is typically on a scale of 1-10 cm in shades of green; locally the phyllite contains thin white, fine-grained, laminated quartz sandstone interbeds (Fig. 6). On the ridge top west of the MEL deposit (Yukon MINFILE 95D 005) the green phyllite is locally interbedded with maroon phyllite (Fig. 7). One exposure along the Coal River contains a thick (greater than 3 m) interbed of coarse-grained, quartzose sandstone. Quartz clasts within the sandstone are up to 1 cm across and are locally bluish in colour.

[1] *http://www.geology.gov.yk.ca/databases_gis.html*

In the type area the Narchilla Formation is Neoproterozoic to Early Cambrian (Gordey and Anderson, 1993). It is regionally laterally correlative with the Vampire Formation and the upper member of the Backbone Ranges Formation (Gordey and Anderson, 1993; Abbott (1981). Gabrielse and Blusson (1969) included the Narchilla Formation as part of their units 1 and 2.

VAMPIRE FORMATION (PЄV)

The north central part of NTS 95D/6 contains several inaccessible exposures tentatively assigned to the Vampire Formation (Fritz, 1982). Exposures from the air in NTS 95D/6 have a blocky appearance in contrast to the platy-weathering, silvery exposures of the overlying Rabbitkettle Formation. Two helicopter stops were made in 2007 to look at Vampire Formation outcrops above tree line in map sheet NTS 95D/11.

Lower and upper contacts of the Vampire Formation are not exposed in NTS 95D/6. It is unconformably overlain by Rabbitkettle Formation and/or Cambrian-Ordovician basalt. Erosion is not extensive enough to expose the lower contact.

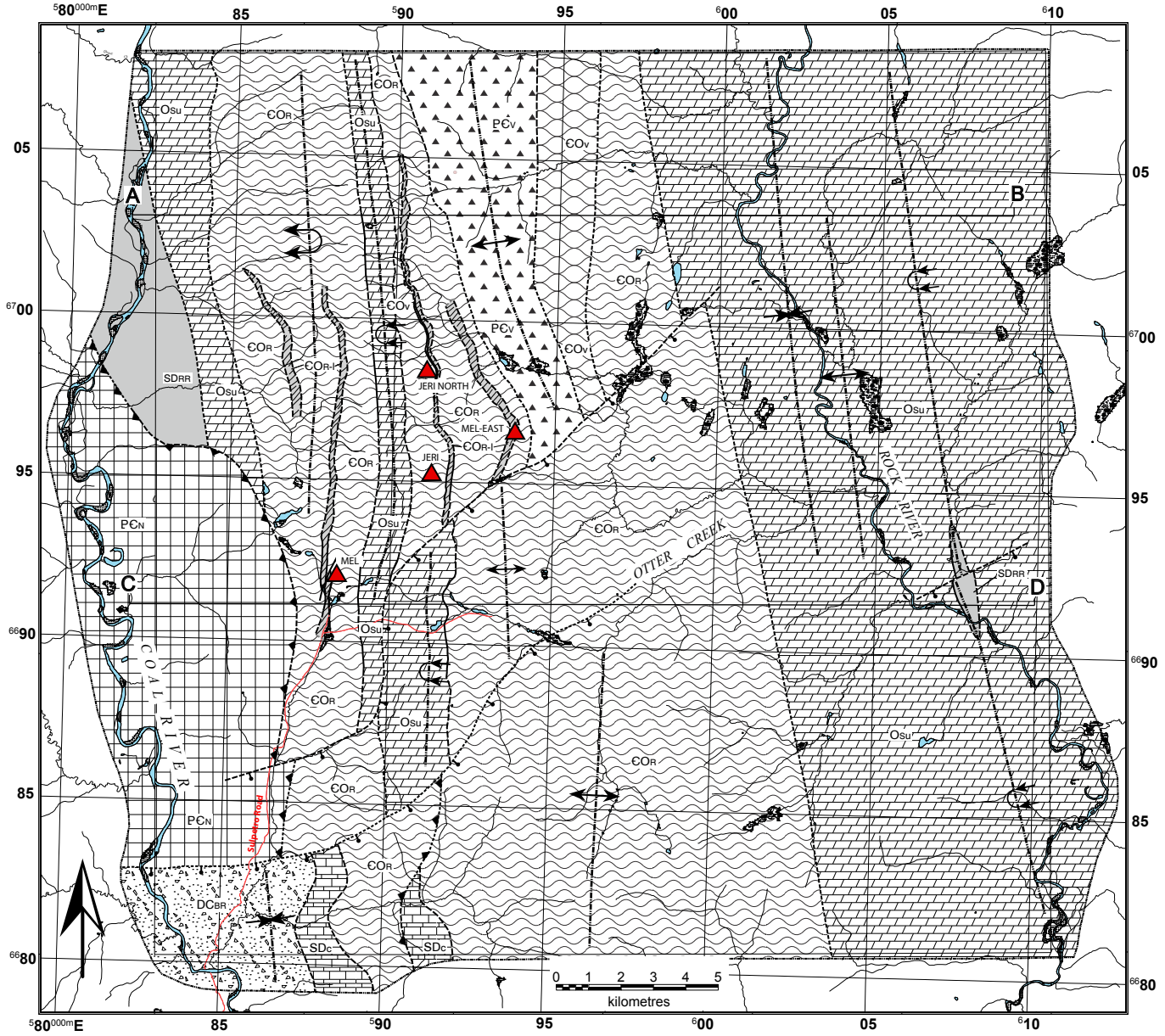


Figure 2. *Bedrock geology map for NTS map sheet 95D/6 in southeast Yukon. Map coordinates are UTM NAD83, zone 9N. Yukon MINFILE occurrences are shown with triangles. Legend is on next page.*

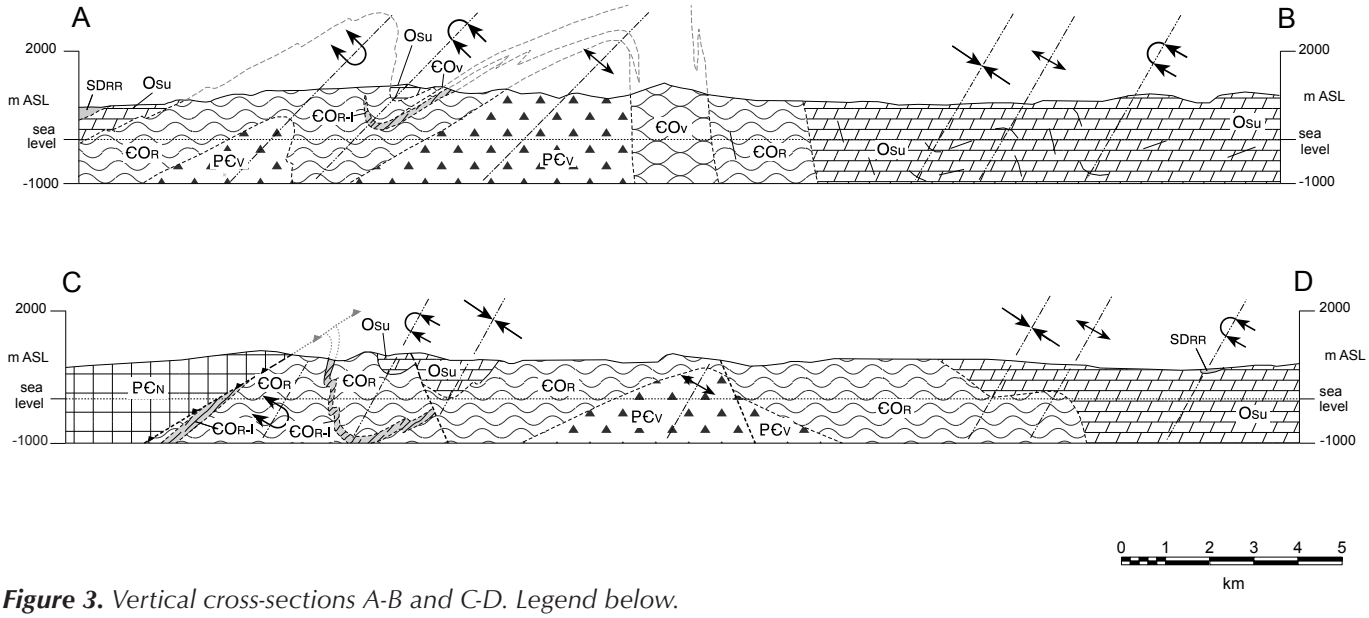


Figure 3. *Vertical cross-sections A-B and C-D. Legend below.*

LAYERED ROCKS

DEVONIAN-CARBONIFEROUS

DCBR — *Besa River Formation*

SILURIAN-DEVONIAN

SDc — carbonate - bedded grey to black dolostone or grey limestone; includes Muncho-McConnell, Stone and Dunedin formations; locally includes Silurian Nonda Formation

SDRR — *Road River Group (undivided)*

ORDOVICIAN

Osu — *Sunblood Formation*

CAMBRIAN-ORDOVICIAN

COv — basalt / gabbro - vesicular and amygdaloidal, dark green basalt; medium crystalline, massive gabbro

COR — *Rabbitkettle Formation* grey to brownish grey, silty to nodular limestone with lesser interbeds of indistinctly bedded, pale grey limestone

COR-I — *Rabbitkettle Formation* light grey, fine-grained, indistinctly bedded, resistant limestone

NEOPROTEROZOIC-LOWER CAMBRIAN

PCv — *Vampire Formation*

PCN — *Narchilla Formation (Hyland Group)*

SYMBOLS

geologic contacts (defined, approximate, inferred).....

fault; movement not known (defined, approximate, inferred).....

thrust fault (defined, approximate, inferred).....

dextral strike-slip fault (defined, approximate, inferred).....

normal fault (defined, approximate, inferred).....

anticline (upright, overturned).....

syncline (upright, overturned).....

wetlands.....

rivers.....

Figures 2 and 3. *Legend.*

One exposure of Vampire Formation in NTS 95D/11 consists of dark grey-green, fissile, pinstriped, noncalcareous, silty phyllite (Fig. 8). Pinstriping is delineated by very thin, orange-weathering laminae containing fine pyrite. The second exposure consists of interbedded massive quartz sandstone and conglomerate. Quartz sandstone is cream, grey-weathering, and consists dominantly of subangular quartz clasts (Fig. 9). Fine pyrite aggregates weathers as small, orange, vuggy openings. The conglomerate in the same outcrop consists of a single 1-m-thick bed. It is clast-supported with dominant clasts being clear quartz grains up to 1-2 cm across in a tan matrix consisting of smaller quartz grains. About 30% of the clasts in the conglomerate consist of large, angular pieces of randomly oriented, fine-grained, orange-weathering quartz sandstone up to 40 cm across (Fig. 9). Locally the conglomerate also contains large clasts of pale silvery green phyllite up to 20 cm across.

Vampire Formation in its type area is Neoproterozoic to early Lower Cambrian (Fritz, 1982). It is laterally correlative with the Narchilla Formation and the upper

Figure 4. *View looking southeast toward Rock River from Jeri North property. Foreground is old burn; middle area contains extensive wetlands with beaver dams. Field station 07LP033.*

Figure 5. *View looking east at small lake on Otter Creek. Outcrops visible on north side of lake are Sunblood Formation dolostones with vertical bedding. Field station 06LP005.*

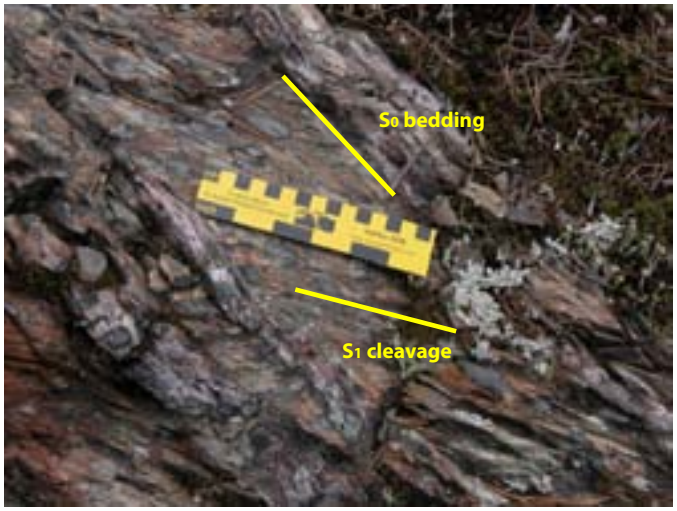


Figure 6. *Tan-weathering phyllite of the Narchilla Formation, field station 07LP001. Immediately below scale is a thin, white sandstone bed. Scale is parallel to the S_1 slaty cleavage.*

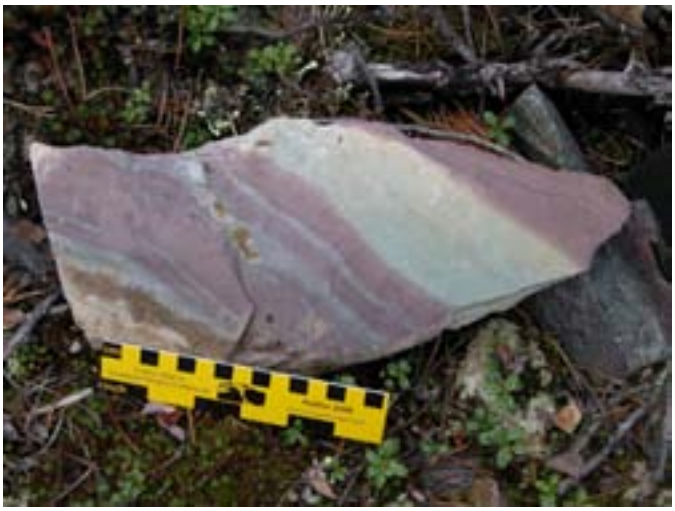


Figure 7. *Interbedded pale green phyllite and maroon phyllite of the Narchilla Formation, field station 07LP003. This specimen was pulled from the outcrop for the photograph.*

Figure 8. *Dark greenish-grey-weathering siltstone of the Vampire Formation, field station 07LP054. Bedding is vertical in photo. View looking north.*

member of the Backbone Ranges Formation (Fritz, 1982). Gabrielse and Blusson (1969) mapped the Vampire Formation as their units 4c or 2a depending on location.

RABBITKETTLE FORMATION (ЄOR, ЄOR-l)

Major portions of NTS 95D/6 are underlain by Rabbitkettle Formation (Gabrielse *et al.*, 1973). It unconformably overlies the Vampire Formation and is overlain by the Sunblood Formation. Recent work in NTS 95D/8 suggests that, at least locally, the upper contact with the Sunblood Formation is conformable (Pigage, 2006). Outcrops of Rabbitkettle Formation in the north-central part of the map area are accessible from exploration roads. Rabbitkettle outcrops in the southern and northern parts of the area are not readily accessible.

The predominant lithology in the Rabbitkettle Formation is a light grey- to brownish-grey-weathering, silty to argillaceous, locally nodular limestone (Fig. 10). Nodules are typically up to 10 cm long and 5 cm thick and consist of pale grey, recessive-weathering, fine-grained limestone which is locally parallel laminated. The silty to argillaceous, anastamosing matrix contains a well developed slaty cleavage (Fig. 11). Informally the formation has been called the 'wavy-banded limestone' as limestone nodules impart a wavy appearance to the beds.

The nodular to silty limestone commonly contains lesser interbeds of pale grey, fine-grained, massive limestone. Typically these massive beds are less than 2 m thick and constitute 50% or less of any outcrop (Fig. 12). In the

Figure 9. *Cream quartz sandstone with a 1-m-thick, tan-weathering quartzose conglomerate interbed, Vampire Formation; field station 07LP056. Bedding is vertical. Arrow just to right of hammer points to large, fine-grained quartz sandstone clast in the conglomerate.*

Figure 10. *Nodular, 'wavy-banded', silty limestone, Rabbitkettle Formation; field station 06LP021. Hammer handle is parallel with bedding. Orientation of S_1 slaty cleavage is indicated. View looking south.*

north-central portion of NTS 95D/6 the Rabbitkettle Formation contains one (or possibly two) massive limestone horizon (Unit ЄORl) up to 150 m thick which has been differentiated on the geology map. This massive limestone horizon consists of light grey to off-white, very fine-grained limestone (Fig. 13). It typically contains ghosted white calcite and tan siderite veinlets. In at least one location (Jeri North property) the limestone has a ghost burrow mottling texture. On the Mel property the limestone horizon contains small, irregular lenses of pale green to cream, noncalcareous phyllite to mudstone (Fig. 14).

Detailed drill logs from the Jeri and Jeri North properties (Miller, 1985; King, 1995; Senft, 1997) and surface geology from the Mel-East property (Miller, 1983) indicate that the uppermost portion of the massive limestone on these properties contains layers of silicified, pale grey, brown- to tan-weathering, locally burrow mottled

Figure 11. *Well developed S_1 slaty cleavage in Rabbitkettle Formation; field station 07LP031 on the Jeri North property. Scale is parallel with bedding. View looking north.*

Figure 12. *Interbedded massive limestone and argillaceous limestone in cliff face, Rabbitkettle Formation; field station 07LP005. View looking south at cliff face from helicopter. Upper massive limestone bed is about 2 m thick. Slaty cleavage dips down to right more steeply than bedding.*

Figure 13. *Close-up view of massive limestone within Rabbitkettle Formation; field station 06LP008, Mel property. View looking south. Note irregular network of carbonate veins in limestone which appear recessive.*

Figure 14. *Close-up view of olive-green mudstone within limestone, Rabbitkettle Formation. Core from Mel drill hole 75-11, depth 254 feet.*

Figure 15. *Massive amygdaloidal basalt from Unit ЄOv, field station 07LP044. Brandon Pike for scale. View looking south.*

dolostone. It is uncertain whether this dolostone is a common feature or whether it is only associated with the mineralization on these properties. It is also uncertain whether the limestone horizon on the Mel-East property is a second limestone horizon or is the same massive limestone horizon from the Jeri and Jeri North properties that has been structurally repeated.

Rabbitkettle Formation is only sparsely fossiliferous. Fossils collected regionally from the formation range from Late Cambrian (Franconian) through Early Ordovician (Gabrielse *et al.*, 1973; Tipnis *et al.*, 1978; Cecile, 1982). Two collections of trilobite and coral fragments submitted by D. Miller from immediately above the massive limestone horizons on the Mel and Mel-East (Joni) properties on this map sheet have a Late Cambrian through Early Ordovician age range (Norford, 1984; Miller and Wright, 1986).

Gabrielse and Blusson (1969) mapped the Rabbitkettle Formation as their unit 8. In some areas of 95D they mapped the massive limestone horizons, interpreted here as being within the Rabbitkettle Formation, as a separate unit 5. The uppermost part of the Rabbitkettle Formation has been regionally correlated with pink to cream, coarse sandstone interbedded with conglomerate and maroon silty shales of the Crow map unit underlying the Sunblood Formation in NTS 95D/8 and NTS 95C/5 to the east (Pigage, 2006).

UNIT ЄOv

Mafic volcanic rocks west of Rock River in the northern part of the map area are interpreted to be Cambrian-Ordovician basalt. A single helicopter landing was made on this unit in NTS 95D/6. A second helicopter landing was made on the same unit slightly to the north in map sheet NTS 95D/11. A 30-m-thick horizon of poorly exposed basalt occurring immediately above the massive limestone horizon on the Jeri North property (Yukon MINFILE 95D 032) is also considered part of this same unit on the west side of the anticline cored by the Vampire Formation. Representative material from this unit has been forwarded for lithogeochemical analysis.

The surface exposure in NTS 95D/6 (field station 07LP044) consists of massive, dark green, silvery-green to red-brown weathering, fine-grained basalt (Fig. 15). The basalt is vesicular to amygdaloidal with sparse 1-cm-diameter vugs or calcite amygdules. Bedding was not visible in the outcrops visited. Exposures locally contain a pervasive foliation. One exposure on the Jeri North property has an autobrecciated texture with angular to rounded chloritic clasts in a green chlorite-rich matrix.

The exposure visited in NTS 95D/11 (field station 07LP055) consists of massive, blocky, unfoliated, medium-grained, hornblende-plagioclase diabase. Locally it contains irregular veinlets of epidote with minor calcite.

Gabrielse and Blusson (1969) correlated this unit (their unit 3) with the Toobally volcanic unit (Goodfellow *et al.*, 1995) immediately west of the Toobally Lakes (NTS 95D/8) and considered it to be Precambrian on that basis. More recently, Pigage (2004b, 2006) delineated four alkali basalt layers in NTS 95D/8 occurring at different horizons within the pink to cream sandstone unit informally called the Crow map unit which is correlated with the Rabbitkettle Formation. These four horizons are correlated with the Toobally and Gusty Lakes volcanic units as described by Goodfellow *et al.* (1995). The uppermost of the four volcanic layers (Gusty Lakes volcanics) was bracketed by conodont samples as having a Tremadocian (Early Ordovician) age. Pigage (2006) discussed the possible age of the volcanic horizons and the enclosing Crow map unit and suggested a preferred age range of Late Cambrian through Early Ordovician for the entire Crow map unit and enclosed volcanic horizons. Geochemistry and age of the volcanic horizons from the Crow map unit are similar to that of the Cambrian-Ordovician Menzie Creek formation in the Faro area (Pigage, 2004a, 2004b, 2006).

Figure 16. *Interbedded light and dark grey dolostone of the Sunblood Formation in cliff exposure on Rock River, field station 06LP043. Cliff is about 40 m high; light-coloured beds are generally between 1 and 2 m thick. View looking north.*

Extensive outcrops of Unit ЄOv occur on the east side of the Vampire Formation in the core of an inferred anticline. Unit ЄOv is interpreted as overlying the Vampire Formation and underlying the Rabbitkettle Formation, providing an approximate age range of Early Cambrian to Early Ordovician. On the Jeri North property the ЄOv horizon occurs immediately above a massive limestone horizon within the Rabbitkettle Formation, which is interpreted as the same Upper Cambrian to Lower Ordovician massive limestone horizon on the Mel property. Using these different constraints and correlations Unit ЄOv is considered to be Late Cambrian to Early Ordovician in age.

SUNBLOOD FORMATION (OSu)

The Sunblood Formation (Kingston, 1951) outcrops extensively on the Rock River and along smaller streams draining into the Rock River. It also occurs as a small series of exposures along the Coal River in the northwest corner of the map area. In the central part of the map area, Sunblood Formation is preserved in north-trending synclinal fold keels. It conformably overlies the Rabbitkettle Formation and is unconformably overlain by the Road River Group.

In all occurrences it consists predominantly of thick-bedded, pale grey, laminated to bioturbated dolostone (Fig. 16) interbedded with thick-bedded, dark grey, bioturbated dolostone (Fig. 17). Bedding in both lithologies ranges from 10 cm to 2 m in thickness. Laminae in the pale grey dolostones are millimetres thick; commonly the laminae are parallel although rarely they outline cross-bedding. The dolostones do not generally contain a readily visible structural fabric; rarely, they exhibit an indistinct fracture to slaty cleavage. These rocks are typically tan to buff weathering. One exposure of Sunblood Formation on the Rock River is a pale grey, thick-bedded, very fossiliferous limestone (Fig. 18).

In the 'type area', Sunblood Formation is Middle Ordovician (Gabrielse *et al.*, 1973; Ludvigson, 1975). More recent conodont collections from Sunblood Formation in NTS 95D/8 and 95C/5 demonstrate that the Sunblood Formation in those areas ranges in age from Early Ordovician (Tremadocian) to early Late Ordovician (Caradocian) (Pigage, 2004b, 2006).

Figure 17. *Light and dark grey, bioturbated dolostones of the Sunblood Formation, field station 06LP041. View looking west.*

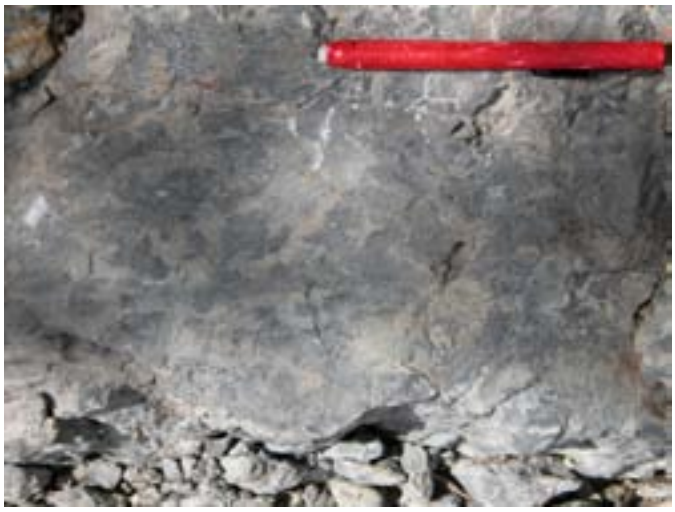


Figure 18. *Burrow mottling texture in limestone of Sunblood Formation, field station 06LP035. Pencil eraser (13 cm long) is parallel to bedding.*

Figure 19. *Interbedded black chert and dark grey, siliceous dolostone, Road River Group, field station 07LP060. Chert bed on left specimen is about 5 cm thick.*

ROAD RIVER GROUP (SDRR)

The Road River Formation was first described and defined in northern Yukon (Jackson and Lenz, 1962). In southern Yukon, Gabrielse *et al.* (1973) restricted the Road River Formation to include only the upper recessive carbonaceous-shale-dominated portion of the original formation; the lower portion was excluded from the Road River and assigned to the Rabbitkettle Formation. More recently, Fritz (1985) and Gordey and Anderson (1993) raised the Road River Formation to formal group status. Gordey and Anderson (1993) retained the exclusion of Rabbitkettle Formation from the Road River Group. This discrepancy over what is included within the Road River Group has not been resolved, and reflects differences in mapping practices between northern and southern Yukon. Pyle and Barnes (2000) have followed the definition proposed by Gabrielse *et al.* (1973) in describing their detailed sections in northeastern British Columbia. More extensive discussion concerning the current status and usage of Road River may be found in Morrow (1999).

Carbonaceous silty shales of the Road River Group outcrop on the Coal River in the northwest part of the map area and in a stream draining southward into the Rock River in the east-central part of the map area. In both areas it unconformably overlies the Sunblood Formation. The unit was examined in the east-central exposures near the Rock River during 2007.

In this area, Road River Group can be divided into two units. The lower unit is about 15 m thick and consists of thinly interbedded black chert and grey-weathering, black, silty dolostone (Fig. 19) on a scale of 2-15 cm, giving the unit a distinctly striped appearance. Both chert and dolostone layers are locally nodular. It forms small cliffs which are locally highly fractured (Fig. 20). The upper unit is thick-bedded, noncalcareous, graptolitic, pinstriped, dull black, silty shale (Fig. 21). Bedding is on a scale of 10-40 cm; pinstriping is on a 1 cm scale. The upper unit weathers recessively into thin platelets along primary bedding. A distinctive, 1.5-m-thick, cream-weathering, black dolostone bed occurs just above the lower contact with the lower unit (Fig. 21).

The exposures in this stream were combined by Gabrielse and Blusson (1969) as both Nonda (their unit 12) and Road River (their unit 11) formations. Graptolite and coral fossils collected from outcrops along the stream have an Early Silurian age (late Llandovery; Norford, 1967; reported in Gabrielse and Blusson, 1969). Fossil collections from Road River Group in NTS 95C/5 range upward to Early Devonian (Lochkovian) in age (Pigage, 2006). Road River lithologies have the same age range as unit SDc (see next section) and are therefore correlative with it. This major change from a thick carbonate succession to black shales marks the southern margin of Selwyn basin during Silurian to Early Devonian time. Although the transition is not directly visible, it occurs within a lateral north-south distance of 12 km.

UNIT SDc

The southwest part of the map area contains the northernmost exposures of a thick assemblage of undivided Silurian to Devonian carbonate. Gabrielse and Blusson (1969) reported this assemblage (their unit 13) as overlying the Silurian Nonda Formation. For purposes of this report, the Nonda Formation has been included within this unit because of limited exposures in the map area. Based on the regional mapping immediately south in map sheet NTS 95D/3, unit SDc is interpreted as overlying Rabbitkettle Formation (Gabrielse and Blusson, 1969).

One exposure at the stratigraphic top of this assemblage in the southwest corner of the map area was accessed from Coal River using a trap-line trail (field station 07LP065). At this location, unit SDc consists of indistinctly laminated, massive, fine-grained, pale grey limestone (Fig. 22).

Gabrielse and Blusson (1969) report this undivided carbonate assemblage as ranging from Early Silurian to early Middle Devonian in age. Unit SDc therefore correlates with Nonda, Muncho-McConnell, Stone and Dunedin formations. It represents the northernmost exposures of the Paleozoic MacDonald carbonate platform forming the southern margin to Selwyn basin marine shale strata during the Silurian and Devonian.

BESA RIVER FORMATION (DCBR)

In the southwest corner of the map area immediately east of Coal River, overlying unit SDc is a silty shale which has been tentatively correlated with the Devonian to Lower Carboniferous Besa River Formation (Kidd, 1963). Several exposures were examined in 2007 along Coal River and

Figure 20. *Interbedded black chert and dark grey, siliceous dolostone of lower unit in Road River Group in outcrop; field station 07LP060. View looking south; bedding is overturned with younging to the left. Shrub in foreground is about 1 m high.*

Figure 21. *Black, silty shale with one cream-weathering dolostone bed, Road River Group; field station 07LP060. View looking north. Dolostone is about 1.5 m thick. Bedding is overturned with younging to the right.*

Figure 22. *Limestone of unit SDc on north side of west-flowing stream; field station 07LP065. Trees on top of outcrop are about 3-4 m high.*

the stream near the Sulpetro Road draining west into the Coal River.

Exposures consist of tan-orange to tan-weathering, striped, greenish-grey, soft, generally noncalcareous, argillaceous siltstone (Fig. 23). Bedding ranges from 2-20 cm in thickness. Orange-weathering stripes are light grey siltstone. Locally, some beds consist of dark grey siltstone. Outcrops contain a moderately well developed slaty cleavage.

Northwest of the Sulpetro Road the formation contains a thick interbed of massive, commonly argillaceous, grey to cream, grey-weathering, poorly sorted quartz sandstone.

Figure 23. *Striped silty shale of Besa River Formation, field station 07LP063.*

Quartz clasts are subangular and clast size is variable. The sandstone is crosscut by abundant (20-30%) planar and irregular white quartz veinlets up to 20 cm thick, locally with open space in the vein centre. This quartz sandstone unit is at least 30 m thick in one location. In one small exposure, a dark grey limestone conglomerate with subangular limestone clasts is associated with the quartz sandstone.

This unit has been correlated with Besa River Formation largely because of its stratigraphic position overlying unit SDc; it does not have the carbonaceous shales and cherts typical of the Besa River Formation in map sheet NTS 95C/5 (Pigage, 2006). The Besa River Formation is Middle Devonian to Lower Carboniferous (Viséan; Richards, 1989).

STRUCTURE

The predominant structures within the map area are north-trending, east-verging, asymmetric, locally overturned, macroscopic folds with sharp hinge zones (Figs. 2, 3). Outcrop-scale minor folds in the map area are rare. All argillaceous to silty lithologies contain a single, pervasive, axial-planar slaty cleavage or spaced fracture cleavage. Cleavage is best developed within the Rabbitkettle Formation. Orientation of S_0 primary bedding relative to the S_1 slaty cleavage has been utilized to help map axial traces of primary folds. Intersection lineations between bedding and slaty cleavage plunge gently to moderately both north and south.

The Mel property (Yukon MINFILE 095D 005) is located on the west overturned limb of a north-trending syncline cored by the Sunblood Formation. West of the syncline, the axial trace of an overturned anticline is within Rabbitkettle Formation, and the axial trace of the upright anticline to the east is located within Vampire Formation. East limbs of these anticlines are vertical to overturned.

A second asymmetric syncline with an overturned west limb located immediately east of the Rock River is cored by Road River Group. Along Rock River, smaller scale parasitic folds on the west limb of this syncline result in abrupt changes in bedding within the Sunblood Formation from vertical to gently to moderately west dipping (Figs. 2, 3).

Cross-section interpretation of this fold pattern (Fig. 3) suggests fold amplitudes ranging from 500 to 2000 m. On vertical section A-B, along the Rabbitkettle-Sunblood contact, shortening related to folding was calculated to be about 25%.

Narchilla Formation is thrust eastward over Cambrian through Devonian strata on the west side of the map area along a west-dipping thrust fault with unknown displacement. In the southern part of the map area, an east-verging thrust results in the structural repetition of west-dipping unit SDc.

Three northeast-trending normal faults have been identified in the map area. These faults consistently have south-side down displacement resulting in preservation of younger strata to the south. The two major normal faults in the central part of the area displace the north-trending syncline and anticline axial traces, placing faulting as later than folding and suggesting the normal faults also have a component of strike-slip displacement.

Gabrielse and Blusson (1969) inferred a major east-directed thrust fault, the Rock River fault, which would have been responsible for emplacing Precambrian volcanic rocks upon Sunblood Formation in the northern portion of the map area. They placed this fault trending southwest through Otter Creek, south of the Jeri and Mel-East mineral showings. However, volcanic rocks interpreted by Gabrielse and Blusson (1969) to be Precambrian are here interpreted to be Cambrian-Ordovician basalts on the east, vertical limb of a north-trending anticline cored by Vampire Formation; a thrust fault is not required with this interpretation. In the area along Otter Creek south of the Jeri and Mel-East showings, the Rock River fault is re-interpreted as a northeast-trending normal fault which displaces the syncline cored by Sunblood Formation.

Folding is loosely constrained to be post-Carboniferous since all units, including the Besa River Formation in the southwest corner of the map area, are folded and contain the same axial planar slaty cleavage. Thrusting is considered to be coeval with folding because of the similar orientation of the deformation trends.

On a regional scale, compressional deformation in the miogeocline is broadly related to the Jurassic through Tertiary Cordilleran orogeny (Nelson and Colpron, 2007). In map sheet NTS 95D/08 (40 km east of 95D/06), Early Triassic sedimentary rocks are deformed in the footwall of the Toobally thrust fault, restricting the timing of deformation to later than Early Triassic (Pigage, 2004b). The Rock River valley in NTS 95D/11 immediately north of the map area contains shallowly dipping, unfolded, Late Eocene and Oligocene fluvial mudstones and coals (Long and Sweet, 1994), restricting the timing of compressional folding to pre-Late Eocene.

Northeast-trending normal faults in the map area are younger than the north-trending folds and thrust faults. Wright and Miller (1986) infer a northeast-trending fault in NTS 95D/11 offsetting the late Eocene-Oligocene sediments in the Rock River basin, suggesting that at least some movement on the normal faults is post-Oligocene.

MINERALIZATION

NTS 95D/6 contains four zinc±lead±barite deposits and showings (Yukon MINFILE 095D005, 095D 027, 095D 032). Each of these mineral occurrences is stratabound and occurs at the stratigraphic contact between massive, fine-grained limestone (stratigraphic footwall; ЄORl) and argillaceous limestone (stratigraphic hanging wall; ЄOR) within the Rabbitkettle Formation. The Mel deposit (Yukon MINFILE 095D 005) is the largest of these with a published, pre-NI43-101 drill-indicated reserve of 6.78 million tonnes grading 54.69% barite, 7.10% Zn, and 2.03% Pb (King, 1995). Miller and Wright (1986) give an overview description of the Mel deposit and also summarize the geology characteristics of the other mineral occurrences. The following descriptions are summarized largely from their article.

The Mel deposit consists of very coarse-grained, white barite and reddish-brown, coarse-grained sphalerite with late interstitial galena occurring along fractures and as selvages. Pyrite, chalcopyrite, tennantite/tetrahedrite, and covellite occur in very minor amounts. Fine-grained pyrite is disseminated in thin bands in mudstone and cherty quartz and as crosscutting veinlets through other sulphide minerals. Surface and near-surface exposures contain smithsonite, locally replacing sphalerite (Carne, 1976).

Mineralization at the Mel deposit is stratabound and forms a lens about 800 m long and up to 22 m thick near its centre. The deposit has been drill-tested to a depth of 300 m; it remains open at depth. Barite content is greatest at the centre of the deposit and zinc content is greatest at the margins. Lead content is greatest in an irregular band extending to depth near the centre of the deposit.

Alteration associated with mineralization consists of silicification and locally dolomitization of the limestone. Mudstone bands in the limestone in the vicinity of the deposit are sericitic.

The Mel-East showings (095D 027) were discovered in 1981 while following up stream geochemistry. Mineralization consists of disseminated smithsonite blebs ranging from less than 1 mm to 20 mm in size at the stratigraphic

top of a thick massive limestone bed in Rabbitkettle Formation. It is poorly exposed for a strike length of 170 m. True width is unknown but may exceed 3 m. Mineralization is associated with dolomitization and silicification of the massive limestone over a width of 10 m.

Smithsonite mineralization was found in three occurrences in silicified dolostone at the stratigraphic top of a massive limestone unit in Rabbitkettle Formation on the Jeri claims (095D 032) in 1984. Mineralization comprises veins and discontinuous masses of smithsonite up to 1 m thick with the total width of mineralization exceeding 11 m.

Mineralization at the Jeri North was discovered in 1995 by drilling on coincident IP and geochemical anomalies north of the Jeri zone (also 095D 032). Mineralization consists of coarse brown sphalerite and quartz infilling fractures in a strongly silicified limestone at the top of the same massive limestone unit hosting the Jeri smithsonite occurrences.

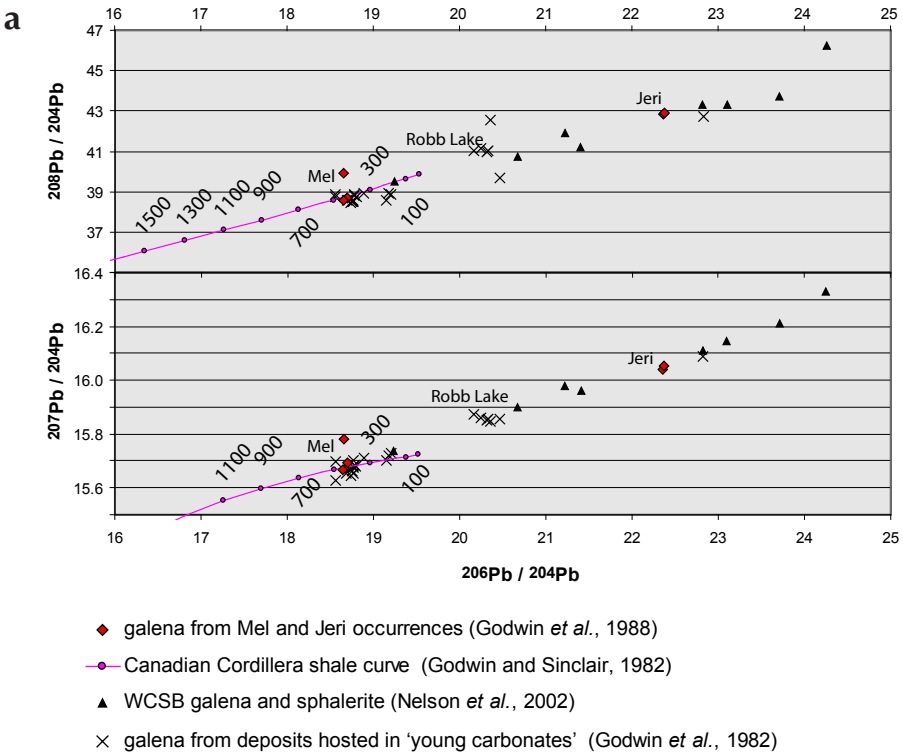
Mineralization at the above occurrences has been difficult to classify unambiguously into a particular deposit type. Yukon MINFILE descriptions currently consider the occurrences as replacement (Mel), sedimentary exhalative (SEDEX, Jeri), or Mississippi Valley-type (MVT, Mel-East) mineralization. In all occurrences, mineralization is stratabound. Extensive silicification and dolomitization are generally associated with the mineralization. Mineralization is coarse-grained; fine laminar mineralization has not been noted at any of the occurrences. Smithsonite occurrences at the Jeri and Mel-East showings are most likely related to supergene weathering of primary sphalerite (Hitzman *et al.*, 2003). Miller and Wright (1986) noted that these different features do not preclude either a syngenetic or epigenetic origin. Possible deposit models include SEDEX (syngenetic), manto replacement (epigenetic), barite vein (epigenetic) and MVT (epigenetic). The barite vein model is not considered plausible given the general stratabound character of the different occurrences.

Selwyn basin and Kechika trough contain major syngenetic zinc-lead-barite deposits that formed during regional mineralizing events of Cambrian-Ordovician (Anvil district), Silurian (Howards Pass district), and Devonian-Mississippian ages (MacMillan Pass and Gataga districts; Abbott *et al.*, 1986). Previous lead-isotope studies of galena samples from Selwyn basin and Kechika trough provide pertinent information for assigning the mineralization of the NTS 95D/6 mineral occurrences to one of these mineralizing events.

Three galena samples from the Mel deposit and one galena sample from the Jeri showing were analysed as part of a Canadian Cordillera study (Godwin *et al.*, 1988). Figure 24a displays the galena lead isotope ratios for the Mel and Jeri occurrences; the figure also shows the lead isotope growth curve for average shales in the Canadian Cordillera as derived from syngenetic SEDEX deposits of known age (Godwin and Sinclair, 1982) and galena lead isotope ratios for epigenetic mineralization as reported in Godwin *et al.* (1982) and Nelson *et al.* (2002). Figure 24b is a more detailed chart for the Paleozoic part of the Cordillera shale curve and includes galena-lead isotope ratios for the Mel deposit, Silurian syngenetic deposits (Howards Pass), and Devonian-Mississippian syngenetic deposits (MacMillan Pass, Gataga; Godwin *et al.*, 1988; Godwin and Sinclair, 1982). Two of the Mel galena samples are noticeably more radiogenic than the galena samples from the Silurian Howards Pass deposits and plot on the shale curve in the same general cluster as the Devonian-Mississippian SEDEX deposits from Selwyn basin and Kechika trough. This is consistent with Mel galena being deposited from Selwyn basin regional hydrothermal fluids in Devonian-Mississippian time. Mel mineralization is therefore consistent with epigenetic deposition.

The Jeri galena-lead ratios are much more radiogenic (Fig. 24a) and plot along a straight line delineated by galena occurrences in Middle Ordovician to Devonian carbonates (Godwin *et al.*, 1982; Nelson *et al.*, 2002). The lower limit for this straight line coincides with the cluster of Devonian-Mississippian syngenetic SEDEX and Mel galena-lead ratios. Godwin *et al.* (1982) and Nelson *et al.* (2002) suggested that this linear trend defines a mixing line between Devonian-Mississippian shale curve lead and an extremely radiogenic end-member. Regional flow of Devonian-Mississippian hydrothermal fluids dissolved the radiogenic lead by nonequilibrium processes during transport before deposition. Jeri galena-lead ratios, therefore, can also be considered consistent with a Devonian-Mississippian mineralization event.

Mel and Jeri galena-lead isotope ratios are consistent with the Devonian-Mississippian mineralizing event in Selwyn basin. Since the mineralized showings occur in the Cambrian-Ordovician Rabbitkettle Formation, mineralization is considered epigenetic rather than syngenetic. Therefore manto replacement and MVT



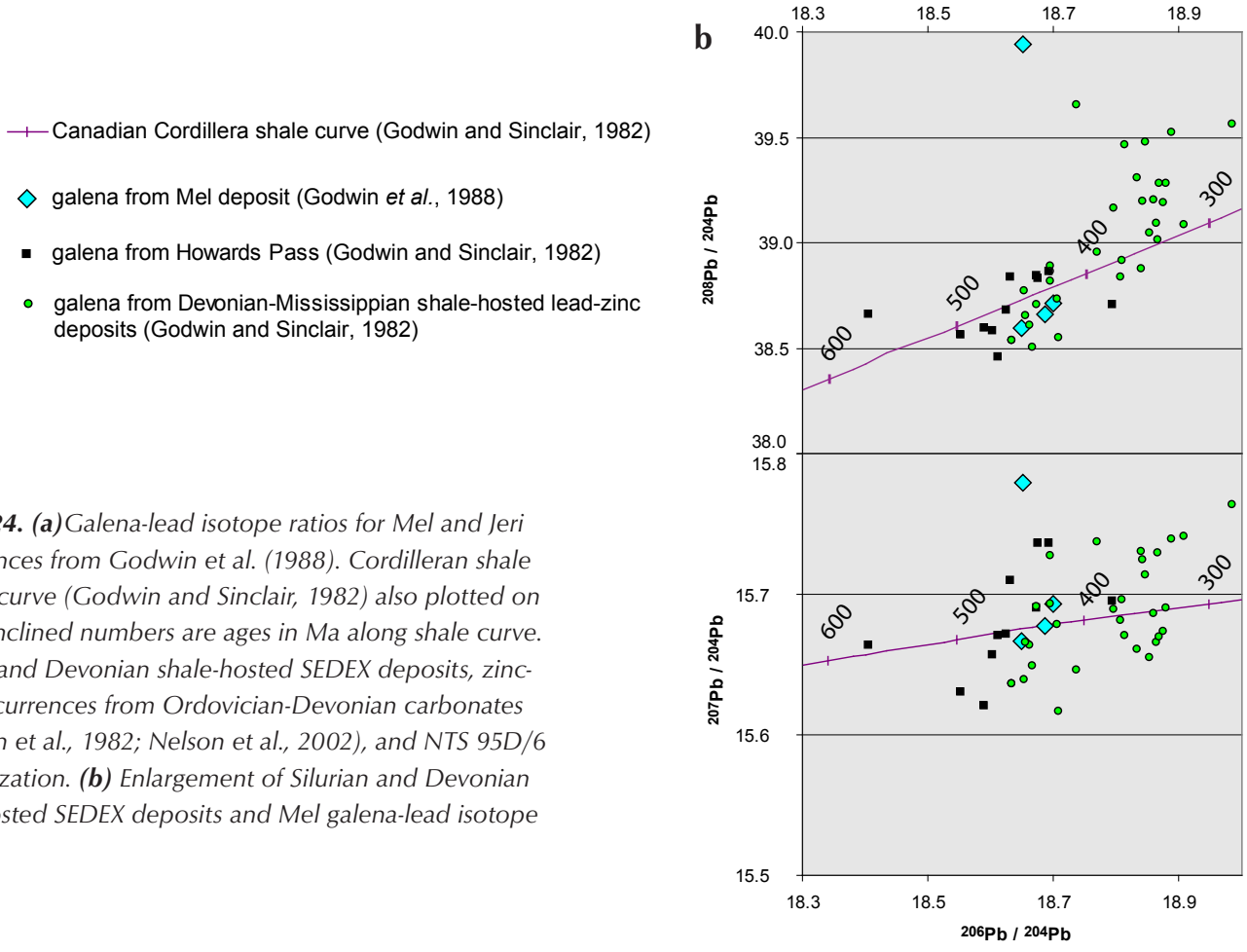


Figure 24. (a) *Galena-lead isotope ratios for Mel and Jeri occurrences from Godwin et al. (1988). Cordilleran shale growth curve (Godwin and Sinclair, 1982) also plotted on figure; inclined numbers are ages in Ma along shale curve. Silurian and Devonian shale-hosted SEDEX deposits, zinc-lead occurrences from Ordovician-Devonian carbonates (Godwin et al., 1982; Nelson et al., 2002), and NTS 95D/6 mineralization.* ***(b)*** *Enlargement of Silurian and Devonian shale-hosted SEDEX deposits and Mel galena-lead isotope ratios.*

deposit models are most appropriate for the 95D/6 zinc-lead-barite occurrences.

Nelson *et al.* (2002) and Nelson and Colpron (2007) presented an overview of tectonics and metallogeny for the western margin of North America during Devonian-Mississippian time. They argued for shale-hosted SEDEX deposits and some volcanic massive-sulphide (VMS) deposits of Selwyn basin and Kechika trough and carbonate-hosted MVT deposits of MacDonald and Mackenzie platforms being precipitated from the same basinal hydrothermal brines. Expulsion of these fluids occurred along deep-seated extensional structures in a back-arc to continental tectonic environment. Extension was caused by slab roll-back of the eastward-dipping subducting plate located west of the ancient North American continent margin.

SUMMARY

Sedimentary units within map sheet NTS 95D/6 range in age from Neoproterozoic through Lower Carboniferous. Strata are part of the ancestral North American miogeocline. The map area contains the south to north transition between Silurian-Devonian carbonate of the MacDonald platform and carbonaceous marine shales of Selwyn basin.

All units were deformed during the Jurassic-Tertiary Cordilleran orogeny. The predominant deformation style consists of north-trending, east-verging, asymmetric, tight folds accompanied by an axial-planar slaty cleavage. Six macroscopic fold axial traces have been identified in an east-west transect across the map area. Shortening due to folding is about 25%; macroscopic folds have interpreted fold amplitudes of 500 to 2000 m. Narchilla Formation is thrust eastward with unknown displacement over Cambrian-Devonian strata along the west margin of the map area. One small-scale east-verging thrust in the southern part of the map area places Cambrian-Ordovician strata over Silurian-Devonian carbonates. Late northeast-trending normal faults consistently have south-side down displacement, preserving younger strata to the south. Normal faults offset fold-axial traces, indicating a strike-slip component to fault movement.

Four epigenetic zinc±lead±barite deposits and occurrences are located at the stratigraphic contact between massive limestone and argillaceous limestone within the Cambrian-Ordovician Rabbitkettle Formation. Classification of the occurrences according to genetic models has not previously been systematic because of confusing characteristics recorded for the different showings. Characteristics of the mineralization and lead isotopes in galena suggest that mineralization is most consistent with an epigenetic Mississippi Valley-type or manto replacement type deposit model. Mineralization is correlated with the major Cordilleran Devonian-Mississippian mineralizing event which formed SEDEX and some VMS deposits in Selwyn basin and MVT deposits in adjacent MacDonald and Mackenzie platform carbonates.

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Glacial history of Howard's Pass and applications to drift prospecting

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ABSTRACT

Four stages of ice-flow occurred in Howard's Pass during the late Wisconsinan McConnell glaciation. The first stage is marked by ice growth from local cirques. During the second stage, an ice divide developed east of the Nahanni River, with ice flowing southwest across Howard's Pass. Ice sheet growth continued during stage 3 and the ice divide migrated southwest into the Logan Mountains. At this time ice flowed northward across the study area. Stage 4 is marked by deglaciation and more topographically influenced ice-flow. This last phase of ice-flow is the most important for drift prospecting in the valley bottoms. Conversely, drift transport directions at higher elevation are likely remnant from earlier stages of ice-flow. A mobile-metal-ion survey over a known deposit returned promising results, supporting the potential of this geochemical technique in other drift-covered areas of Howard's Pass.

RÉSUMÉ

Pendant la glaciation de McConnell, au cours du Wisconsinien tardif, quatre phases d'écoulement glaciaire se sont opérées à Howard's Pass. La première a été marquée par la formation de glace depuis les cirques environnants. Durant la deuxième, une ligne de partage glaciaire s'est formée à l'est de la rivière Nahanni et de la glace s'est écoulée vers le sud-ouest, en passant par Howard's Pass. Au cours de la troisième phase, la formation de l'inlandsis s'est poursuivie, et la ligne de partage glaciaire s'est déplacée vers le sud ouest jusque dans les monts Logan; c'est alors que la glace s'est dirigée vers le nord et qu'elle a traversé la zone d'étude. La quatrième phase a été marquée par une déglaciation et un écoulement glaciaire circonscrit par la topographie et représente la phase d'écoulement glaciaire la plus importante en matière de prospection glaciosédimentaire des fonds de vallée. Par contre les directions dans lesquelles les sédiments glaciaires ont été charriés à des altitudes plus élevées correspondent probablement aux premières phases d'écoulement glaciaire. Un levé d'ions métalliques mobiles exécuté au-dessus d'un gisement connu a donné des résultats encourageants montrant que cette technique géochimique pourrait être utilisée avec succès dans d'autres zones glaciosédimentaires d'Howard's Pass.

INTRODUCTION

The late Wisconsinan glacial history of Howard's Pass is important because of ongoing resource exploration and development in the area, and its proximity to the ice divide for the Selwyn lobe (Fig. 1). This lobe is one of several source areas for the northern Cordilleran Ice Sheet (Fig. 2). The sequence of ice-flow and the style of deglaciation remain enigmatic as do the location and potential migration of the ice divide in relation to Howard's Pass.

Ice-flow directions and the pattern of deglaciation were reconstructed in conjunction with investigations into the distribution of surficial sediments (Fig. 3). This information allows interpretation of soil geochemistry and helps locate materials needed for further infrastructure development in Howard's Pass. These applications are essential for the current drift-prospecting programs aimed at extending mineralized zones in the study area.

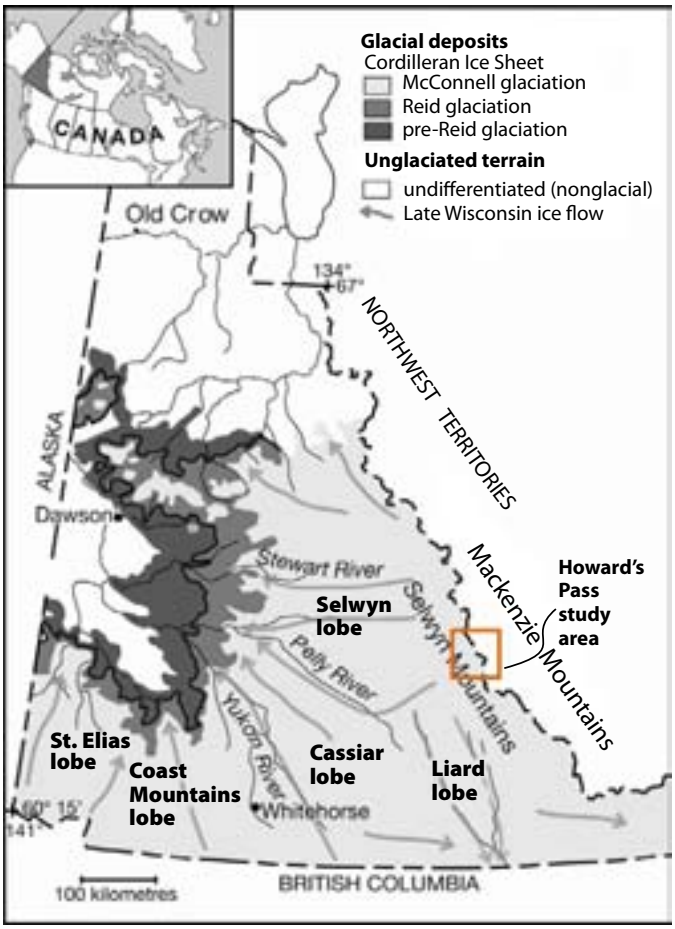


Figure 1. *Location map of the Howard's Pass study area (see square) in context with late Wisconsinan ice lobes and glacial extents of Yukon Territory (modified from Ward et al., 2007; Duk-Rodkin, 1999).*

In 2007, a 1:50 000-scale terrain map and an ice-flow history were constructed for Howard's Pass. In addition, a mobile-metal-ion (MMI) geochemistry case study was completed over a known deposit to test this technique's ability to detect anomalies directly over mineralized bedrock in glaciated terrain. These will be tools for future drift prospecting in Howard's Pass. The purpose of this paper is to summarize the late Wisconsinan glacial history of Howard's Pass, outline implications this history has for drift prospecting and discuss the applicability of the MMI technique in the area.

PHYSIOGRAPHY AND BEDROCK GEOLOGY

Howard's Pass straddles the continental divide with the Pelly River flowing west to the Yukon River, and the Nahanni River flowing east to the Mackenzie River (Figs. 1 and 3). In the Pelly River drainage, broad river valleys oriented east-west contrast with the narrower valleys running north-south in the Nahanni watershed. The steep, sediment-filled valleys in Howard's Pass have relief of over 800 m. Cirques are common throughout the study area and those facing north typically contain rock glaciers.

Howard's Pass lies within the central part of the Selwyn basin, a Paleozoic fault-controlled basin at the continental margin of the Mackenzie and Cassiar platforms (Gordey, 1981; Goodfellow, 2007). The basin formed during rifting of the western margin of North America during the Late Proterozoic. Ordovician and Cambrian limestone, and Devonian and Mississippian Earn Group sedimentary rocks dominate the bedrock in the study area. The nearest sizable intrusive bodies are the Central Nahanni pluton and the O'Grady batholith (Fig. 4), members of the Tungsten and Tombstone plutonic suites, respectively, part of the Selwyn Magmatic Province (Hart *et al.*, 2004). They are located approximately 20 km east of Howard's Pass, across the Nahanni River. The closest large pluton to the west is located over 100 km away.

The Late Proterozoic rifting made the Selwyn basin ideal for metalliferous fluids to exit onto the seafloor creating sedimentary-exhalative zinc-lead-silver deposits (SEDEX) (Morganti, 1979). The resulting sulphide minerals, composed predominantly of zinc and lead bound in sphalerite and galena, occur interlaminated with chert, cherty mudstone and limestone of the Lower Silurian Road River Group (Gordey, 1981; Goodfellow *et al.*, 1983). The Howards Pass SEDEX deposit is estimated to

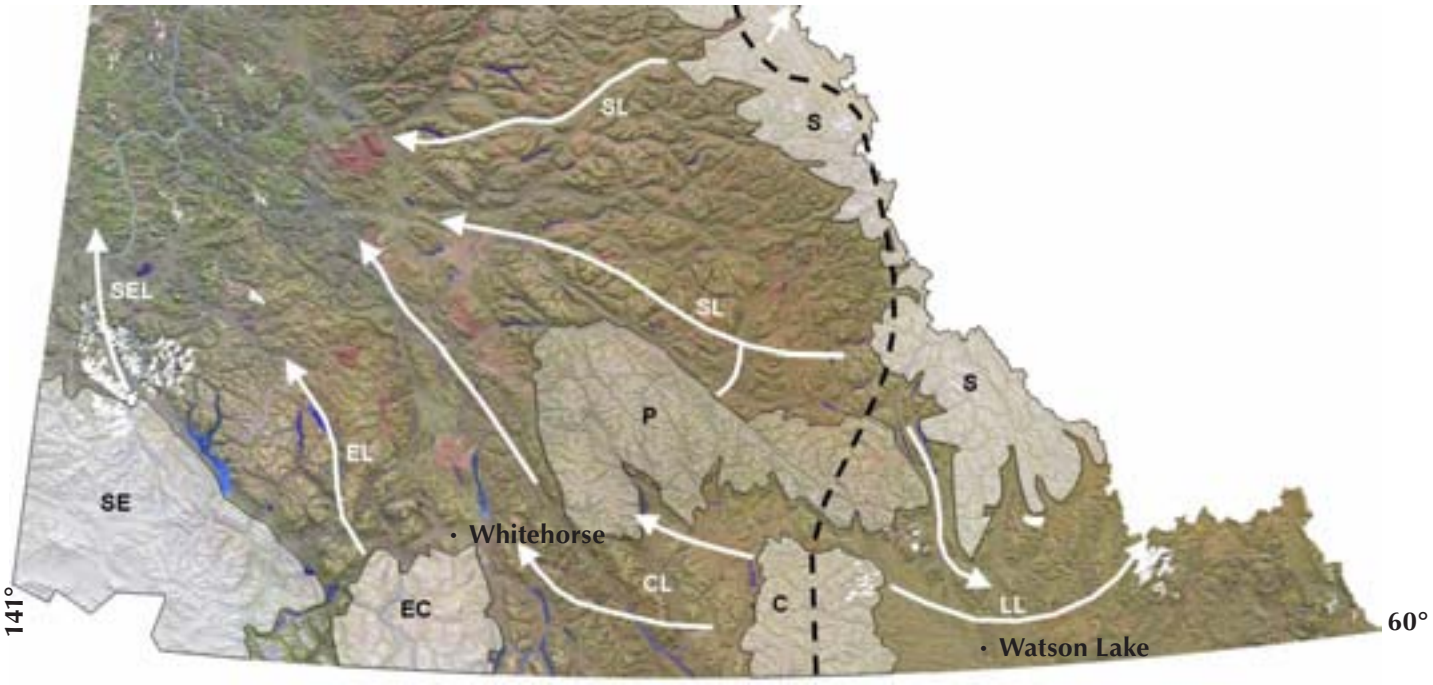


Figure 2. *Ice-flow in the northern Cordillera during the late Wisconsinan (modified from Jackson et al., 1991). EC = Eastern Coast Mountains, P = Pelly Mountains, C = Cassiar Mountains, S = Selwyn Moutains, SE = St. Elias Mountains, EL = Eastern Coast Mountain lobe, CL = Cassiar lobe, SL = Selwyn lobe, SEL = St. Elias lobe, LL = Liard Lowlands. The dotted line is the position of an inferred ice divide.*

have 86.6 millions tonnes of Indicated mineral resources, with an additional 215.46 million tonnes of Inferred resources (C. Pearson, 2007).

REGIONAL LATE WISCONSINAN GLACIATION

The northern Cordilleran Ice Sheet (CIS) comprised several distinct ice lobes centred in the St. Elias, Coast, Cassiar and Selwyn mountains (Fig. 2). These lobes extended into the surrounding lowlands from a major ice divide that extended from the Cassiar Mountains to the Pelly and Selwyn mountains (Jackson *et al.*, 1991; Bond, 2007). The Selwyn Mountains were the largest centre of ice accumulation in the northern CIS during the late Wisconsinan (Klassen, 1987; Dyke, 1990). Ice flowed from the Selwyn divide southeast into the Liard Lowlands, where it was deflected east by ice from the Cassiar Mountains (Dyke, 1990). Ice also extended east from this divide into the Mackenzie Mountains, but was far more limited than ice spreading west (Ford, 1976; Jackson, 1989). The westward-flowing Selwyn lobe spread across more than 300 km (Fig. 2; Jackson, 1989; Jackson *et al.*, 1991).

The Selwyn lobe grew in stages, likely similar to those proposed by Kerr (1934) and Davis and Matthews (1944) for the southern CIS. Ice thickness likely exceeded 2000 m near the divide and topped most mountain peaks (Jackson, 1989). Despite the thickness of the Selwyn lobe, ice-flow was thought to be dominantly topographically controlled (Jackson, 1987; Jackson *et al.*, 1991). However, aligned landforms below 1700 m in the Big Salmon Range (southwest of Pelly Mountains) suggest Cassiar lobe flow over these mountains was topographically unconstrained (Bond, 2007). This indicates that glacial flow dynamics varied across the northern CIS and were more complex than previously thought.

METHODS

TERRAIN MAPPING

A 1:50 000-scale terrain map was constructed for Howard's Pass utilizing 1:40 000-scale air photos (2004), combined with helicopter and foot traverses during the 2006 and 2007 field seasons. Mapping criteria followed a modified version of the Terrain Classification System for BC (Howes and Kenk, 1997). Some common processes,

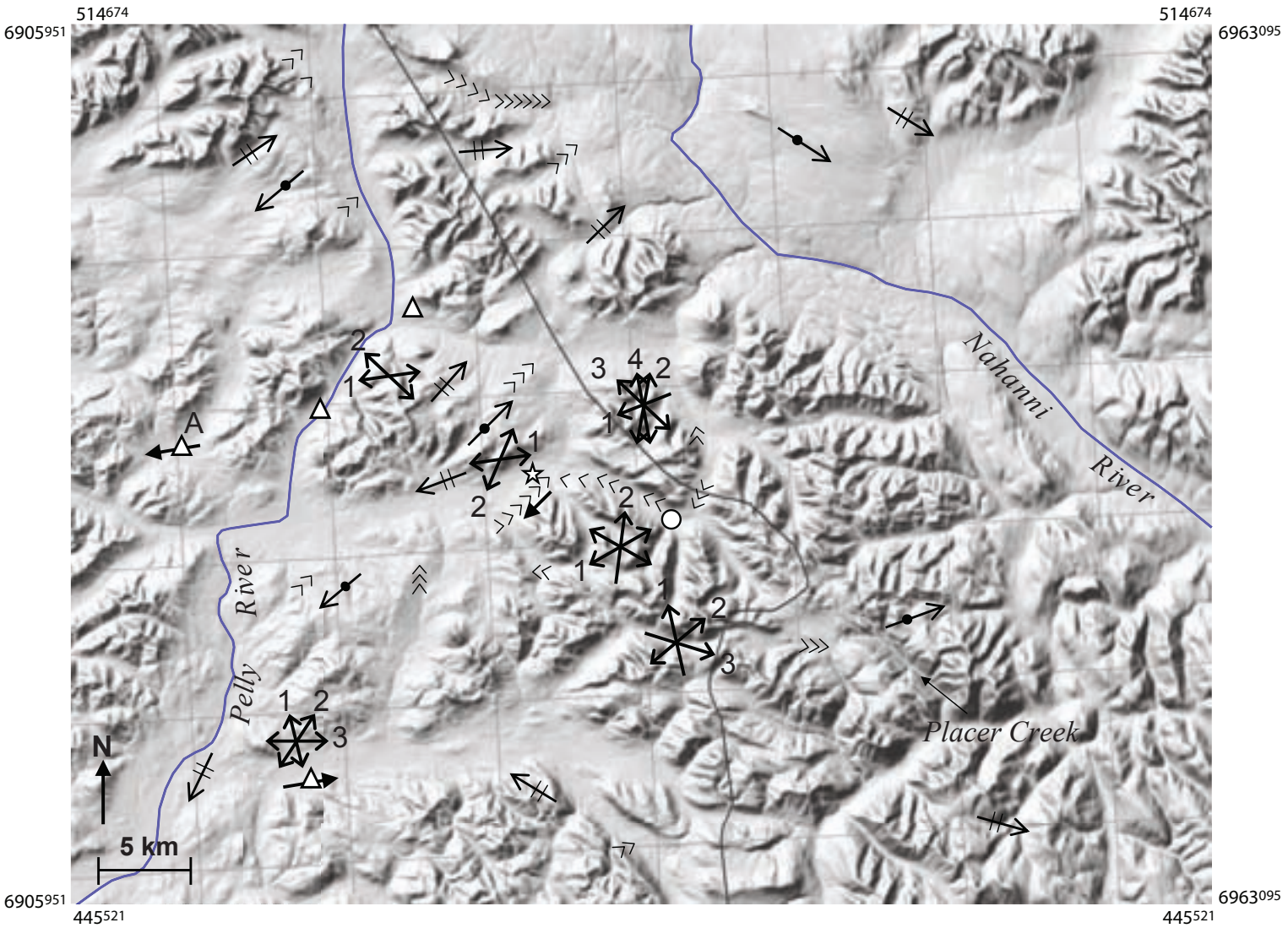


Figure 3. *Map of ice-flow indicators in Howard's Pass. Numbers by striations denote age relations. The section in Figure 5 is indicated with an A. The road section denoted by a star is at Don camp.*

such as permafrost and creep, were only indicated where they were unusually prevalent or hazardous.

ICE-FLOW

The ice-flow history of Howard's Pass was investigated during the 2007 field season in order to create a terrain map. In addition to investigating the distribution of surficial sediments, detailed descriptions were made of stratified sections exposed by streams and roads, and Quaternary sediments in drill core. These data provide important information on the timing and dynamics of the various ice-flows and the sedimentology of surficial units.

Other methods allowed quantification of late Wisconsinan ice-flow in Howard's Pass. One such technique used was tracing erratic boulders of distinctive lithology throughout the study area. Direct ice-flow indicators such as striations, rat-tails, till fabrics, crag and tails, and roches moutonnées were measured throughout the area. Indirect indicators such as the distribution of meltwater channels, moraines and eskers were also noted during mapping.

GEOCHEMISTRY

Previous analysis of glacially dispersed geochemical anomalies in Howard's Pass has been impeded by a lack of documented ice-flow history, combined with a sample

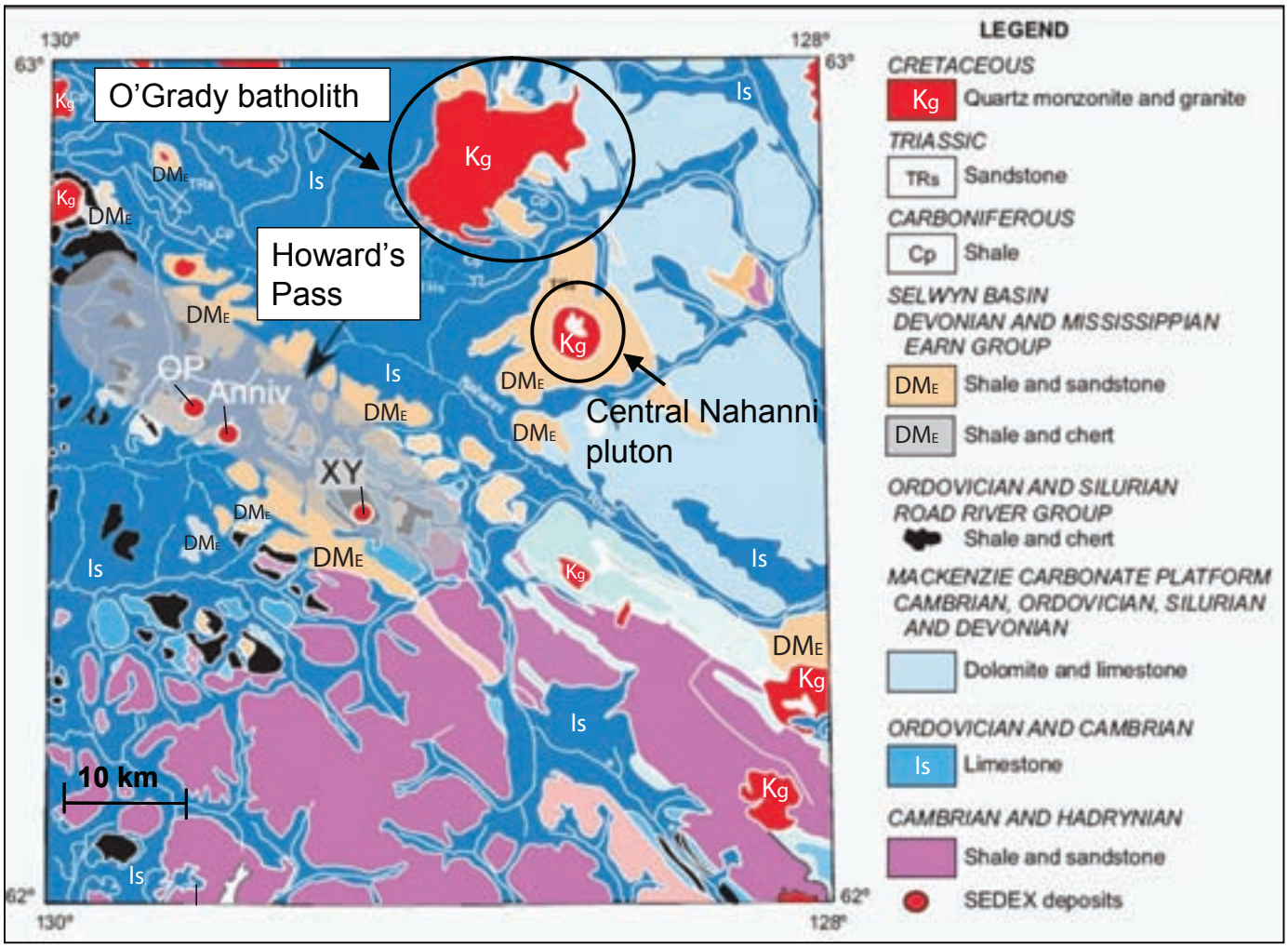


Figure 4. *Bedrock map of Howard's Pass. Granodiorite erratics found in Howard's Pass are likely sourced in either the O'Grady batholith or the Central Nahanni pluton (modified from Gordey, 1981).*

collecting procedure that did not take into account the source of surficial materials. In order to test the applicability of MMI geochemistry versus till geochemistry, a case study was conducted over the known Anniv Central deposit, part of the Howards Pass property (105I 012, Yukon MINFILE 2007[1]).

MMI geochemistry is a controversial method that utilizes the loose attachment of mobile ions to soil particles as they migrate from oxidizing mineral deposits to the surface. Diffusion, convection and capillary rise are all suggested mechanisms for this transportation. Mobile ions are converted at the surface to insoluble compounds or particles occluded to, or strongly adsorbed onto, soil materials (Mann *et al.*, 1998). This conversion occurs during pedogenic development. MMI anomalies are found directly above underlying mineralized bedrock (Harris *et al.*, 1988).

The purported benefits of using MMI geochemistry in mountainous terrain include sharp and precise anomalies, minimal nugget effects and the ability to detect deeply buried mineralization (Mann *et al.*, 1998). In addition, because the mobile ions migrate upwards to the same depth regardless of material type, samples are taken at a fixed depth, simplifying the sampling process.

In the summer of 2006, MMI and till geochemistry samples were collected at 39 locations over the known Anniv Central deposit in Howard's Pass. MMI samples were collected using four 10-cm increments at each location to evaluate which interval contained the highest element concentrations. MMI samples were analysed for 45 elements by the MMI Multi-Element Leach (MMI-M)

[1]http://www.geology.gov.yk.ca/databases_gis.html

complimentary of SGS Minerals. Aqua-regia digestion and multi-element analyses of the silt and clay fraction of the till samples, with sieving down to the 180-micron (80 mesh) size, was done at ALS Chemex Labs Ltd.

RESULTS

TERRAIN MAPPING

A terrain map of Howard's Pass is being completed as part of this thesis study and will be released as an open file map soon. The map will be useful for reconstructing the glacial history by indicating the location of meltwater channels, eskers, streamlined bed-forms and potential stratigraphic sections. This map will also assist resource development in the area, as it will portray the character and distribution of surficial materials. Six types of surficial material were identified in Howard's Pass: till, glaciofluvial, glaciolacustrine, colluvium, organic and fluvial.

Till: Till is ubiquitous throughout the study area, occurring as thick deposits on valley bottoms, and blankets and veneers on gentle to moderate slopes. It is composed of clayey silt diamicton with 10 to 40 % clasts of variable lithology. Till locally contains segregated ice lenses, so development on northern or organic-material-mantled slopes should proceed with caution. It is suitable as a bulk fill and, because of its fine-grained matrix, as an impermeable liner for tailing ponds.

Glaciofluvial: Glaciofluvial deposits are concentrated in the valley sides and bottoms where they comprise terraces, kames and eskers. These sediments are typically massive to weakly stratified sand and gravel. Their quality as an aggregate resource varies, with some gravel consisting of poorly indurated shales that break down easily. The excellent drainage of these deposits results in few segregated ice lenses. Glaciofluvial deposits therefore make good locations for roads and other infrastructure development.

Glaciolacustrine: Glaciolacustrine sediments are uncommon in Howard's Pass. They are mostly restricted to small tributary valleys or are adjacent to glaciofluvial ridges and hummocks. Northeast of the study area,

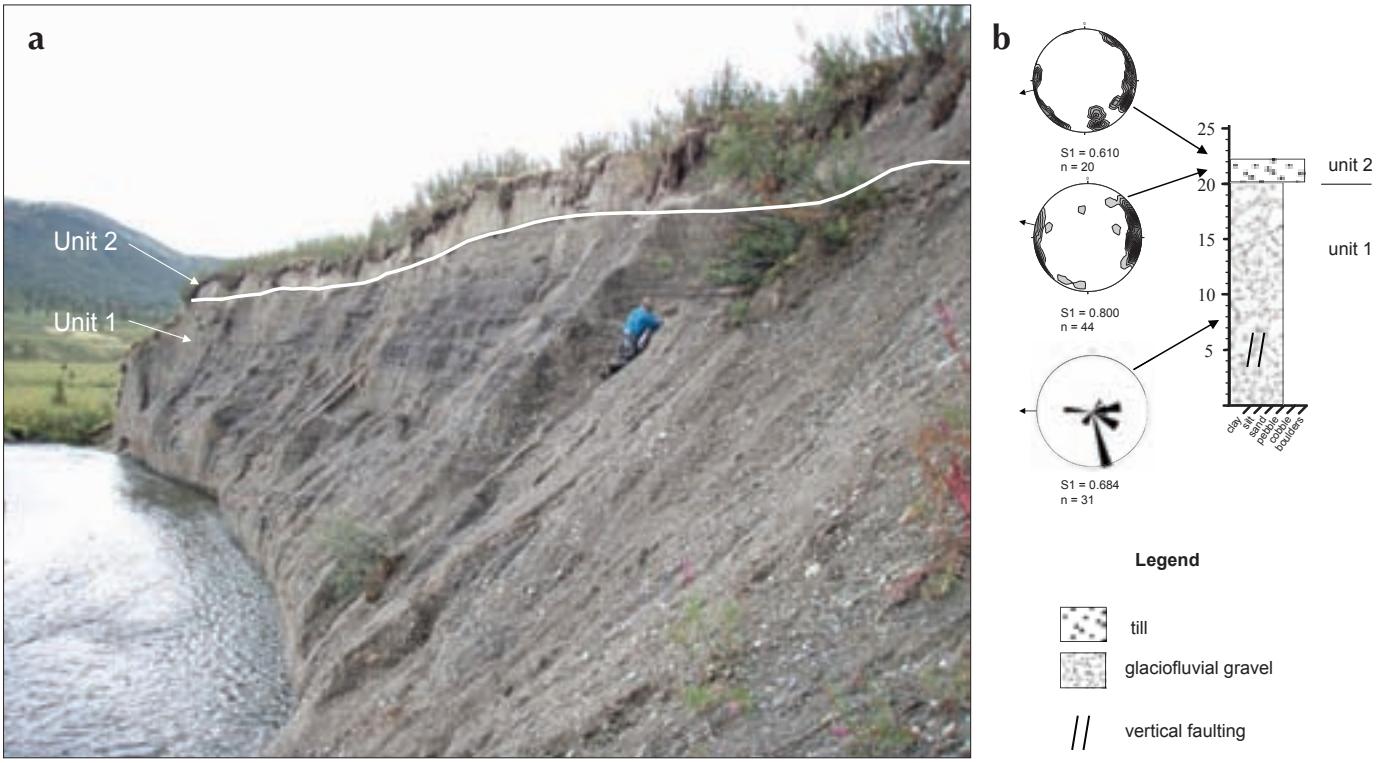


Figure 5. ***(a)*** *Section exposed by a river west of the Pelly River.* ***(b)*** *Stratigraphic log of the exposure. Unit 1 is coarsening-upwards pebble-cobble glaciofluvial gravel. Unit 2 is a basal lodgement till. The primary eiganvalue (S1) is a statistical analysis of the orientation of elongate clasts. The higher the S1, the more representative the distribution plot is for ice-flow. Little arrows indicate the interpreted westward ice-flow direction.*

Jackson (1987) mapped a large glaciolacustrine deposit in the Nahanni valley that formed during ice retreat. Glaciolacustrine sediments consist of stratified sand, silt and clay. Their low permeability, poor drainage and high *in-situ* moisture content can result in ice lenses that melt and cause large slumps, but this permeability also makes them excellent liner material for mine construction.

Fluvial: Fluvial deposits consisting of stratified sand and gravel found in, and adjacent to, modern streams running through Howard's Pass occur as floodplains, terraces and fans. Most of these deposits are limited to narrow channels and fans, but in the larger rivers, such as the Pelly and the Nahanni, these materials can be substantial. Floodplains are generally poor sites for development despite favourable foundation conditions. This is due to potential flooding, especially from ice jams during break-up. Many smaller streams transporting sediment down mountain-sides develop fans in valley bottoms. These features may contain useful construction materials, but they are also prone to hazards such as debris flows, debris floods and rapid channel avulsions.

Organic: Organic deposits are accumulations of vegetative matter thicker than 1 m. They are commonly found in floodplains, areas of shallow permafrost, and other locations with poor drainage. Their susceptibility to freeze-thaw processes, compressibility and the common presence of permafrost makes them a poor foundation for roads. In zinc-rich areas in Howard's Pass, organic deposits are highlighted by bright green zinc accumulation in mosses fed by spring water (Jackson, 1987).

Colluvial: Colluvium is material that was transported by direct, gravity-driven processes. This includes rapid processes such as rock falls, debris flows and avalanches, as well as slow processes like solifluction and creep. The texture and composition of colluvium varies more than any other material in Howard's Pass due to the range of these processes; angular boulders occur at high elevations, and finer grained sediments are on gentle slopes. Thus, its utility as aggregate material also varies across the study area. However, due to the hazards commonly associated with this material, sites with colluvium are not recommended for infrastructure development.

QUATERNARY STRATIGRAPHY

River sections

Four river-cuts in valleys oriented both west and south expose similar stratigraphy. One section in a valley west of the Pelly River reveals two units (Fig. 5). Although the upper unit is exposed at the surface, glaciofluvial hummocks and terraces lie adjacent to, and stratigraphically above, the exposure. This relation is similar to the stratigraphy preserved in drill core and described below.

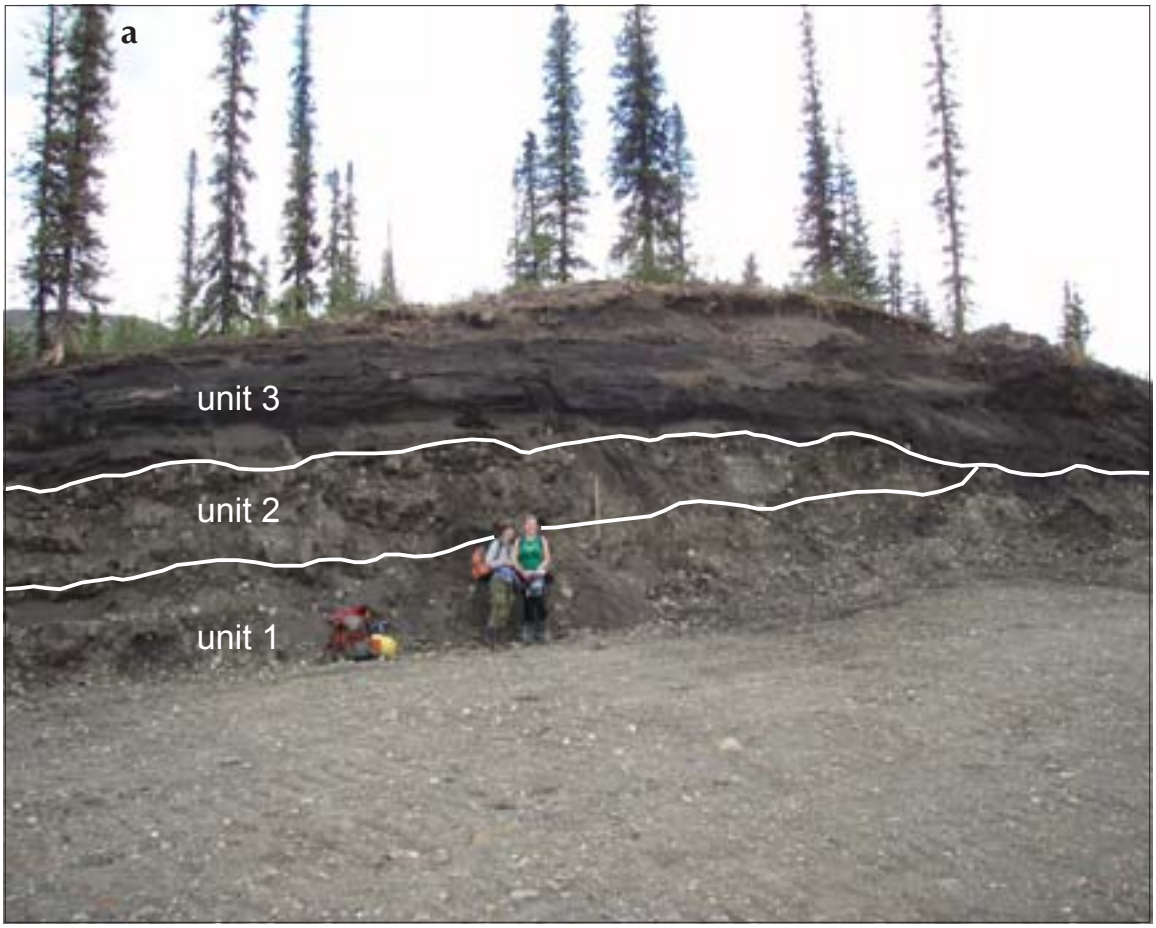
Unit 1 is a 20-m-thick deposit of coarsening-upward, horizontally bedded pebble and cobble gravel with a fine to coarse sand matrix. Paleocurrent measurements in this unit suggest it was deposited by a river flowing down-valley to the west (Fig. 5b). Extensive post-depositional faulting crosscuts bedding. This faulting was caused by glacial compression after deposition and indicates that unit 1 is a glaciofluvial deposit that pre-dates the last glaciation.

Unit 2 is a consolidated grey diamicton with a clayey silt matrix approximately 1.8 m thick. It is interpreted as a till lying unconformably over unit 1. Mean clast measurements of two fabrics between 50 and 75 cm above the lower contact are plunging east and only vary by 10°. These fabric measurements indicate ice was flowing west down this valley since till clasts are deposited plunging 180° to the direction of ice-flow. Unit 2 is a late Wisconsinan till deposited during valley-parallel flow.

Road sections

A recent road cut through a 17-km-long, 10-m-high system of eskers near Don camp was examined (Figs. 3, 6). The best exposure contained three units (Fig. 6). Unit 1 is a consolidated, grey, jointed diamict with a strong clast fabric indicating it is a till deposited by a glacier flowing to the southwest (Fig. 6b). In addition, a 3-m-diameter boulder exposed near Don camp that likely originated from this unit has rat-tails and striations on it, supporting a southwest flow direction.

Unit 2 is a 1 m, loosely consolidated, black diamict. It has a weak fabric and abundant interlaminated silt and sand rip-ups. Its upper contact undulates and the unit pinches out to the southeast. Unit 2 is interpreted as a meltout till that deposited into a subglacial channel. The associated silt and sand rip-ups were deposited as unit 2 was remobilized during deposition of unit 3.



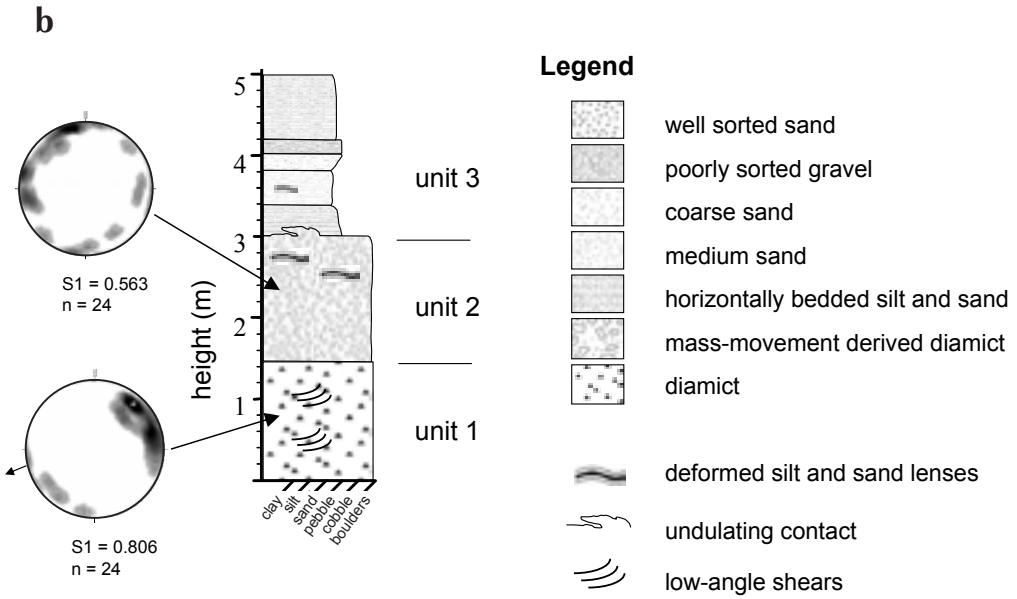


Figure 6. ***(a)*** *Road cut through an esker at Don camp.* ***(b)*** *Stratigraphic log of the section. Unit 1 is interpreted as a basal till, unit 2 is a meltout till that was subsequently remobilized, and unit 3 is the base of an esker. The difference between the S1 of the basal and meltout till supports their formation through different processes.*

Unit 3 is a 60-cm-thick, horizontally interbedded sand and silt layer that was exposed by road cuts throughout the esker system. These sand and silt layers are reversely graded with parallel to sub-parallel stratification and contain large diapirs that crosscut bedding. However, in this exposure and others, the unit becomes finer grained outward from the ridge crest, and contains climbing ripples. This sedimentology, combined with the morphology of the ridges, suggests unit 3 is a subglacially deposited esker flowing to the northeast (Saunderson, 1975; Brennand, 1994).

Drill core

Drill core from 18 holes in the Don valley provides otherwise inaccessible stratigraphic information. Eight of these holes contain multiple units that correlate across the valley and reveal both advance- and retreat-phase glacial deposition (Fig. 7). Holes Don-87, 104, 111 and 112 contain thick glaciofluvial deposits overlying a diamict interpreted as a till. Don-104 and 111 also have a thin glaciofluvial unit lying stratigraphically below the till. This sequence suggests advance glaciofluvial accumulation, followed by till deposition during glaciation, and subsequent deglacial glaciofluvial deposition. The pre-glacial floodplain illustrated in Figure 7 is inferred from the position of unit 1 exposed in the river cuts, below till.

ICE-FLOW

The most reliable and direct ice-flow indicators in Howard's Pass are striations and rat-tails. Crosscutting, bidirectional striations were observed in six areas (Fig. 3). These striations show either minor changes in ice-flow or multiple ice-flows in different directions. Striations in Earn Group conglomerates are typically accompanied by rat-tails that indicate unidirectional flow and confirm all the major flow directions. Supporting the striation data are large-scale streamlined bedrock features. These ridges observed on aerial photographs are prominent west of the Pelly River and in the Nahanni River valley (Fig. 3).

Erratics, meltwater channels and glaciofluvial deposits are indirect indicators of ice-flow in Howard's Pass (Fig. 3). Approximately 35 granodiorite erratics were observed at elevations ranging from 1100-1650 m. These erratics likely originated from either the Central Nahanni pluton or the O'Grady batholith to the east, indicating ice-flow to the west (Fig. 4). Abundant meltwater channels formed either as lateral channels beside a glacier, or proglacially, in front of a glacier during deglaciation. In the study area, meltwater channels at high elevations trend towards the northeast, whereas at lower elevations, they tend to be oriented valley-parallel. As these form during deglaciation, they indicate that the ice sheet was initially sloping toward the northeast and then became more topographically controlled. Eskers and kame deltas indicate the direction of flow during late deglaciation.

GEOCHEMISTRY

MMI surveys require sampling at the same depth regardless of material type. The case study was therefore designed to test which interval would be best for future

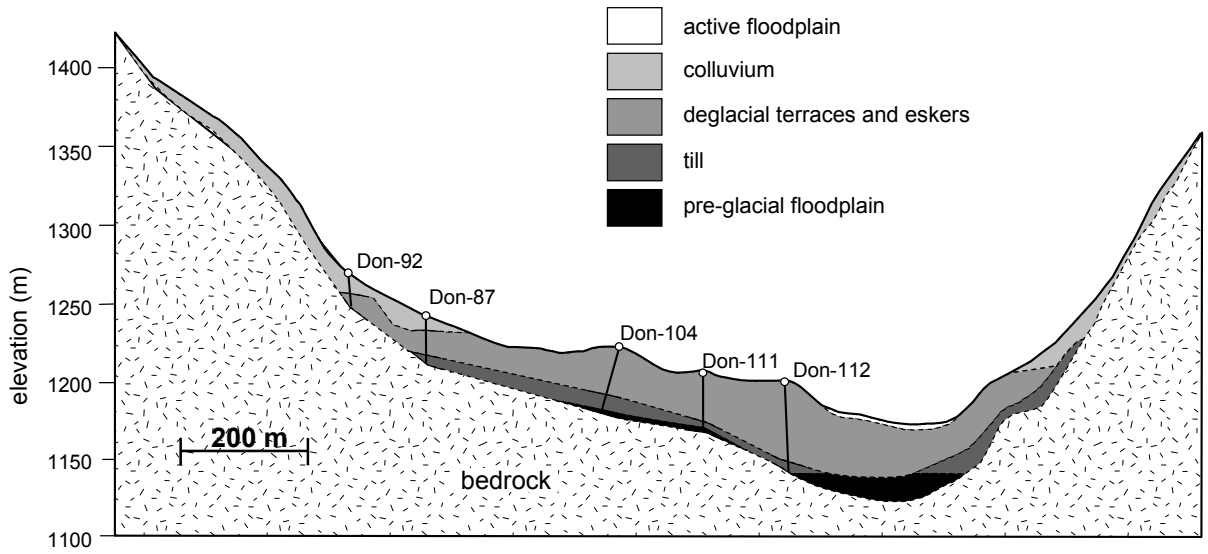


Figure 7. *Cross-section of the surficial materials in the Don valley. Depths of materials are inferred from Quaternary sediments in drill holes.*

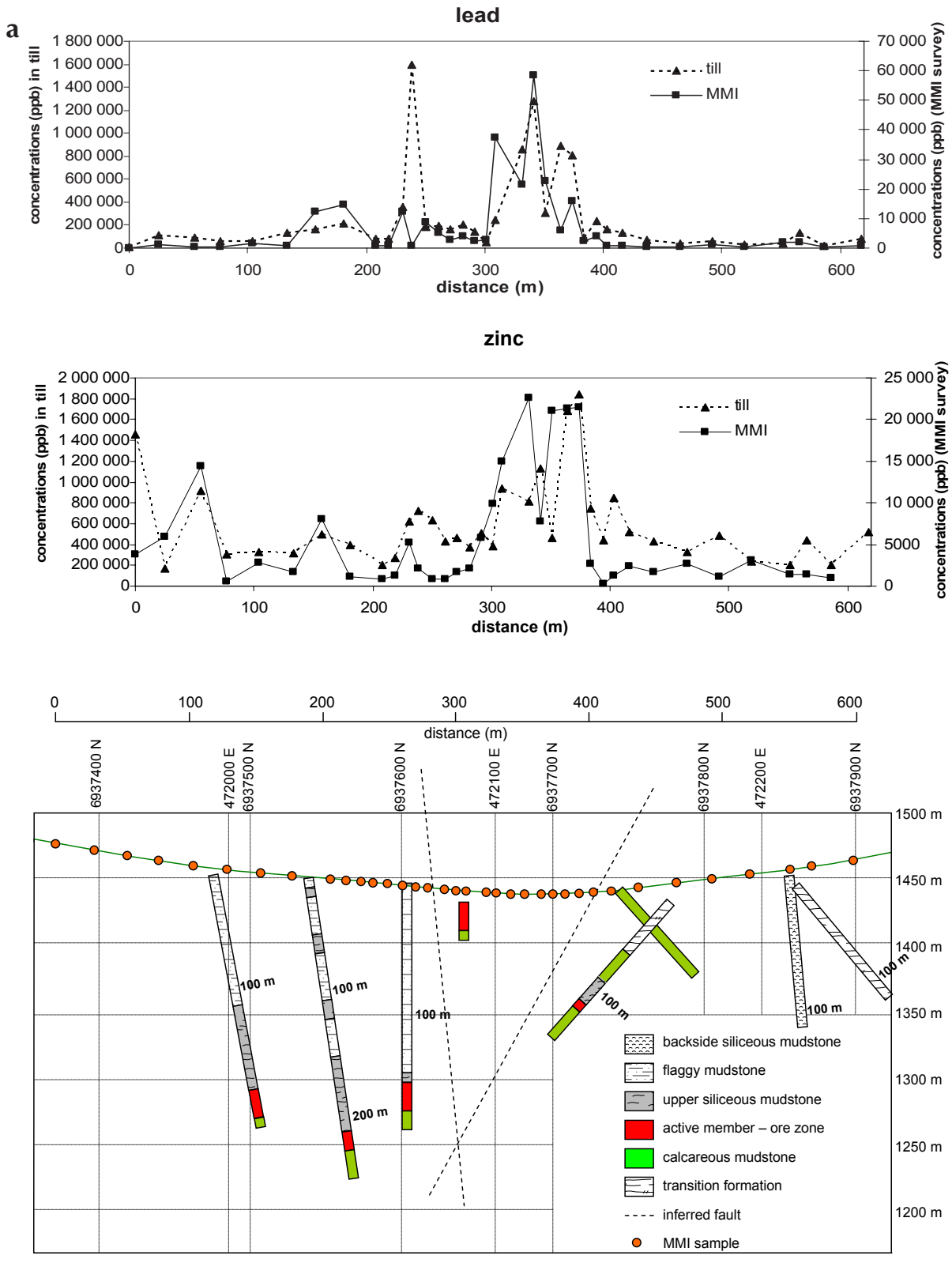


Figure 8. ***(a)*** *MMI vs till geochemistry profiles for lead and zinc from the 0-10 cm increment of an orientation survey completed in 2006 over the Anniv Central deposit, compared with drill hole logs. Till metal concentrations are significantly higher than those done with MMI. The ore zone is bounded by two inferred faults.* ***(b)*** *Profiles for potential pathfinders silver, nickel and cobalt over the same ore zone.*

b

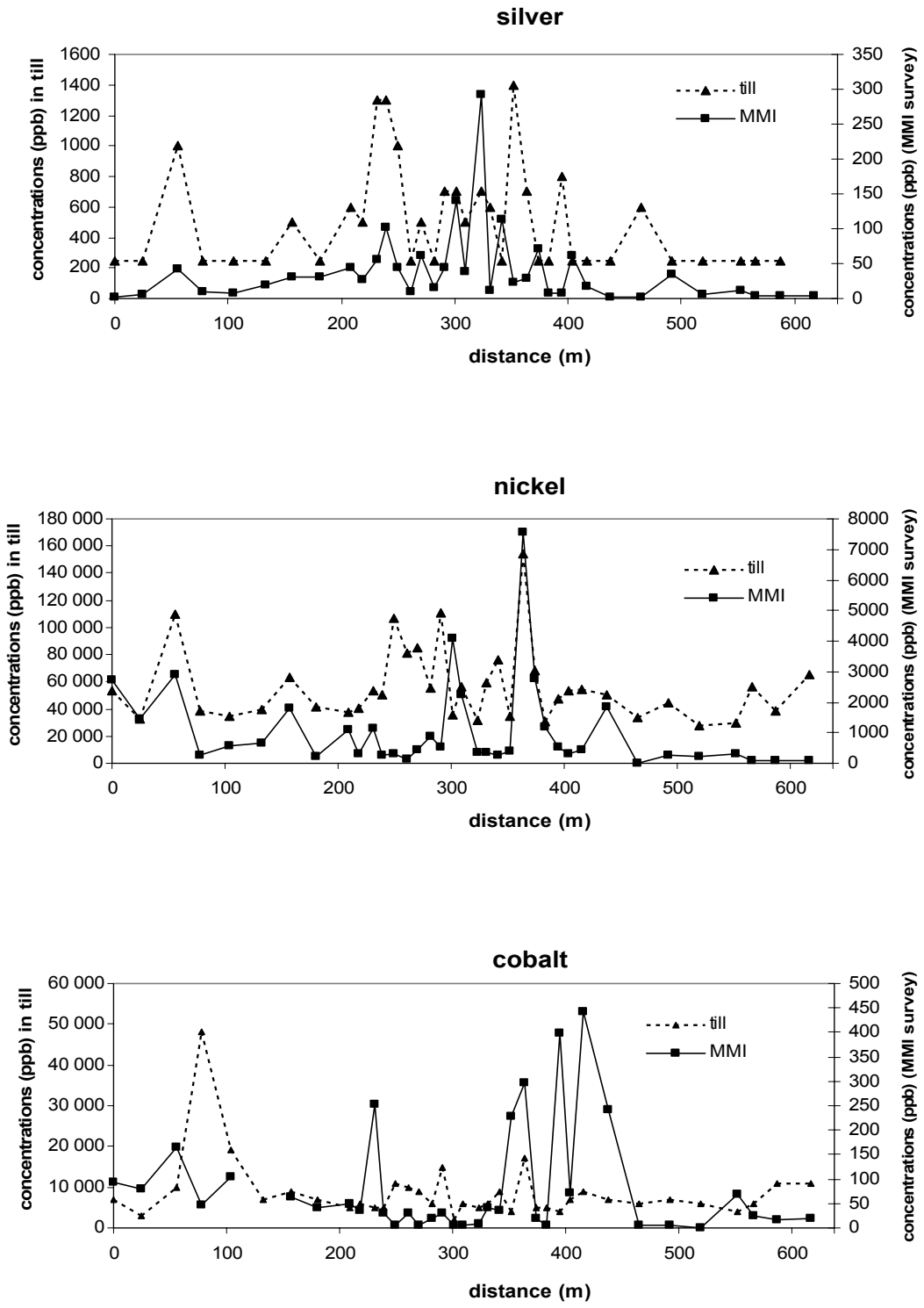


Figure 8. (b) *caption on previous page*

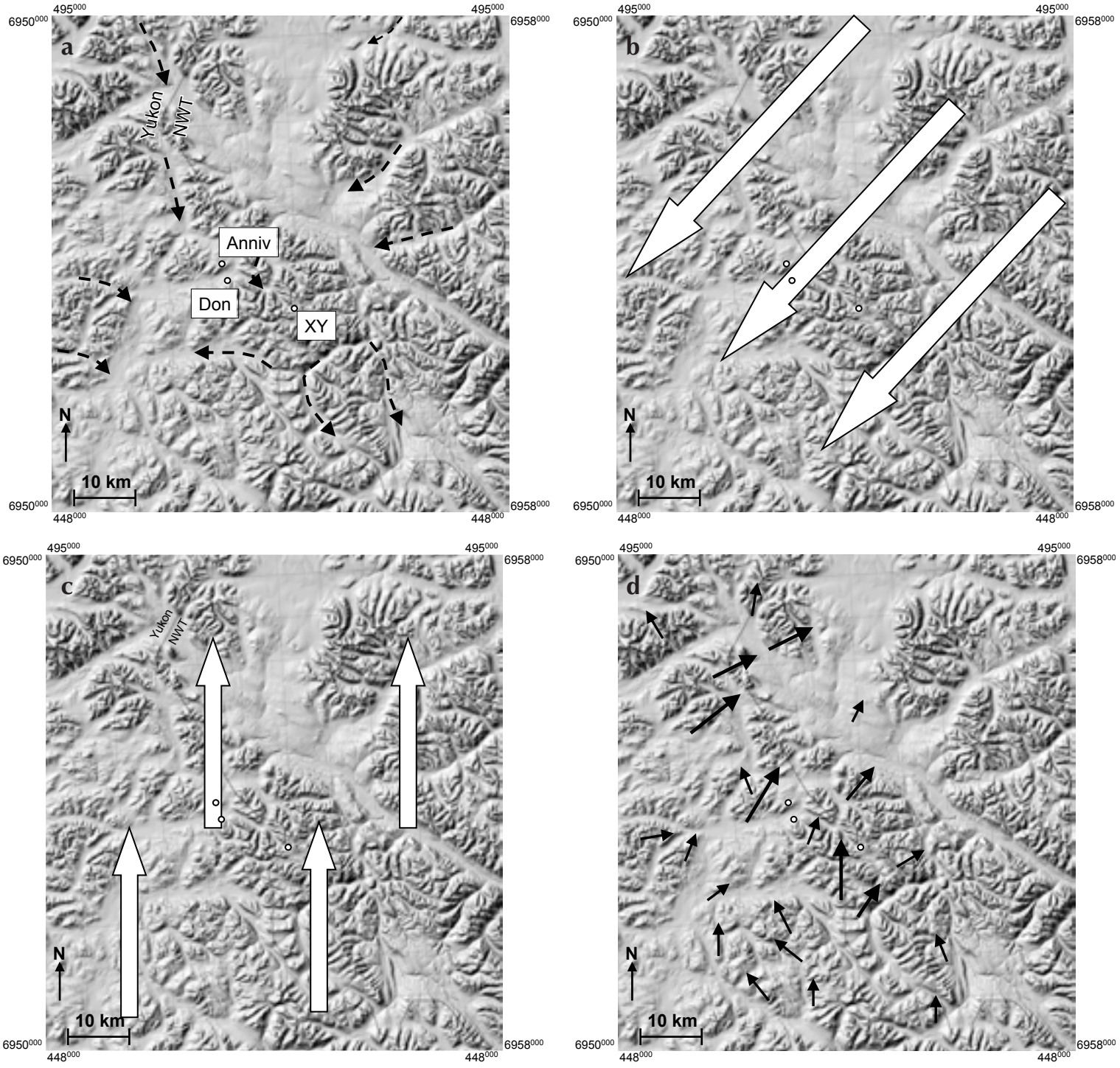


Figure 9. ***(a)*** *Alpine stage – topographically controlled ice-flow from local cirques. The only evidence for this is a groove found west of Anniv. Arrow size indicates strength of flow.* ***(b)*** *Nahanni stage – ice-flow originating east of the Nahanni River flowing southwest across Howard's Pass.* ***(c)*** *Logan stage – following an ice-divide migration across the study area, ice-flow was directed north across Howard's Pass.* ***(d)*** *Don stage I – as the ice thinned it became more topographically controlled. Ice-flow was still generally north-northeast across the study area.* ***(e)*** *Don stage II – When the ice thinned below topographic highs, it oriented parallel to the major valleys in Howard's Pass. It was during this phase that the till exposed in river sections (white triangles) was deposited.*

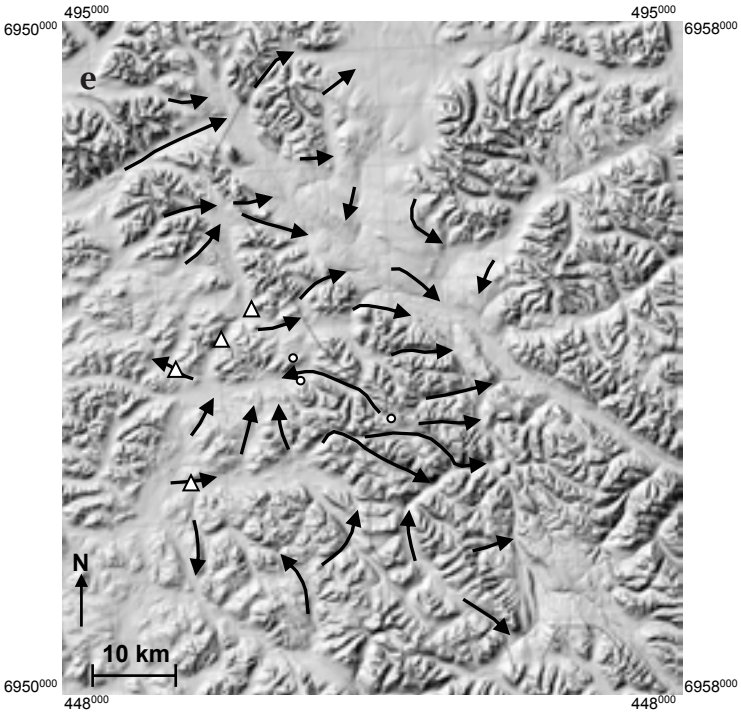


Figure 9. *continued from previous page*

surveys in addition to what the concentration ranges of various elements of interest were. For most elements, the most reactive interval was 30-40 cm. However, lead was more reactive between 0-10 cm. Both zinc and lead show significant peaks above the ore zone (Fig. 8). Other elements such as nickel, silver and cobalt also showed small anomalies over the ore zone. The average concentration of lead over the ore zone was 20 060 ppb, compared to 2880 ppb outside the ore zone. Zinc ranged from 17 260 ppb over the ore zone to 4580 ppb outside the ore zone (Fig. 8a). The trends from the till samples for lead, zinc and to a lesser extent, silver mimic those from the MMI survey. The concentrations of the till samples were significantly higher than the MMI samples, likely due to the different digestion techniques used.

DISCUSSION

ICE-FLOW STAGES

At least four stages of ice-flow occurred during the last glaciation. These stages corroborate Fulton's (1991) model of growth and decay for the Cordilleran Ice Sheet (CIS). The earliest of these (Alpine stage, Fig. 9a) involved alpine ice extending out of local cirques. While this stage is largely inferred, evidence was documented at one site where a glacial groove was crosscut by striations from a subsequent phase.

When the Selwyn lobe initially attained maximum thickness, the ice divide was positioned east of the Nahanni River, causing a southwestward flow across the study area (Nahanni stage, Fig. 9b). Multiple granodioritic boulders of various textures located at different elevations throughout Howard's Pass indicate that this flow covered the highest peaks in the study area. There are also streamlined bedrock ridges and striations that corroborate the Nahanni stage.

Following the Nahanni stage, the ice divide migrated to the southwest causing ice-flow to shift to the north (Logan stage; Fig 9c). This migration was likely due to increased accumulation on the windward side of the Selwyn lobe. Evidence for the subsequent northward flow from this stage are crag and tails near the Anniv camp airstrip, multiple sets of striations and rat-tails, and abundant meltwater channels at high elevations across Howard's Pass. The deflection of some striations and crag and tails around topographic highs indicate that this flow was at least somewhat topographically controlled.

During initial deglaciation, ice thinned until topography had a significant effect on ice-flow (Don stage, Fig. 9d, and 9e). Initially, ice flowed across the Nahanni River to the northeast. However, with increasing ablation, the ice eventually flowed down the Nahanni Valley to the southeast.

In the Don Valley, meltwater channels above ~1400 m above sea level (a.s.l.) indicate the ice sloped towards the northeast, which contrasts with westerly dipping channels below 1400 m a.s.l. As ice thinned further, it was unable to flow over the ridge adjacent to Anniv camp and instead flowed valley-parallel (Fig. 9e). In the latest stages, ice began to stagnate; eskers formed according to localized controls on subglacial hydraulics, mainly ice thickness, and likely do not represent significant ice-flow.

Several data indicate that Howard's Pass deglaciated by stagnation and downwasting before approximately 9000 ka BP (McDonald, 1983), rather than by frontal retreat into source areas. The only end moraines observed in the study area are located in cirques and are likely due to a small, local readvance following regional deglaciation. The lack of large, recessional moraines in the valley bottoms suggests linear retreat did not occur in these valleys. Instead, thick kame and kettle deposits in many valley bottoms indicate that ice melted in place. These deposits imply an uneven ice surface during melt, causing

pockets of coarser sediments to collect and form local topographic highs bounding lower energy deposition in lakes. These landforms are more likely to form with stagnant ice rather than flowing ice.

IMPLICATIONS FOR DRIFT PROSPECTING

The ice-flow history of Howard's Pass is significant for drift prospecting. Typically, the last phase of ice-flow is the most important for tracing anomalous geochemical signatures (Plouffe and Bond, 2004; Bond, 2007). However, the direction and distance that sampled material has been transported changes with elevation across the study area.

At lower elevations in the study area, the Don stage was the last phase of ice-flow. This stage was highly topographically dependant and likely remobilized material that had been previously transported by earlier ice-flows. Anomalies at low elevations are therefore more likely to be valley-parallel and may be more difficult to interpret as they contain sediment that could reflect transport during multiple stages of ice-flow. Conversely, at higher elevations, the ice-flow history is simplified and the Nahanni and Logan stages of ice-flow controlled drift transport. These flows would result in more fan- or amoeba-shaped anomalies. Unfortunately, the elevation at which the change occurs, from simple to complex ice-flow history, varies across Howard's Pass.

Locally, variations in ice-flow can affect drift prospecting. Ice-flow during the Don stages was simpler at XY camp than at Don camp. At the XY camp, ice emanated from cirques to the south and southwest and was directed by topography to the northwest across XY camp, and east down Placer Creek. As this ice melted, a small lake developed on the plateau where XY camp is currently located. This lake was ponded against ice in the valley to the northwest and fed by ice to the north and east.

The MMI survey over Anniv Central shows anomalous values of lead and zinc directly over near-surface mineralized bedrock (Fig. 8a). However, samples taken at the edge of the survey that overlie more deeply buried mineralization, are also unusually high for background concentrations (W. Grondin, pers. comm., 2007). These high background values suggest either that the MMI technique can recognize mineralization through approximately 200 m of non-mineralized bedrock and drift, or that background levels are unusually high because of abundant black shales in the area. If the survey edges are detecting deeply buried mineralization, then this geochemical cross-section provides important data into the concentration change with depth. The central lead and zinc anomaly would then be reflecting the near-surface mineralization, with the inferred faults possibly acting as conduits for ion transmission. Another MMI survey extending further off an ore zone is necessary to reveal the true background concentrations in the area and to test the penetration depth of MMI geochemistry through bedrock.

Other elements, such as nickel and cobalt, were anomalous over the ore zone only in MMI samples (Fig. 8b). Conversely, elements like silver were detected by both MMI and till geochemistry, but had more contrast in the MMI samples. The similarity between the anomalies found with these elements, and the anomalies found for lead and zinc, indicates that silver, nickel and cobalt are potential pathfinders in Howard's Pass.

CONCLUSIONS

A better understanding of the glacial history is vital to interpreting geochemical data in Howard's Pass. The earliest stage of ice-flow involved valley glaciers originating in local cirques. As these glaciers coalesced and developed into an ice sheet, the ice divide was centred east of the Nahanni River. The flow during this stage was southwest across Howard's Pass and completely covered the landscape.

Prior to deglaciation, the ice divide migrated across the study area and ice flowed dominantly north across Howard's Pass. As the ice sheet melted, increased topographic control channeled flow parallel to the major valleys. Deglaciation in Howard's Pass commenced through rapid starvation and widespread stagnation of the ice sheet.

The complicated glacial history of Howard's Pass makes tracing geochemical anomalies difficult. A MMI geochemistry case study completed directly over a known deposit resulted in anomalous values of lead, zinc, silver, nickel and cobalt. This result possibly indicates that MMI geochemistry can penetrate through at least 200 m of bedrock, and potentially reveals multiple elements that are potential pathfinders for lead and zinc in Howard's Pass.

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