

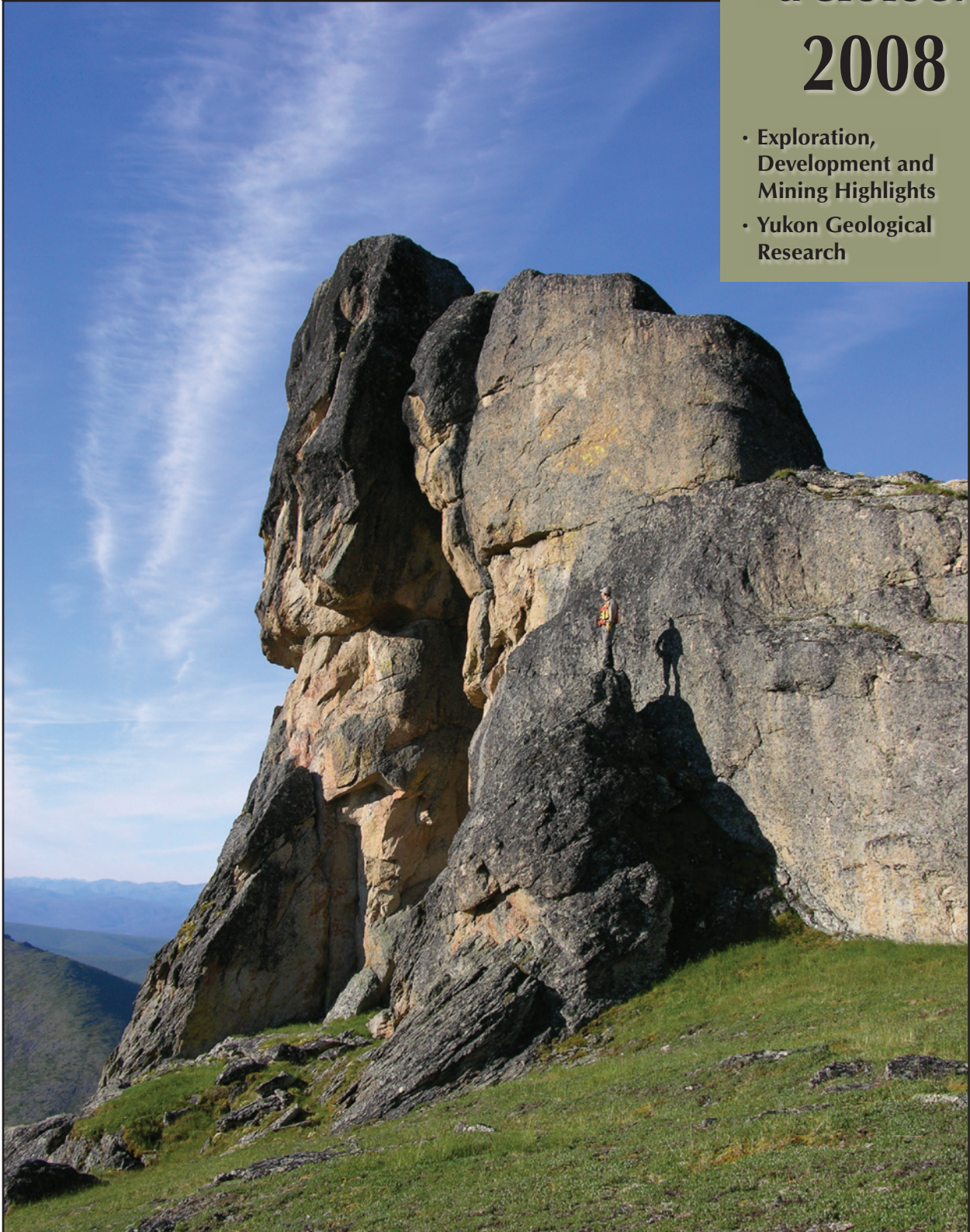
Energy, Mines and Resources • *Yukon Geological Survey*

YUKON

EXPLORATION & GEOLOGY

2008

- Exploration, Development and Mining Highlights
- Yukon Geological Research



YUKON
EXPLORATION
& GEOLOGY
2008

Edited by
L.H. Weston, L.R. Blackburn and
L.L. Lewis

Yukon Geological Survey
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FRONT COVER PHOTOGRAPH: The mega-tors of Britton Ridge, east of Wellesley Lake, southwest Yukon. Photo by Lesley Dampier.

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 31st volume of the series.

YEG 2008 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 Yukon. Their assistance and patience is sincerely appreciated.

After nine years as Chief Editor, Diane Emond has stepped down and has taken a leave of absence from the Yukon Geological Survey to pursue a diploma in Practical Nursing. Diane began as a staff geologist for the Exploration and Geological Services Division in 1983. She has been a mentor and a wonderful colleague; her enthusiasm, strong work ethic and positive nature will be greatly missed. We wish Diane all the best in her future endeavours. This year our editing team consisted of Lauren Blackburn, Lara Lewis and I. I thank my co-editors for their dedication, patience and hard work; they were truly committed while under great pressure. We would also like to thank the Translation Bureau, Public Works and Government Services Canada for translating the French abstracts. Appreciation is also extended to Maurice Colpron and Rachelle Dufour of the Yukon Geological Survey (YGS) for their able assistance in the review of French translations of abstracts.

Wynne Krangle and Peter Long of K-L Services continue to provide excellent service in putting this publication 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.

This year saw the loss of several more colleagues and dear friends. We would like to dedicate this year's Yukon Exploration and Geology to all those geologists, prospectors and colleagues who are no longer with us today but who will always remain in our memories.

We welcome any input or suggestions that you may have to improve future YEG publications. Please contact me at (867) 667-8701, or by e-mail at leyla.weston@gov.yk.ca.

Leyla Weston

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 31^{ème} de la série.

YEG 2008 contient une mise à jour sur l'exploitation et l'exploration minière, 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 du secteur privé ainsi que 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.

Après neuf ans au poste de rédactrice en chef, Diane Emond a pris un congé de la Commission géologique du Yukon pour poursuivre un diplôme d'infirmière. Diane a commencé sa carrière en tant que géologue avec la Division de l'exploration et des services géologiques en 1983. Elle fut pour moi un mentor et une superbe collègue de travail; son enthousiasme, son éthique de travail, et son optimisme nous manqueront beaucoup. Cette année notre équipe de rédaction comprenait Lauren Blackburn, Lara Lewis et moi-même. Je tiens à remercier mes corédactrices pour leur engagement, leur patience et leur bon travail; elles se sont vraiment dévouées à leurs tâches malgré la pression des échéances. Nous remercions le Bureau de la traduction, Travaux publics et Services gouvernementaux du Canada, pour la traduction française des résumés. Nous remercions également Maurice Colpron et Rachelle Dufour de la Commission géologique du Yukon pour leur aide avec la révision des traductions françaises.

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 et la mise en page tout en respectant les échéances serrées. Sherry Tyrner de l'Imprimeur de la Reine a, pour sa part, veillé au bon déroulement de l'impression.

Plusieurs de nos collègues et bons amis sont décédés en 2008. Nous dédions ce YEG 2008 à tous ces géologues, prospecteurs et collègues qui ne sont plus avec nous aujourd'hui mais qui persistent dans nos mémoires.

Pour tout commentaire ou suggestion afin d'améliorer les futures publications du YEG, vous être priés de communiquer avec moi par téléphone au (867) 667-8701 ou par courriel à l'adresse suivante: leyla.weston@gov.yk.ca.

Leyla Weston



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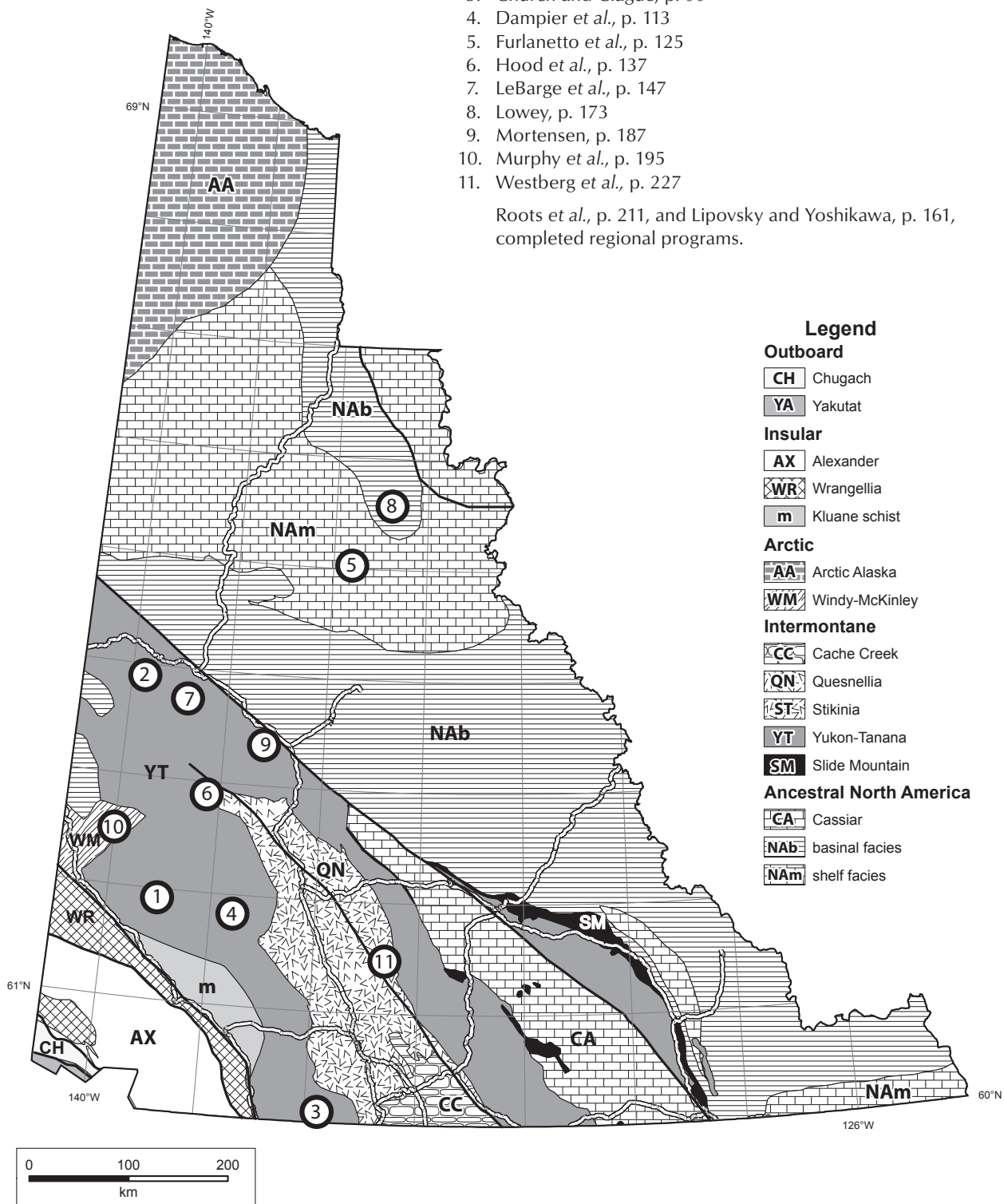
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CONTRIBUTING AUTHORS WORK LOCATIONS

1. Bunbury and Gajewski, p. 77
 2. Calmels and Froese, p. 85
 3. Church and Clague, p. 99
 4. Dampier *et al.*, p. 113
 5. Furlanetto *et al.*, p. 125
 6. Hood *et al.*, p. 137
 7. LeBarge *et al.*, p. 147
 8. Lowey, p. 173
 9. Mortensen, p. 187
 10. Murphy *et al.*, p. 195
 11. Westberg *et al.*, p. 227
- Roots *et al.*, p. 211, and Lipovsky and Yoshikawa, p. 161, completed regional programs.





Prospector J.P. Ross

1948 TO 2008

John Peter Ross, known among friends as J.P., died suddenly at his home in Whitehorse, Yukon in early May, 2008.

J.P. was a Yukon resident for nearly 35 years. He was a dedicated member of the Yukon Prospectors' Association, where, at the time of his death, he was vice-president.

Before coming to the Yukon, he graduated from McGill University in 1970 with a Bachelor of Science in chemistry and a minor in biology. He began his Yukon career at the United Keno Hill Mines' mill at Elsa where he worked on five different occasions.

Inquisitive, he began exploring the northland as soon as he set foot in the Yukon. He read prodigiously and interviewed prospectors and miners who sparked his interest in pursuing independent mineral prospecting as a primary vocation in 1985. A smart business person, his new-found career began to flourish. In 1995, the Yukon Prospectors' Association selected John Peter Ross as Prospector of the Year. The award, based on a prospector's successes in uncovering new mineral discoveries, recognized his good fortune in finding the Killermun Lake gold property in the Ruby Range-Aishihik area in the vicinity of Haines Junction.

J.P. liked being out alone where there were no pressures, and he enjoyed listening to the sounds of silence. "There's a certain music in nature — the wind, rock avalanches, bears at 3 a.m., gurgling streams and wind in the grass. Even the stars seem to have a sound to them."

He will be missed by his prospecting friends. Besides his vast interest and knowledge on an eclectic array of subjects, J.P. shared his information willingly, indeed an extraordinary trait for a person operating in the highly competitive prospecting and exploration business where most people keep their secrets close to their vest.

J.P. was definitely his own person. His staunch individualism earned him rite of passage into Jim Robb's illustrious Colourful Five Percent club.

Jane Gaffin



George W. Gilbert

1925 TO 2008

George Gilbert passed away in Whitehorse, February 14, 2008, at the age of 82. He was a man of many professions, all of them self-taught.

George was a geologist, hard-rock miner, prospector, naturalist, as well as a government inspector of mining, fisheries and land use. He was a published author and self-described rock-hound. He counted amongst his friends not only regular folk, but those who served in high office such as Ed Schreyer, Governor General of Canada; James Smith, Commissioner of Yukon; and various heads of state and scientific organizations from across the world.

Born in Vancouver, British Columbia, in 1934 George moved with his family to the Cariboo mining town of Wells when it was just being established. He joined the Air Force near the end of World War II and served two years, returning to work at the Cariboo Gold Quartz (CGQ) mine in 1946. George eventually became the manager of the CGQ mine.

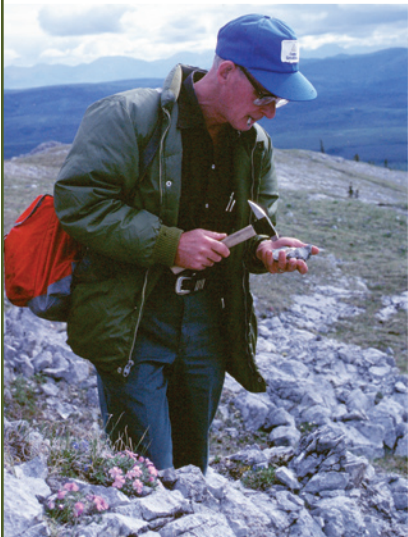
In 1967, when the CGQ mine ceased operations, George moved to Whitehorse to take on the position of Newmont Mining's resident geologist. While with Newmont, George and his prospecting crews explored many grassroots properties and mineral deposits in Yukon, including those in the Kluane Ranges and the Bonnet Plume area.

In 1970, George joined Keno Hill Exploration Ltd. and managed several exploration programs for three years before joining the Geology Division of the Department of Indian Affairs and Northern Development in the mid-1970s. He eventually became the Chief Mining Inspector of the Placer Mining Division, where he remained until he retired in 1989. He maintained his contacts with the mining industry and former colleagues throughout his retirement, even attending the annual Yukon Geoscience Forum two months before his passing.

George was a loving father and friend and will be greatly missed by all of his family, his colleagues and friends, and anyone who ever had the pleasure of his company. *Bill LeBarge*



*George inspecting claims.
(Photo by Robin Armour)*



*George prospecting.
(Photo by Robin Armour)*



*Part of Ishpa Glacier, British Columbia
(Courtesy of "Kicked by a dead moose" (G. Gilbert))*

EXPLORATION, DEVELOPMENT AND MINING HIGHLIGHTS

Yukon Hardrock Mining, Development and Exploration Overview 2008

Mike Burke, Lara Lewis and Steve Traynor
Yukon Geological Survey

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Yukon Placer Mining and Exploration Overview 2008

William LeBarge
Yukon Geological Survey

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Yukon Oil and Gas Overview 2008

Bernie Adilman
Oil and Gas Resources, Energy, Mines and Resources, Government of Yukon

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Yukon Mining Incentives Program 2008

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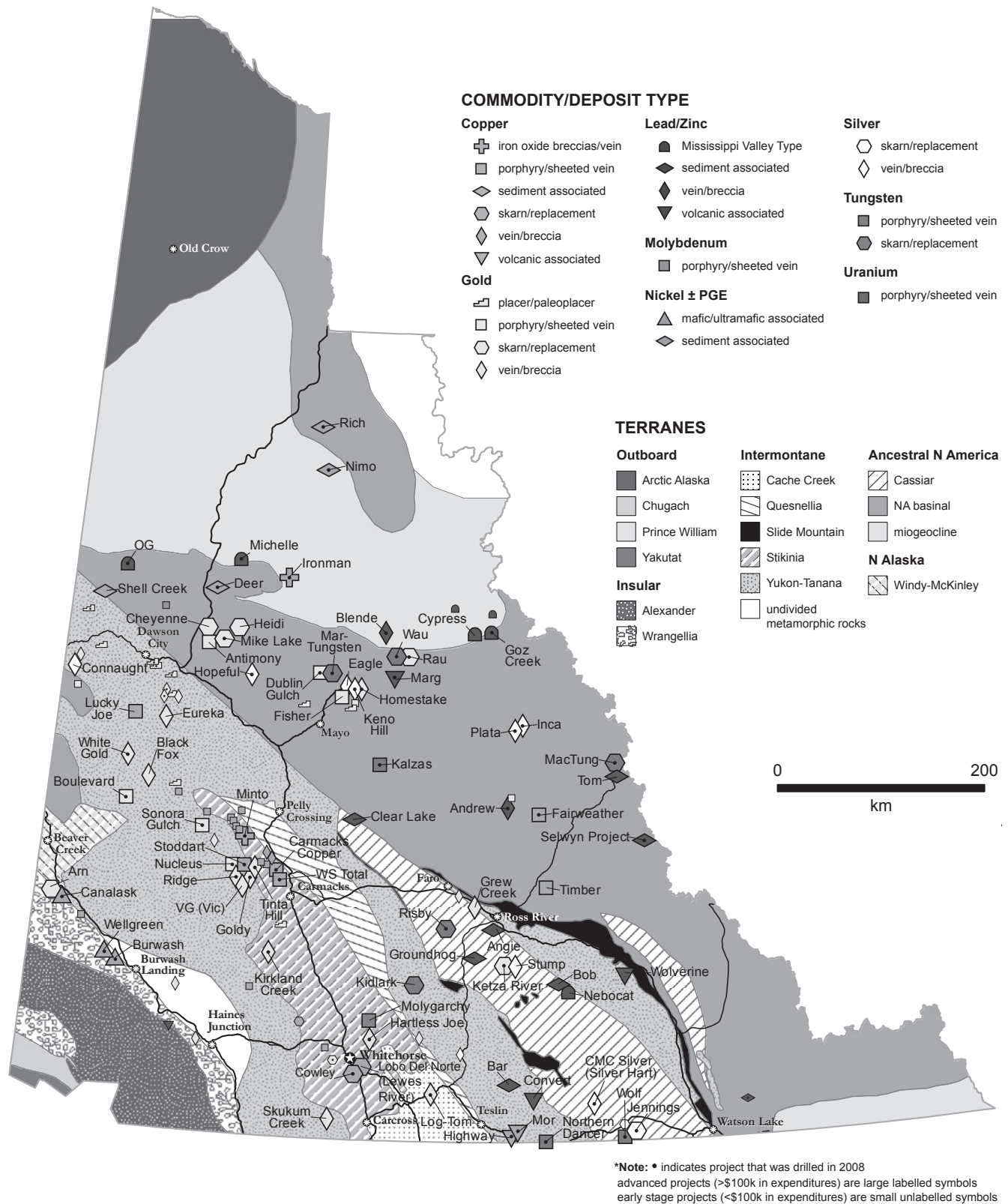


Figure 1. Yukon advanced exploration projects, 2008.

Yukon Hardrock Mining, Development and Exploration Overview 2008

Mike Burke¹, Lara L. Lewis and Steve Traynor
Yukon Geological Survey

Burke, M., Lewis, L. and Traynor, S., 2009. Yukon Mining, Development and Exploration Overview 2008. *In: Yukon Exploration and Geology 2008*, L.H. Weston, L.R. Blackburn and L.L. Lewis (eds.), Yukon Geological Survey, p. 2-37.

ABSTRACT

Mineral exploration in Yukon in 2008 remained strong – exploration expenditures were estimated to be \$100 million. Several advanced exploration projects returned significant drill results, highlighting the under-explored potential of these properties even at an advanced stage of exploration. Yukon’s untapped mineral potential is exemplified by several significant new discoveries made on exploration properties this year. Mine development expenditures were incurred at the Minto copper-gold-silver mine where the mill underwent a phase 3 expansion, and at the Wolverine zinc-silver-copper-gold-lead deposit where development has begun and production is scheduled for the 3rd quarter of 2010.

There were over 150 active hard rock exploration projects in Yukon: 73 projects recorded expenditures of greater than \$100 000, and 22 spent more than \$1 million. The remaining projects were regional or grassroots generative projects.

RÉSUMÉ

En 2008, le secteur de l’exploration minière au Yukon est demeuré fort, et les dépenses liées à l’exploration sont estimées à 100 millions de dollars. Plusieurs projets d’exploration avancés ont donné lieu à des forages aux résultats importants, ce qui met en évidence le potentiel peu exploré de ces propriétés de prospection même à un stade d’exploration avancé. Le potentiel minier non exploité du Yukon est illustré par plusieurs nouvelles découvertes importantes faites sur des propriétés de prospection cette année. Des dépenses ont été effectuées afin de mettre en valeur la mine cupro-auri-argentifère Minto, où l’usine de concentration a fait l’objet d’un agrandissement (phase 3), et la mine de zinc, d’argent, de cuivre, d’or et de plomb Wolverine, où les travaux de mise en valeur sont commencés et où la production est prévue pour le troisième trimestre de 2010.

On dénombre plus de 150 projets actifs d’exploration des roches métamorphiques au Yukon, dont 73 ont eu des dépenses supérieures à 100 000 \$ et 22 ont dépensé plus d’un million de dollars. Les autres projets sont des projets génératifs locaux ou régionaux.

¹mike.burke@gov.yk.ca

INTRODUCTION

The Yukon mineral industry experienced a very successful year: Minto Mine completed its first full year of mining, development occurred at a number of deposits, and exploration was directed at a wide variety of commodities and deposit types. Expenditures are estimated at \$110 million for exploration (Figs. 1 and 2), and mine development costs were approximately \$10 million. The mineral potential of Yukon is highlighted by the outstanding exploration results that continue to expand resources at the high-grade Minto deposit. Other known deposits in Yukon that benefited from large exploration programs consistently had results that expanded or upgraded resources. In addition, there have been several new discoveries made on Yukon exploration properties this year, which highlights the territory's untapped mineral potential and ability to produce significant new mineral discoveries.

Mine development expenditures were incurred at the Minto copper-gold-silver mine, with phase 2 expansion of the mill to 2400 tonnes per day and subsequent phase 3 expansion to 3200 tonnes per day, and at the Wolverine zinc-silver-copper-lead-gold deposit, where upgrading of road access to the mine, site preparation for the construction camp, and diversion ditches in the tailings pond area were completed. Final development of the Wolverine polymetallic deposit will begin in 2009, with a production target of the 3rd quarter of 2010. The Carmacks Copper deposit, a copper-silver-gold project, is in the final stages of permitting, and a production decision is expected to be made in 2009. The Bellekeno silver-lead-zinc deposit is in the final stages of exploration to upgrade resources in support of a production decision and final permitting of the project in 2009. Claim staking remained at high levels, with a total of 13 834 claims staked in 2008 (Fig. 3). The number of claims in good standing rose to a total of 79 734 by year-end (Fig. 4).

The under-explored potential of Yukon is demonstrated by the quality of new discoveries that underwent drilling for the first time in 2008, or received further work based on significant drill results in 2007. Drilling on previously undrilled properties produced consistent results in a number of holes on the White Gold,

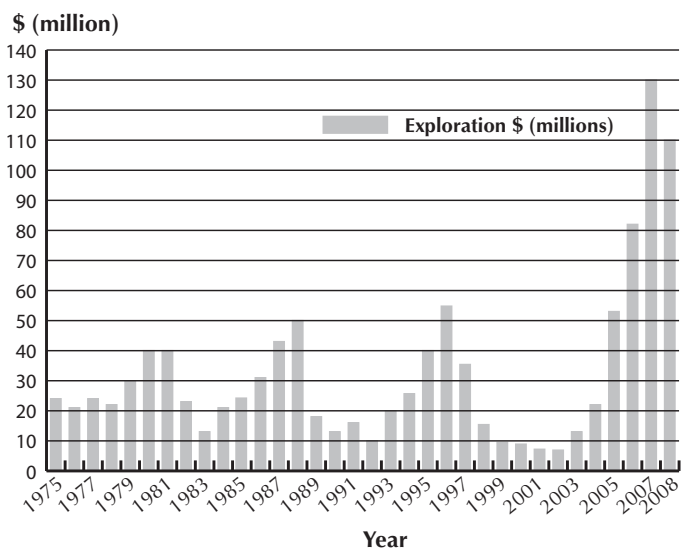


Figure 2. Exploration and development expenditures in Yukon, 1972 to 2008.

Rau and Ridge (Freegold Mountain) precious metals properties. Follow-up drilling on the Sonora Gulch and Mike Lake precious metals projects confirmed the significance of discovery holes drilled in 2007. The discovery of new zones of mineralization, or perhaps the recognition of a much larger mineralized system with discrete higher grade areas, was made in 2008 at the Minto copper project. At the Andrew zinc-lead project, the Darcy zone was intersected by several holes when following up on a single historical drillhole. The Michelle zinc-lead property returned several more drill intersections on the heels of a 2007 discovery hole, and drilling at the huge Selwyn zinc-lead project (Howards Pass) continued to intersect new areas of mineralization well outside areas of known mineralization.

The reader is reminded that this exploration overview is by no means a comprehensive overview of the activity in Yukon. Many results are still pending at the publication

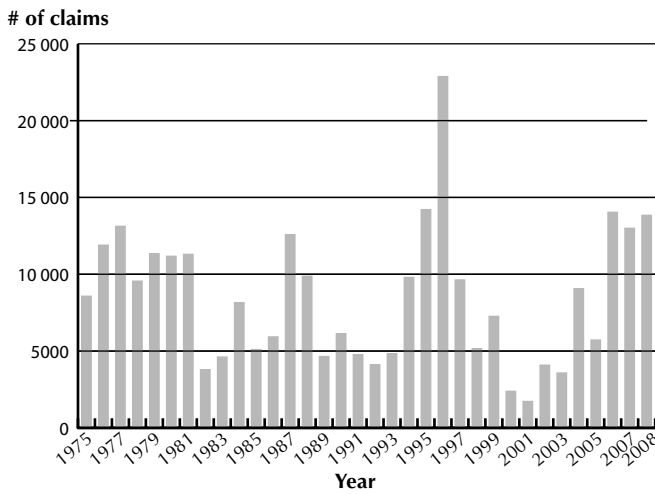


Figure 3. Mineral claims staked, 1976-2008.

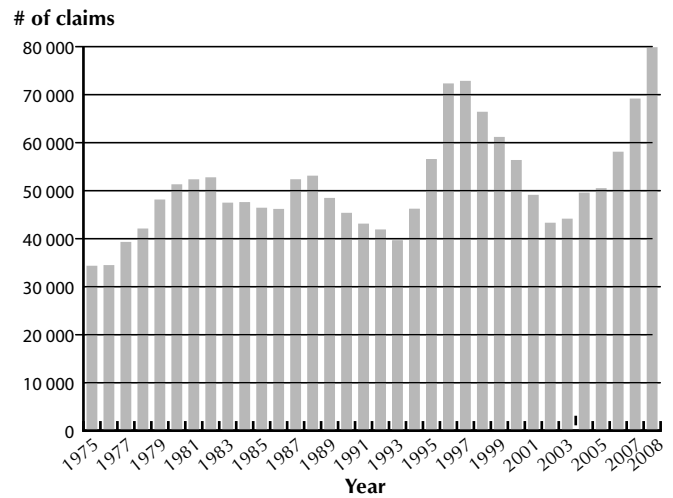


Figure 4. Mineral claims in good standing, 1976-2008.

deadline of this volume and, thus, the contents are preliminary in nature. This publication is available on the Yukon Geological Survey (YGS) website (www.geology.gov.yk.ca) in colour. Links to company websites are available in this report. These websites contain much more comprehensive information including, in many cases, up-to-date results, maps and sections.

MINING AND MINE DEVELOPMENT

The **Minto** mine (Yukon MINFILE 1151 012) is a high-grade copper-gold deposit (Fig. 5) operated by Capstone Mining Corp. (www.capstonemining.com). Production at Minto for 2008 is forecast to be 24.9 million kg (55 million pounds) of copper, 693 530 g (22 300 ounces) of gold and 10 138 600 g (326 000 ounces) of silver. Cash costs of production to the end of the 3rd quarter of 2008 were US\$1.37 per pound, but these costs are expected to drop significantly due to higher copper production, reduced stripping requirements, recently completed connection to grid electrical power, and falling input costs, such as fuel. Current total resources for all deposits at the Minto mine



Figure 5. Open pit at Minto mine site.

Table 1. NI 43-101-compliant resource for Minto deposit (2008).

Class	Tonnage	Grade*
measured	11.4 Mt	1.77% Cu, 0.66 g/t Au, 6.85 g/t Ag
indicated	7.83 Mt	0.91% Cu, 0.29 g/t Au, 3.24 g/t Ag
inferred	15.07 Mt	0.88% Cu, 0.25 g/t Au, 2.61 g/t Ag

*0.5% cut-off grade

7(Table 1) have increased 140% in the last two years and do not incorporate any of the 2008 drilling results (see Table 22, page 21) which hit significant ore-grade intersections outside of the known resource areas.

Yukon Zinc Corporation (www.yukonzinc.com) began development of the **Wolverine** project (Yukon MINFILE 105G 072), which has a production target of the 3rd quarter of 2010. Development includes upgrading the mine access road, preparing foundations for the camp, and completing civil works including diversion ditches for the tailings pond. In July 2008, Yukon Zinc Corporation was acquired by Jinduicheng Molybdenum Group Ltd. and Northwest Nonferrous International Investment Company Ltd., and is now operated as a private company. Jinduicheng is the largest producer of molybdenum and associated products in Asia and reportedly the third largest molybdenum producer in the world. It is publicly traded on the Shanghai Stock Exchange after a recent US\$1.3 billion initial public offering. Jinduicheng's operations are concentrated in Shaanxi province, China. Northwest represents the Shaanxi state geological bureau. In terms of revenue and technical capacity, Northwest is one of the top five exploration and mining bureaus in China. Wolverine is a high-grade polymetallic volcanogenic massive sulphide deposit in the Finlayson Lake District of east-central Yukon. It remains open down-dip under ground held by Teck Corporation. Yukon Zinc Corporation has several other property holdings in the Finlayson Lake District with considerable exploration potential.

EXPLORATION

PRECIOUS METALS - GOLD

SKARN/REPLACEMENT

Table 2. NI 43-101-compliant resource for Ketz River deposit (2008).

Class	Tonnage	Grade (g/t Au)
measured	712 200 t	6.4
indicated	3 369 500 t	4.61
inferred	1 075 600 t	3.26

Yukon Nevada Gold Corporation (www.yukon-nevadagold.com), formerly YGC Resources Ltd., continued with exploration and completed geotechnical work required for mine planning and metallurgical test work at its **Ketz River** (Yukon MINFILE 105F 019) gold property in south-central Yukon. The company is working on a pre-feasibility study for mining the sulphide deposits (Table 2) at the mine, which produced over 3 100 000 g (100,000 ounces) of gold from oxide deposits in 1988-1990. Mineralization at Ketz River consists of massive pyrrhotite-pyrite replacement manto-style bodies hosted in Lower Cambrian limestone, and quartz-pyrrhotite-pyrite veins (Shamrock area) hosted in a slightly older Lower Cambrian argillite. Exploration in 2008 consisted of 30 151 m of drilling in 223 holes (Table 3) which was successful in expanding the known mineral resources. Exploration results from 2007 and 2008 will be incorporated into a future resource estimate.

Table 3. Selected 2008 drill intersections for Ketzta property.

Drillhole	Zone	Depth of intersection (m)	Intersection
Manto			
KR08-1362	Peel	32.6	14.47m @ 8.95 g/t Au
KR08-1365	Peel	19.7	3.8 m @ 20.6 g/t Au
KR08-1378	Tarn	11.3	9.14 m @ 7.13 g/t Au
KR08-1347	Penguin	48.7	4.0 m @ 6.60 g/t Au
KR08-1288	Break	20.4	1.9 m @ 22.4 g/t Au
KR08-1270	Lab	54.1	2.87 m @ 16.8 g/t Au
Shamrock			
KR08-1293	QB vein	44.8	7.27 m @ 56.0 g/t Au
KR08-1367	QB vein	39.5	3.6 m @ 21.2 g/t Au
KR08-1304	Gully vein	51.2	6.77 m @ 19.1 g/t Au

Dynamite Resources Ltd. (www.dynamiteresources.com) explored the **Mike Lake** gold-copper-tungsten property (Yukon MINFILE 116A 012), which covers a number of intrusion-related gold targets associated with Cretaceous Tombstone Suite stocks, dykes and sills. The property is located 25 km north of the former producing Brewery Creek gold mine. The company concentrated its efforts on the Skarn Ridge area with an extensive drill program that consisted of 10 004 m of helicopter-supported diamond drilling in 68 holes (Table 4). The mineralization at Skarn Ridge was discovered in 2007, in diamond drillhole SK-2007-01, which returned 89.31 m grading 0.61% Cu, 1.383 g/t Au and 13.6 g/t Ag. Mineralization consists of an earlier pyroxene-scapolite and pyroxene-garnet skarn with pyrrhotite-chalcopyrite and coarse scheelite mineralization associated with a later cross-cutting skarn vein event.

Table 4. Selected 2008 drill intersections for Skarn Ridge, Mike Lake property.

Drillhole	Depth of intersection (m)	Intersection
SKDH08-17	43.1	23.85 m @ 0.26% Cu, 1.97 g/t Au
SKDH08-18	23.1	21.85 m @ 0.29% Cu, 3.53 g/t Au
SKDH08-19	37.3	75.89 m @ 0.69% Cu, 2.86 g/t Au
SKDH08-28	18.2	33.01 m @ 0.22% Cu, 1.62 g/t Au

Atac Resources (www.atacresources.com) made a significant new discovery of skarn and replacement-style gold mineralization on its **Rau** property (Yukon MINFILE 106D 005), located east of the Keno Hill area in central Yukon. The discovery was made following up on a 99th percentile regional stream sediment survey sample (Hornbrook *et al.*, 1990) of 150 ppb gold plus elevated tungsten. Following conventional soil geochemistry and Variable Time-domain Electromagnetic (VTEM) airborne surveys, the property was drilled for the first time in 2008; the discovery hole returned an intersection of 68.7 m grading 1.24 g/t gold in replacement-style mineralization within a stratabound carbonate horizon. A total of 3423 m of drilling was completed in 18 holes with most of the significant assay intervals (Table 5; Fig. 6) clustered in a 300 by 200 m zone at the west end of the drill area. The main gold zone is one of a series of thick sulphide-rich horizons vertically stacked near the crest of a broad anticline of dolomitized limestone. The area of drilling is

located along the trend of the anticline approximately 2.7 km from a high-level Late Cretaceous pluton. The area is within a 6 km trend of anomalous soil geochemistry and coincident geophysical anomalies.

Table 5. Selected 2008 drill intersections for the Rau property.

Drillhole	Depth of intersection (m)	Intersection
Rau08-02	52.7	68.7 m @ 1.24 g/t Au
Rau08-03	9.1	53.4 m @ 1.73 g/t Au
Rau08-04	98.6	71.6 m @ 1.59 g/t Au
Rau08-05	71.5	78.5 m @ 1.71 g/t Au
Rau08-06	6.7	62.0 m @ 1.50 g/t Au
Rau08-07	172.9	65.0 m @ 1.52 g/t Au
Rau08-016	19.8	46.4 m @ 2.92 g/t Au



Figure 6. Rau property drill core (DDH08-05) with arsenopyrite, pyrite and pyrrhotite mineralization.

VEIN/BRECCIA

A significant new gold discovery was made by Underworld Resources (www.underworldresources.com) on the **White Gold** property (Yukon MINFILE 1150 011,012), 90 km south of Dawson, which was drilled for the first time in 2008 (Fig. 7). Two near-surface gold mineralized zones – the Golden Saddle and Arc – were intersected in drilling. Both zones are open in all directions for expansion. The discovery hole on the Golden Saddle zone returned an impressive 4.03 g/t Au over 19.58 m, and the discovery hole on the Arc zone intersected 1.18 g/t Au over 28.5 m. Drilling has traced continuous gold mineralization at Golden Saddle for



Figure 7. Geologist Al Doherty and prospector Shawn Ryan examine visible gold in core at the White Gold property.

450 m along strike and to 170 m down-dip. The Arc zone soil anomaly, which is characterized by gold values exceeding 80 ppb, extends over 2 km. The two drillholes that intersected mineralization on the Arc Zone were located 600 m apart (Table 6). The two-phase drilling program on the property consisted of 3431 m in 27 holes. Mineralization consists of quartz veins and breccia zones with minor pyrite and arsenopyrite associated with low-angle thrust faulting hosted in altered gneiss and schist of the Yukon-Tanana terrane. The property has been extensively soil-sampled and contains several more areas of anomalous geochemistry that are still untested by drilling. Underworld completed additional geological and structural mapping on the property and has financed the 2009 drilling program.

Table 6. Selected 2008 drill intersections for the White Gold property.

Drillhole	Depth of intersection (m)	Intersection
Golden Saddle zone		
WD08-04	14.5	18.08 m @ 4.35 g/t Au
WD08-013	63.6	24.58 m @ 5.60 g/t Au
WD08-021	96.0	50.70 m @ 3.10 g/t Au
WD08-24	from surface	15.0 m @ 2.91 g/t Au
Arc zone		
WD08-14	from surface	28.5 m @ 1.18 g/t Au
WD08-17	100.0	29.0 m @ 1.47 g/t Au

The **Sonora** property (Yukon MINFILE 115J 008) of Northern Tiger Resources (www.northerntigerresources.com) is host to yet another new gold discovery in Yukon. Drilling in 2008 consisted of 10 holes for 2238 m (Table 7). The Nightmusic zone returned several intersections including a 4.8 m intercept with visible gold grading 2.31 g/t Au, 19.8 g/t Ag and 0.737% Cu. The drilling was following up on a single

drillhole in 2007 that intersected gold and silver epithermal-style mineralization occurring adjacent to an ultramafic body. The Nightmusic zone is characterized by an extensive soil geochemical anomaly which extends for over 2 km along the southern contact of an ultramafic body. This ultramafic body crosses the headwaters of Sonora Gulch, an area known for producing spectacular gold-tetradymite nuggets. Northern Tiger also completed drilling on the Amadeus zone, which is centred on a Cretaceous granitic stock, where previous drilling intersected gold-silver mineralization. The company conducted geochemical and geological programs on several other claim holdings in the Dawson Range acquired through an exploration alliance with Minto Explorations, a wholly owned subsidiary of Capstone Mining Corp. (formerly Sherwood Copper Corporation), operator of the nearby Minto copper-gold-silver mine.

Table 7. Selected 2008 drill intersections for the Sonora property.

Drillhole	Depth of intersection (m)	Intersection
Nightmusic zone		
SG-08-25	42.7	1 m @ 0.35 g/t Au, 57.3 g/t Ag, 0.58% Cu
	51.7	2 m @ 1.41 g/t Au, 2 g/t Ag
	95.7	2 m @ 0.96 g/t Au, 17.4 g/t Ag
	108.5	4 m @ 0.52 g/t Au, 16.8 g/t Ag, 0.05% Cu
	117.4	4.8 m @ 2.31 g/t Au, 19.8 g/t Ag, 0.74% Cu
	160.0	1.4 m @ 0.91 g/t Au, 13.8 g/t Ag, 0.07% Cu
SG-08-27 including	70.0	26.6 m @ 4.96 g/t Au, 11.9 g/t Ag, 0.23% Cu
	70.0	4 m @ 25.76 g/t Au, 6.5 g/t Ag
Amadeus zone		
SG-08-31	64.0	8 m @ 0.52 g/t Au, 16.7 g/t Ag
	154.0	31 m @ 1 g/t Au, 4.2 g/t Ag
Jupiter zone		
SG-08-26	216.5	2 m @ 1.18 g/t Au, 81.9 g/t Ag

Northern Freegold Resources (www.northernfreegold.com) completed an extensive program on its **Freegold Mountain** property including diamond drilling of 97 holes totalling 22 773 m on five different targets within their extensive road-accessible land package in the southern Dawson Range. The **Nucleus** zone (Yukon MINFILE 115I 107) consists of Cretaceous granodiorite sills intruding metasedimentary rocks, which were later intruded by quartz-feldspar porphyry dykes. Drilling in 2008, consisting of 13 287 m (53 holes), was directed at defining a NI 43-101-compliant resource in the low-grade bulk-tonnage Nucleus zone. Early season drilling results were spectacular due to the discovery of high-grade zones consisting of massive sulphide mineralization with visible gold (Table 8). Mineralization in the Nucleus zone occurs in all rock types (Fig. 8) and typically consists of: sulphide-bearing hydrothermal breccias; quartz, quartz-sulphide and sulphide veins and stockworks; disseminated sulphides; and, the newly discovered massive sulphide skarn-type mineralization. At the **Goldy** zone (Yukon MINFILE 115I 112), epithermal-style quartz-sulphide veining, silicified zones, and extensive alteration are associated with a shear zone; altered quartz-feldspar-porphyry dykes were intersected in drill core. A total of 1500 m was drilled in eight holes. Drilling in 2008 built on previous

Table 8. Selected 2008 drill intersections for Freegold Mountain.

Drillhole	Depth of intersection (m)	Intersection
Nucleus zone		
GRD08-68	42.2	37.8 m @ 10.41 g/t Au, 0.29% Cu
GRD08-73	102.4	46.96 m @ 9.6 g/t Au, 0.22% Cu
Goldy zone		
GY08-23	3.4	4.72 m @ 3.47 g/t Au
GY08-27	25.0	23.7 m @ 2.84 g/t Au
Ridge zone		
08RZ-03	37.6	1.4 m @ 1.88 g/t Au, 11.0 g/t Ag, 0.17% Cu
08RZ-04	71.8	24.5 m @ 1.18 g/t Au, 36.6 g/t Ag, 0.11% Cu, 1.2% Pb, 0.53% Zn
08RZ-09	100.3	0.9 m @ 10.62 g/t Au, 243.0 g/t Ag, 0.31% Cu, 2.08% Pb, 0.19% Zn

success by continuing to return significant assays for gold and silver (Table 8). At the **Tinta Hill** zone (Yukon MINFILE 1151 058) – an intrusion-hosted gold-silver-copper mineralized vein – drilling (3807 m in 17 holes) was directed at defining a NI 43-101-compliant resource. Previous drilling intersected the vein system to a depth of 300 m within a small 100 m length of the vein which has been traced for approximately 1 km on surface. Results from the drilling were pending at year-end. The company also drilled 10 holes totaling 2560 m in the **Stoddart** zone (Yukon MINFILE 1151 050), a copper-molybdenum-gold porphyry target that was discovered in drilling in 2007. Results from the Stoddart drilling were pending at year-end. Drilling was also completed on the **Ridge** zone (1 km from the Stoddart zone), where high-grade gold-silver-copper mineralization was discovered in trenching in 2007. Nine holes totaling 1079 m were drilled into the shear zone that



Figure 8. Sulphide mineralization (pyrrhotite-pyrite) in drillcore at the Nucleus property.



Figure 9. Dan Lui of Rimfire Minerals examines core at the Boulevard property.

hosts the mineralization along the contact of two granite bodies. The shear zone is a prominent linear feature that can be traced on surface for over 2 km. The drilling returned several significant intersections (Table 8), which again define a new gold discovery in Yukon.

The **Boulevard** property is a new target approximately 135 km south of Dawson City, in the Dawson Range. The property was discovered by regional exploration conducted by Rimfire Minerals Corporation (www.rimfireminerals.com) and Northgate Minerals Corporation (www.northgateminerals.com) targeting Pogo-style mineralization. Soil sampling on the claims outlined a 2.0 by 0.4 km arsenic-antimony-gold anomaly. Kubota trenching on the property encountered gold mineralization hosted in strongly sericite-clay-altered schists with disseminated pyrite, arsenopyrite, stibnite and specular hematite that envelopes quartz and massive stibnite veins. Two trenches, spaced 100 m apart,

encountered 7.04 g/t Au over 6 m and 6.43 g/t Au over 2 m. Diamond drilling consisting of 525 m in seven holes was completed (Fig. 9); results are pending.

Tagish Lake Gold (www.tagishgold.com) suspended exploration activity at the **Skukum Creek** deposit (Yukon MINFILE 105D 022) to concentrate on finding a partner to advance the deposit (Table 9) towards production. At year-end, Tagish was negotiating a merger with Yukon-Shaanxi Mining Co. Inc., a private company formed in 2007 by Yukon-Nevada Gold Corp. and Northwest Non-Ferrous International Investment Co. Ltd., a Chinese investment company.

Table 9. NI 43-101-compliant resource for Skukum Creek (2007).

Class	Tonnage	Grade* (g/t)
measured	195 000 t	5.8 Au, 240 Ag
indicated	880 000 t	6.5 Au, 174 Ag
inferred	206 000 t	6.8 Au, 155 Ag

*4 g/t Au cut-off grade

The **Hartless Joe** property (Yukon MINFILE 105D 203) hosts low-sulphidation gold and silver-rich quartz veins, breccias and replacement zones. Mineralized specimens of quartz vein material taken from talus slopes commonly grade from 2 to 10 g/t Au and 30 to 70 g/t Ag, and occasionally return bonanza-type values to 251 g/t (7.32 oz/ton) Au and 5780 g/t (168.6 oz/ton) Ag. Three diamond drillholes totaling 612.2 m were completed as follow-up to soil sampling, prospecting and geophysical targeting (VTEM and Induced Polarization) by ATAC Resources (www.atacresources.com), and funding from Ferus Resources Ltd. Drilling encountered pyritic dykes and veins that cut through a thick section of predominantly volcanic rocks. Assay results are pending.

The **Kirkland Creek** (Yukon MINFILE 115H 057) property of New Shoshoni Ventures (www.newshoshoni.com) was drilled with seven holes totaling 1158 m. Drilling at this property in south Yukon targeted gold geochemical anomalies and ground and airborne geophysical anomalies overlying Tertiary and Eocene volcanic rocks. The volcanic complex is a target for epithermal-type mineralization.

The **Log-Tom** Property (Yukon MINFILE 105D 069) owned by 1356139 Alberta Inc. consists of 145 contiguous quartz claims in the Marsh Lake area. In 2008, Aurora Geosciences Ltd. was retained to conduct a five-hole (663 m) diamond drill program, 61 line-km of ground magnetics, 15 line-km of IP, a soil sampling program, mapping and prospecting. Drilling was directed at a quartz-carbonate alteration zone that occupies the sheared north-trending contact between Laberge Group greywacke, argillite and conglomerate, and a serpentinite body associated with

Cache Creek volcanic rocks. Diamond drill core samples recovered from two holes returned 1.215 g/t Au over 6 m with the best individual assay returning 4.78 g/t Au over 1 m, and 0.998 g/t Au over 12 m with the best individual assay returning 3.175 g/t Au over 1 m.

Strategic Metals Ltd. (www.strategicmetalsLtd.com) conducted helicopter-borne VTEM, magnetic and soil geochemical surveys, and a three-hole, 884 m diamond drill program on the **Fairweather** property (Yukon MINFILE 105J 010) in Central Yukon. The property hosts copper-gold porphyry, skarn and vein targets associated with high-level Tombstone Suite intrusions. Analytical results are not yet available.

PORPHYRY/SHEETED VEIN

StrataGold Corp. (www.stratagold.com) conducted 4249 m of drilling in 15 holes at the Eagle zone deposit (Table 10) on its **Dublin Gulch** property (Yukon MINFILE 105D 025). The Eagle zone, an analogue of the Fort Knox deposit in Alaska, is an intrusion-hosted gold deposit consisting of sheeted veins within a Tombstone-age granodiorite stock. Drilling was successfully directed at expanding the deposit outside of its current known limits. Results include drill intercepts of 100.2 m at 0.90 g/t Au (DG08-357C) and 19.5 m at 2.74 g/t Au (DG08-342C). The deposit remains open in several directions and to depth. An updated resource estimate utilizing drilling from 2006 to 2008 is being produced.

PRECIOUS METALS - SILVER

VEIN/BRECCIA

Alexco Resources Corporation (www.alexcoresource.com) continued with a comprehensive exploration program on its **Keno Hill** (Yukon MINFILE 105M 001) project (10 360 m of diamond drilling; Fig. 10). Over the past century, the silver mines at Keno Hill have produced approximately 214 million ounces (6 656 000 kg) of silver at an average grade of 40.4 ounces/ton (1389 g/t) Ag, 5.62% Pb and 3.14% Zn. Alexco's 2008 exploration program includes a new 650 m decline to access existing workings and approximately 2300 m of underground rehabilitation at the historic **Bellekeno** mine.

To upgrade resources (Table 11), 10 000 m of underground drilling is planned for Bellekeno, in addition to test mining and collection of a bulk sample to confirm earlier metallurgical testwork. The company's goal is to achieve a production decision for the Bellekeno deposit by early 2009. Alexco completed a positive Preliminary Economic Assessment (PEA) on the Bellekeno deposit earlier in the year for a 250 tonne-per-day operation. The PEA estimated the cost to bring the mine into production would be \$61.2 million. Details of the PEA can be viewed on the company website. Alexco also negotiated a silver purchase agreement with Silver Wheaton Resources Corp. for 25% of the life-of-mine silver production from the mines at Keno Hill. The purchase agreement includes a US\$50 million

Table 10. NI 43-101-compliant resource for the Eagle zone, Dublin Gulch (2006).

Class	Tonnage	Grade* (g/t)
indicated	66.54 Mt	0.916 Au
inferred	14.39 Mt	0.803 Au

*0.5 g/t Au cut-off grade

Table 11. NI 43-101-compliant resource for Bellekeno (2008).

Class	Tonnage	Grade*
inferred	537 400 t	1016 g/t Ag, 10.7% Zn, 13.5% Pb, 0.4 g/t Au

*1000 g/t Ag-equivalent cut-off grade



Figure 10. Coarse galena in drillcore from Keno Hill (Bellekeno).

up-front payment which will provide the company with the capital needed to place the mine into production. Although exploration efforts have focused on Bellekeno, several other targets have been tested with drilling including Lucky Queen, Onek, Keno 700, Hector-Calumet and Leo. Partial results available at this time confirm high-grade intercepts on some of these targets (Table 12).

Table 12. Selected 2008 drill intersections for the Keno Hill project.

Drillhole	Zone	Intersection
K08-132	Leo	4.34 m @ 16.4% Zn, 0.1 g/t Au, 25.7 g/t Ag
K08-141	Onek	5.45 m @ 18.2% Zn, 0.6 g/t Au, 182.7 g/t Ag
K08-153	Onek	5.71 m @ 22.3% Zn, 0.7 g/t Au, 143.5 g/t Ag
K08-161	Lucky Queen	2.45 m @ 2249 g/t Ag, 8.3% Pb, 0.4% Zn

The contiguous **Connaught** (Yukon MINFILE 115N 040) and **Mag** property of ATAC Resources (www.atacresources.com) and Klondike Silver (www.klondikesilver.com) host a number of silver-gold veins within a 13 by 5 km area of anomalous geochemical response that approximately coincides with a pronounced magnetic high. Where exposed, the veins are typically 0.3 to 2 m wide and grade 100 to 2000 g/t Ag with 0.3 to 2 g/t Au and 3 to 60% Pb. A program of soil sampling and excavator trenching at Connaught and Mag, which are located in the Stewart River area, began in late June 2008.

The **Hopeful** property (Yukon MINFILE 115P 047; Fig. 11) of ATAC Resources (www.atacresources.com) consists of a silver-rich greisen zone along the contact between a Cretaceous syenite stock and surrounding Ordovician quartzites, shales and carbonate rocks. The zone is 10 to 30 m thick and consists of quartz-tourmaline greisen veins flanked by kaolinite-hematite-limonite-talc altered wallrocks. Historical diamond drilling has tested the zone for a length of 260 m along strike and to a depth of 50 to 90 m below surface. The mineralized veins are tourmaline-rich but contain few sulphide minerals. The main silver mineral is jamesonite. Six diamond drillholes totalling 685 m were completed at the main silver zone in early July, 2008 (Table 13).



Figure 11. Exploration Camp at the Hopeful property.

Table 13. Selected 2008 drill intersections for the Hopeful property.

Drillhole	Depth of intersection (m)	Intersection
HF-08-01	171.4	4.6 m @ 207.5 g/t Ag, 1.55% Pb
including	171.4	1.42 m @ 558 g/t Ag, 3.89% Pb
HF-08-02	112.3	5.3 m @ 149.1 g/t Ag, 1.06% Pb
HF-08-04	77.5	9.75 m @ 225 g/t Ag, 0.54% Pb
including	83.85	2.1 m @ 931 g/t Ag, 1.54% Pb
HF-08-06	122.12	1.93 m @ 249.2 g/t Ag, 0.42% Pb

CMC Metals Ltd., (www.cmcmetals.ca) conducted trenching, diamond drilling and bulk sampling on the **Silver Hart** (Yukon MINFILE 105B 021) property. The company is proposing a small-scale mine project for a

20 000 tonne-per-year mine and an 80 tonne-per-day mill facility. The property has a historical (non-NI 43-101-compliant) inferred resource of 45 634 tonnes grading 2088 g/t Ag. High-grade polymetallic silver-lead-zinc veins are hosted in the mid-Cretaceous Cassiar Batholith and Cambrian or older biotite-quartz schist, limy hornfels and calcareous horizons. Additional studies, including metallurgical work, can be viewed on the company website. During trenching and bulk sampling of the TM zone, three additional veins were encountered. They returned grades in the range of the existing historical resources using a portable Niton XRF analyzer. Laboratory assays are pending.

Rockhaven Resources Ltd., (www.rockhavenresources.com) explored the **Plata** property (Yukon MINFILE 105N 003) with a diamond drill program consisting of 4113 m in 51 holes, excavator trenching and a VTEM geophysical survey. The primary target was vein mineralization emplaced within the Plata thrust fault, a moderately dipping structure that strikes east-west across the property. The Plata property hosts a 1996 historical resource on the Plata #4 vein or Plata Thrust Vein (453 592 t at 376.71 g/t Ag, 10% Pb+Zn and 3.77 g/t Au), which consists of arsenopyrite-pyrite-quartz. The property also hosts numerous other polymetallic silver-lead-zinc veins consisting of galena-tetrahedrite-siderite, several of which have been subjected to historical selective high-grade mining. The Plata comprises over 14 veins that occur over a 2 by 5 km area. Veins are hosted in fault or fracture zones cutting the structural fabric in Proterozoic and/or Lower Cambrian limestone, quartzite and shale, which unconformably overlie Devonian shale and chert. Drilling was successful at outlining an area of mineralization over 500 m downdip and 850 m along strike (Table 14). Exploration on the property also uncovered new areas of mineralization with average grades in chip samples from two trenches located 200 m apart of 1060 g/t Ag, 3.57 g/t Au and 6.6% Pb over 1.87 m (Fig. 12).



Figure 12. Trail building at the Plata property. Photo provided by Rockhaven Resources.

Table 14. Selected 2008 drill intersections for the Plata property.

Drillhole	Depth of intersection (m)	Intersection*
PL-08-02	101.02	1.30 m @ 769.00 g/t Ag, 3.60 g/t Au, 2.42% Pb, 3.00% Zn
PL-08-16	12.81	2.44 m @ 778.81 g/t Ag, 0.80 g/t Au, 11.25% Pb, 0.79% Zn
PL-08-17	14.94	1.52 m @ 711.00 g/t Ag, 4.57 g/t Au, 7.24% Pb, 6.17% Zn
PL-08-45	55.47	1.83 m @ 203.15 g/t Ag, 1.64 g/t Au, 3.48% Pb, 4.89% Zn

*Intersection represents 95-100% of the true width of the vein.

The A-1 vein on the **Stump** property (Yukon MINFILE 105F 056) of Klondike Silver Corp. (www.klondikesilver.com) was subjected to additional bulk sampling in 2008, following up on an 80 ton bulk sample that was collected in 2007 (Table 15) and processed at Klondike Silver's Sandon mill in southeastern British Columbia. In 2008, an additional 2500 to 3000 tonnes were excavated and shipped to the Sandon mill. Exact tonnages and grades will be determined during processing. The A-1 vein is located approximately 5 km east of the Ketzka River gold property, and the dominantly galena-rich vein is hosted in upper Cambrian and Lower Ordovician thinly bedded silty limestone.

Table 15. Head grades for Stump property bulk sample, Sept./Oct. 2007.

Sample	Tonnage (short tons)	Pb (%)	Ag (g/t)	Zn (%)
Head sample Lot B	8.7	39.87	1578	0.38
Head sample Lot C	31.5	37.41	1416	0.37
Head sample Lot E	27	39.32	1559	1.34
Head sample Lot F	13.5	42.62	1612	0.3

Monster Mining spent approximately \$1 million trenching and drilling its newly acquired properties in the Keno Hill Mining District, east of the past-producing mines in the area. The Caribou Zone, Alice Zone and **Homestake** (Yukon MINFILE 105M 011) were trenched, and intersected sulphide-mineralized veins with visible galena. In total, 17 holes of diamond drilling (1928 m) and 53 holes (1763 m) of rotary air blast drilling were completed. In addition to prospecting historical showings in the area, Monster rebuilt the portal at Homestake (Fig. 13) in anticipation of future underground exploration.



Figure 13. Prospector Matthias Bindig, geologist Lauren Blackburn and an investor visiting the rebuilt portal at the Homestake property.

Mega Silver Inc., (www.megasilver.ca) explored the **Eagle** project (Yukon MINFILE 105M 021) which comprises the SpiderMan property, the Fisher property and the recently acquired Eagle property in the historic Keno Hill silver district. The company performed airborne magnetometer and VLF geophysical surveys, trenching, soil sampling and geological mapping in 2008, and compiled previously unreported historical information. Historical trenches at the Eagle vein expose silver-lead-zinc mineralization at surface. The Eagle vein is the only known significant mineralized transverse vein-fault on Galena Hill that has not been developed and explored by underground drifting. The Eagle vein is located roughly 1.5 km south of, and parallel to, the vein structures of the Hector-Calumet mine, which produced almost half of all metal in the Keno Hill camp from 1935 to 1972. The Eagle vein varies from 0.6 to 4.9 m wide with mineralized lenses of silver-rich galena, sphalerite and tetrahedrite in a siderite, pyrite and quartz gangue hosted in Keno Hill quartzite. Historical drilling is reported to have intersected values of up to 1886 g/t Ag over 2.1 m. Mega Silver is financed and intends to conduct a major drill program on the property in 2009.

BASE METALS – ZINC

SEDIMENTARY

In 2008, Selwyn Resources Ltd. (www.selwynresources.com) completed a large program on its **Selwyn** (Howards Pass; Yukon MINFILE 105I 12, 37, 38) zinc-lead property located on the Yukon/NWT border, 160 km northeast of Ross River. The Selwyn Sedex deposit is one of the largest zinc-lead resources in the world (Table 16). Fine-grained, rhythmic laminations of sphalerite, pyrite and galena are hosted in black shale of the Ordovician-Silurian Road River Formation. The 2008 program focused on exploring for high-grade mineralization, with 3857 m drilled in 13 drillholes. A new area of high-grade mineralization was discovered in the XY West zone, which remains open for expansion; deep drilling in the Don East deposit confirmed the continuity of the mineralized 'active member' at depth (Table 17). The company also continued comprehensive baseline environmental studies and a technical program focused on metallurgy, mining techniques and project infrastructure.

Table 16. NI 43-101-compliant resource for the Selwyn deposit (2007).

Class	Tonnage	Grade
indicated	154.35 Mt	5.35% Zn, 1.86% Pb
inferred	231.54 Mt	4.54% Zn, 1.42% Pb
High-grade resource (January 2008)		
indicated	16.064 Mt	10.25% Zn, 4.43% Pb
inferred	23.156 Mt	8.86% Zn, 2.8% Pb

Table 17. Selected 2008 drillhole intersections for the Selwyn property.

Drillhole	Depth of intersection (m)	Intersection*
XY West zone		
XYC-172	257.10	9.10 m @ 8.16% Zn and 2.88% Pb
including	257.10	3.71 m @ 14.81% Zn and 5.49% Pb
including	258.30	1.96 m @ 21.68% Zn and 8.84% Pb
and	282.60	5.11 m @ 5.98% Zn and 2.07% Pb
XYC-174	105.10	35.84 m @ 9.99% Zn and 3.34% Pb
including	139.70	10.36 m @ 16.08% Zn and 5.71% Pb
including	140.40	4.62 m @ 22.48% Zn and 8.74% Pb
Don East zone		
DON-142	968.50	4.24 m @ 7.07% Zn and 2.07% Pb
including	968.50	2.55 m @ 7.88% Zn and 2.21% Pb

*Approximate thickness given is calculated based on true thickness being 70% of intercept length

Copper Ridge Exploration (www.copper-ridge.com) explored its **Clear Lake** sedimentary exhalative property (Yukon MINFILE 105L 045), located 110 km northwest of Faro. The zinc-lead-silver-barite massive sulphide deposit is hosted by carbonaceous argillite, siltstone, chert and tuff of the Devonian to Mississippian Earn Group within Selwyn Basin. A 235 km VTEM airborne geophysical survey was completed over the property in 2008. A number of targets that could represent buried massive sulphide bodies similar to Clear Lake have been identified. The Company is awaiting final interpretation of results before planning further exploration on the property.

Table 18. JORC Code (Australia) compliant resource base for the Andrew Zinc Deposit (2008).

Class	Tonnage	Grade*
measured	88 000 t	7.2% Zn, 1% Pb, 4.9 g/t Ag, 26.3 g/t Ge
indicated	4 100 000 t	7.7% Zn, 1.8% Pb, 5.7 g/t Ag, 18.5 g/t Ge
inferred	856 000 t	6.6% Zn, 1.3% Pb, 4.1 g/t Ag, 11.7 g/t Ge
total	5 044 000 t	7.5% Zn, 1.7% Pb, 5.4 g/t Ag, 17.4 g/t Ge

*3% Zn cut-off grade

VEIN/BRECCIA

The **Andrew** (Yukon MINFILE 105K 089) is a zinc-lead-silver-germanium property owned by Overland Resources (www.overlandresources.com), an Australian-based exploration company. At the Andrew, sphalerite-galena-calcite-quartz veins and breccias occupy fractures in Upper Devonian to Mississippian Earn Group clastic rocks. Drilling in 2008 resulted in the completion of 134 drillholes at the property (Fig. 14), located 105 km north of Ross River. The 23 545 m drill program was designed to expand and upgrade the resource (Table 18) and test other exploration targets on the property. Ore grade intercepts were drilled outside the limits of the proposed open pit, including drillholes collared in the newly discovered Darcy Zone (Table 19), approximately 600 m southeast of the Andrew Zinc Deposit. Drilling on the new Adrian and Darin prospects and a new zone to the west of the Andrew Zinc deposit also produced significant intersections in several holes (Table 19). The Company has begun the permitting process for the property and is re-evaluating the proposed mine design based on new drilling data.

Table 19. Selected 2008 drill results for the Andrew property.

Drillhole	Zone/Area	Depth of intersection (m)	Intersection
AN08-051	open pit	158.00	16.0 m @ 9.4% Pb
		178.80	10.2 m @ 2.3% Zn, 13.0% Pb
AN08-068	NE of open pit	122.40	45.0 m @ 8.7% Zn
AN08-110	W of Andrew	246.10	7.8 m @ 6.2% Zn, 0.9% Pb
		262.70	6.4 m @ 7.6% Zn, 11.6% Pb
DY08-002 including and	Darcy	85.70	28.3 m @ 13.6% Zn
		85.70	10.8 m @ 22.4% Zn
		139.30	43.9 m @ 11.9% Zn
AD08-004	Adrian	25.80	2.0 m @ 4.6% Zn



Figure 14. Aerial view of Andrew property.



Figure 15. Drilling at the Blende property. Photo courtesy of Eagle Plains Resources.

Table 20. NI 43-101-compliant resource for the Blende property (2004).

Class	Tonnage	Grade
inferred	15.3 Mt	3.23% Pb, 3.04% Zn, 67.5 g/t Ag

Eagle Plains Resources (www.eagleplains.com) and option partner Blind Creek Resources Ltd. (www.blindcreekresources.com) explored the **Blende** zinc-lead-silver property in central Yukon with seven holes (1047 m) in 2008 (Fig. 15). The deposit (Table 20) is hosted by Lower Proterozoic Gillespie Group dolomite. Epigenetic mineralization occurs in breccia along a shear zone about 6 km long and up to 200 m wide. The 2008 program was designed to outline and expand known mineralized zones and provide samples from the West and Far West zones to carry out metallurgical test work. Two holes were completed in the West zone; five holes were collared in the Far West zone (one hole was abandoned). Drilling results are pending.

MISSISSIPPI VALLEY TYPE/REPLACEMENT

The **Michelle** property (Yukon MINFILE 116A 016) of Zinccorp Resources Inc. (www.zinc-corp.com), located 130 km northeast of Dawson, represents a new base metal discovery for Yukon. The discovery was made while drilling in 2007, and results were announced in 2008. The discovery hole returned an impressive 7.94 m that averaged 22.72% Zn, 17.38% Pb and 510.7 g/t Ag. Early Proterozoic Gillespie Lake Group dolomite hosts the carbonate-replacement mineralization in fractures and breccia zones. Structural controls on mineralization are evident at the Peak showing, which is hosted in an easterly trending fault, and at the Gully showing,

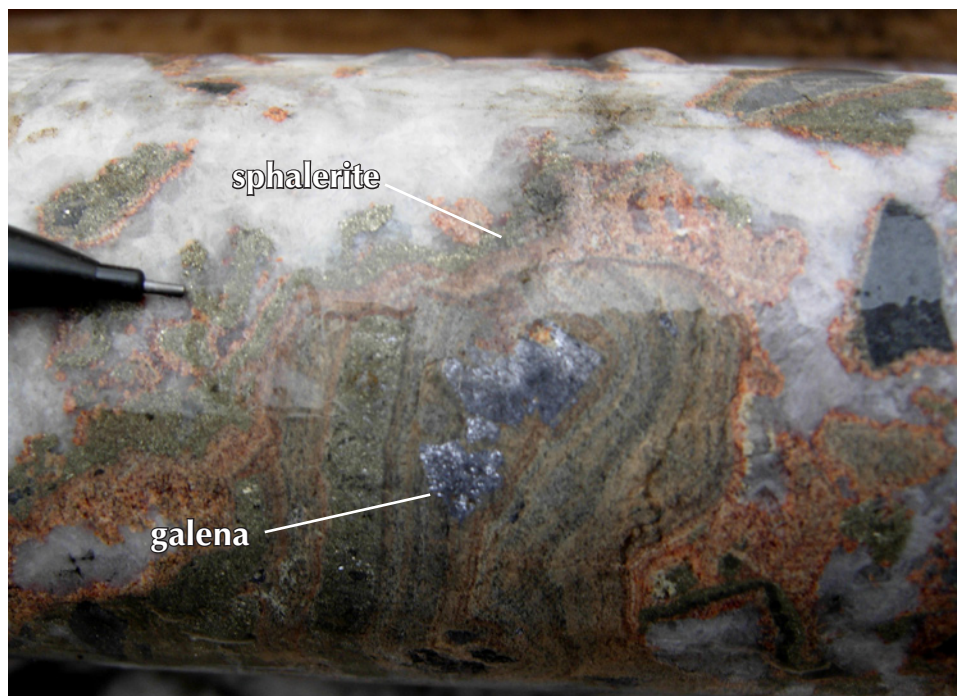


Figure 16. Galena, red sphalerite and pyrite in Og property core.

where the mineralization occurs in a northerly trending structure. A total of 3113 m (26 holes) of drilling was completed in 2008 on the Peak and Gully showings. Mineralization and geochemical anomalies overlying these zones have been traced for about 600 m along strike and remain open to extension. Results from the 2008 drilling are pending.

Full Metal Minerals' (www.fullmetalm minerals.com) **Og** property (Yukon MINFILE 116B 083), optioned by Ashburton Ventures Inc., covers several sediment-hosted and carbonate replacement zinc-silver-lead prospects (Fig. 16). Full Metal drilled eight holes (2182 m) on the land package, located 40 km north of Dawson City – the first drill holes on the property in over 30 years. Full Metal also performed a ground-based gravity survey in 2008. Results are pending.

The **Goz** property (Yukon MINFILE 106C 020), which hosts a carbonate-replacement deposit occurring in stratabound and discordant zones within Late Proterozoic dolostone, was explored with drilling in 2008 by Tarsis Resources (www.tarsis.ca). The historical non-NI 43-101-compliant resource for Goz is 2.49 Mt grading 11% Zn. Drilling (773 m in seven holes) was completed along a 160 m portion of the interpreted structural trend hosting sphalerite-rich mineralization defining the Main Zone. Most drillholes were located along historical lines to test previously reported intersections. Significant intersections included an intercept of 62.05% Zn and 45.10 g/t Ag over 0.70 m. Select drill results are provided in Table 21. Trial gravity surveys were conducted on two grids in 2008. At the Main Zone, the survey highlighted a linear residual gravity anomaly approximately 200 by 40 m. Results from the Walt Ridge survey, a zinc-lead soil geochemical anomaly, are pending. The company is currently conducting detailed geological modelling and working towards the completion of a NI 43-101-compliant resource estimate for the deposit.

Table 21. Selected 2008 drillhole results for the Goz property.

Drillhole	Depth of intersection (m)	Intersection
GZ-08-58	35.51	40.68 m @ 13.55% Zn, 29.88 g/t Ag
including	48.28	27.91 m @ 17.19% Zn, 39.67 g/t Ag
and	93.80	14.69 m @ 8.56% Zn, 6.76 g/t Ag
GZ-08-60	24.13	25.31 m @ 7.00% Zn, 5.10 g/t Ag
including	48.74	0.70 m @ 62.05% Zn, 45.10 g/t Ag
GZ-08-61	25.54	27.50 @ 12.83% Zn, 10.91 g/t Ag
including	28.74	9.29 m @ 19.48% Zn, 14.47 g/t Ag
including	37.01	1.02 m @ 43.20% Zn, 7.06 g/t Ag

BASE METALS – COPPER

PORPHYRY/SHEETED VEIN

Capstone Mining (www.capstonemining.com) drilled 120 holes for a total of 23 840 m on the Area 2, Area 118 and Ridgetop deposits at its copper-gold **Minto** property (Yukon MINFILE 1151 012; see page 5 for development summary). Multiple ore-grade intercepts were intersected, particularly on the Ridgetop deposit (Table 22), which remains open to the east. The 2008 drilling expanded the resources in these areas peripheral to the main Minto deposit, providing data to support a pre-feasibility study for developing these deposits. Completion of the pre-feasibility study is targeted for mid-2009. The study will incorporate results of 2008 drilling for all deposits and evaluate development options, as well as determine optimal throughput levels, including a possible mill expansion to 4000-5000 tonnes per day.

Table 22. Selected 2008 drill intersections for Ridgetop East target, Minto property.

Hole ID	Depth of intersection (m)	Intersection
08SWC-358	53.4	61.9 m @ 0.97% Cu, 0.26 g/t Au, 2.5 g/t Ag
including	53.4	6.5 m @ 3.99% Cu, 1.11 g/t Au, 6.3 g/t Ag
and	97.9	10.1 m @ 1.9% Cu, 0.41 g/t Au, 6.3 g/t Ag
including	104.0	4.0 m @ 3.15% Cu, 0.64 g/t Au, 9.5 g/t Ag
08SWC-359	39.2	60.6 m @ 0.72% Cu, 0.16 g/t Au, 1.5 g/t Ag
and	78.9	20.9 m @ 1.04% Cu, 0.38 g/t Au, 2.8 g/t Ag
including	78.9	6.8 m @ 2.12% Cu, 0.82 g/t Au, 5.1 g/t Ag

In 2007, Western Copper Corp. (www.westerncoppercorp.com) reported the key findings of the independent feasibility study by M3 Engineering and Technology Inc. of Tucson which supports the development of the **Carmacks Copper** deposit (Yukon MINFILE 1151 008), located 192 km north of Whitehorse. The Yukon government issued a decision document in September, 2008, agreeing with the recommendation of the Yukon Environmental and Socio-economic Assessment Board (YESAB) that Western Copper Corp.'s Carmacks copper project proceed. The issuance of the positive decision document completed the assessment process under the *Yukon Environmental and Socio-economic Assessment Act* (YESAA).

A technical report with a new NI 43-101-compliant resource estimate for the **Carmacks Copper** property was released in January 2008 (Table 23). The deposit has a measured and indicated resource estimate of 16 million tonnes containing 351.7 million pounds of copper (159.9 million kg), 206,600 ounces of gold (6 425 260 g) and 2.1 million ounces of silver (65 310 000 g). Geotechnical drilling, engineering studies and water sampling were conducted in 2008 in preparation for mine development. The next steps for the company are to obtain its Quartz Mining Licence and Class A Water Licence, which will complete permitting of the project. The property is being developed as an open-pit operation that will use solvent extraction/

electrowinning technology to produce 14 500 tonnes of LME Grade A cathode copper annually from the oxide deposits.

Table 23. NI 43-101-compliant resource for Carmacks Copper (2008).

Class	Type	Tonnage	Grade*
measured and indicated	oxide resource	12 Mt	0.86% Cu oxide, 0.21% Cu sulphide, 0.457 g/t Au, 4.578 g/t Ag
measured and indicated	sulphide resource	4.3 Mt	0.03% Cu oxide, 0.73% Cu sulphide, 0.221 g/t Au, 2.369 g/t Ag

*0.25% total Cu cut-off grade

Western Copper Corp. (www.westerncoppercorp.com) completed a pre-feasibility study in August 2008 on the porphyry copper-gold-molybdenum **Casino** property (Yukon MINFILE 115J 028) in west-central Yukon (Fig. 17). The study determined the property could be developed economically as an open-pit mine with an initial capital cost of \$2.1 billion. Initial development on the property would target the deposit's oxide cap (see Table 24 for resource estimate). Preliminary production estimates for the project are 5.1 million ounces of gold (158.6 million g), 3.6 billion pounds of copper (1.63 billion kg) and 320 million pounds of molybdenum (145.5 million kg) over a 30-year mine life. The Casino deposit is hosted by the Casino Complex, a Cretaceous plutonic suite with an intense hydrothermal alteration overprint. In 2008, the company refurbished the camp, drilled three holes totalling 1163 m, and continued baseline environmental studies.



Figure 17. Aerial view of the refurbished Casino camp.

Table 24. NI 43-101-compliant resource for the Casino property (2008).

Class	Tonnage	Grade*
Leached cap/oxide gold zone		
inferred	1 Mt	0.1% Cu, 0.45 g/t Au, 0.01% Mo
measured and indicated	38 Mt	0.07% Cu, 0.57 g/t Au, 0.02% Mo

*0.40 g/t Au cut-off grade

Class	Tonnage	Grade*
Supergene oxide zone		
inferred	9 Mt	0.26% Cu, 0.18 g/t Au, 0.01% Mo
measured and indicated	46 Mt	0.31% Cu, 0.33 g/t Au, 0.02% Mo

*0.25% Cu-equivalent cut-off grade

Class	Tonnage	Grade*
Supergene sulphide zone		
inferred	23 Mt	0.21% Cu, 0.14 g/t Au, 0.01% Mo
measured and indicated	133 Mt	0.31% Cu, 0.31 g/t Au, 0.02% Mo

*0.25% Cu-equivalent cut-off grade

Class	Tonnage	Grade*
Hypogene zone		
inferred	200 Mt	0.15% Cu, 0.18 g/t Au, 0.02% Mo
measured and indicated	200 Mt	0.19% Cu, 0.21 g/t Au, 0.02% Mo

*0.25% Cu-equivalent cut-off grade

VOLCANIC

The **Mor** property (Yukon MINFILE 105C 061) of Tarsis Capital Corp. (www.tarsis.ca) is a volcanogenic massive sulphide target discovered in drilling in 2004. It is located 35 km east of Teslin and just 1.5 km north of the Alaska Highway. An eight-hole, 1703 m drill program in 2008 tested the Discovery horizon (down-dip and along-strike) and the new SD zone (Fig. 18), 2 km south of the Discovery horizon, a target identified by an airborne geophysical survey in 2007 (Table 25). Massive sulphide mineralization at the Mor occurs within mafic volcanoclastic strata of the Big Salmon Complex and is commonly flanked by moderately heavily disseminated sulphide above and below the mineralization.



Figure 18. Yukon Geological Survey geologist Maurice Colpron and Mark Blythe of Tarsis Resources at the SD zone, Mor property.

Table 25. Selected 2008 drill intersections for the Mor property.

Drillhole	Depth of intersection (m)	Intersection*
Discovery zone		
MOR07-03	141.44	5.46 m @ 1.36 g/t Au, 55.80 g/t Ag, 1.20% Cu, 0.83% Pb, 2.85% Zn
MOR08-06	93.53	9.95 m @ 0.63 g/t Au, 21.60 g/t Ag, 0.45% Cu, 0.3% Pb, 1.9% Zn
including	96.17	1.15 m @ 0.58 g/t Au, 51.00 g/t Ag, 0.24% Cu, 0.93% Pb, 6.74% Zn
MOR08-07	124.83	5.78 m @ 0.26 g/t Au, 13.20 g/t Ag, 0.47% Cu, 0.08% Pb, 0.55% Zn
SD zone		
MOR08-12	96.51	0.79 m @ 0.01 g/t Au, 0.21% Cu
	207.25	0.87 m @ 0.14 g/t Au, 3.10 g/t Ag, 0.45% Cu

*Thicknesses represent true thickness

Yukon Gold Corporation (www.yukongoldcorp.com) conducted an exploration program on the **Marg** (Yukon MINFILE 106D 009) deposit that consisted of 3674 m of drilling in 10 holes. A preliminary economic study on the deposit was also initiated by the company. Six drillholes produced metallurgical test samples and four holes were designed to test the extension of known mineralization (Table 26). The property, located 80 km northeast of Mayo, is host to a volcanogenic massive sulphide deposit (Table 27) occurring within Devonian to Mississippian Earn Group volcanoclastic and sedimentary rocks.

Table 26. Selected 2008 drillhole results for the Marg property.

Drillhole	Depth of intersection (m)	Intersection
Main zone		
M-109	145.80	11.55 m @ 1.72% Cu, 1.72% Pb, 3.64% Zn, 42.41 g/t Ag, 0.63 g/t Au
Exploratory drilling		
M-114	418.60	1.50 m @ 0.38% Cu, 0.48% Pb, 0.86% Zn, 10.74 g/t Ag, 0.13 g/t Au
including	419.60	0.5 m @ 0.90% Cu, 1.16% Pb, 2.03% Zn, 25.80 g/t Ag, 0.24 g/t Au
M-116	361.35	1.15 m @ 1.60% Cu, 0.86% Pb, 2.61% Zn, 24.16 g/t Ag, 0.44 g/t Au
including	361.95	0.55 m @ 3.05% Cu, 1.55% Pb, 4.78% Zn, 42.30 g/t Ag, 0.81 g/t Au

Table 27. NI 43-101-compliant resource for the Marg property (2007).

Class	Tonnage	Grade
indicated	1.72 Mt	1.97% Cu, 4.59% Zn, 2.4% Pb, 59.7 g/t Ag, 0.95 g/t Au
inferred	4.8 Mt	1.81% Cu, 4.64% Zn, 2.28% Pb, 55.4 g/t Ag, 0.78 g/t Au

In early June 2008, a 215 m diamond drillhole was completed at the new **Highway** property of Strategic Metals (www.strategicmetalsLtd.com) in south Yukon. The single drillhole tested a VTEM anomaly defined by a survey flown in 2007 over stratigraphy known to host volcanogenic massive sulphide deposits. This hole intersected a deep section of conductive clays deposited in an old lake bottom.

SKARN

Yankee Hat Minerals (www.yankeehatminerals.com) explored the **Lobo del Norte** property (formerly Cowley Park; Yukon MINFILE 105D 053, 059) and drilled 20 holes for a total of 2000 m in 2008 (Table 28). The claims are located in the Whitehorse copper belt and contain several mineralized occurrences associated with the intrusion of the mid-Cretaceous Whitehorse Pluton into Triassic carbonates and calcareous siltstones, forming copper-molybdenum skarn. Several other near-surface deposits on the property remain to be tested.

Table 28. Selected 2008 drillhole results for the Lobo Del Norte property (Cowley Park zone).

Drillhole	Depth of intersection (m)	Intersection
CP-140-2008	32.18	3.00 m @ 0.53% Cu
	36.33	7.87 m @ 3.85% Cu, 0.1% Mo
	55.03	1.00 m @ 2.65% Cu, 0.4% Mo
	62.67	1.34 m @ 8.37% Cu
CP-142-2008	48.77	8.66 m @ 2.31% Cu, 0.07% Mo
CP-144-2008	16.76	7.62 m @ 0.51% Cu
	32.28	41.77 m @ 1.62% Cu, 0.04 % Mo

BASE METALS – NICKEL + PLATINUM GROUP ELEMENTS (PGE)

MAFIC/ULTRAMAFIC

Northern Platinum Ltd. continued exploration on its **Wellgreen** (Yukon MINFILE 115G 024) property in southwestern Yukon with 4533 m drilled in 12 holes. Nickel, copper and PGE mineralization occurs within a layered 600 m-thick Triassic mafic-ultramafic sill (Fig. 19). An updated resource was released in July 2008 (Table 29). Drill results are pending.

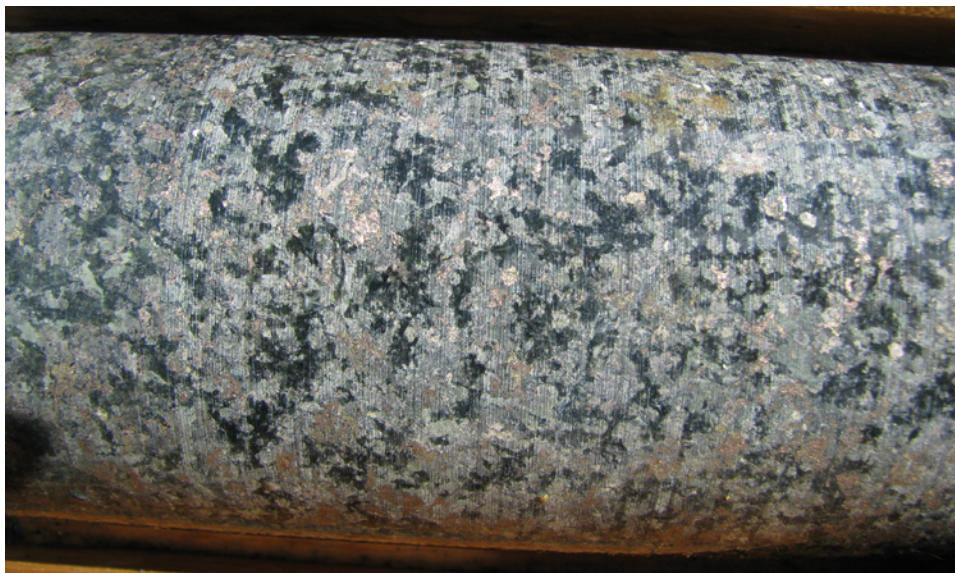


Figure 19. Disseminated sulphide minerals (pyrrhotite-pentlandite) in gabbro drilled at the Wellgreen property.

Table 29. NI 43-101-compliant resource for the Wellgreen property (2008).

Class	Tonnage	Grade*
indicated	6.4 Mt	0.45% Cu, 0.43% Ni, 0.309 ppm Pd, 0.377 ppm Pt
inferred	23.9 Mt	0.28% Cu, 0.29% Ni, 0.274 ppm Pd, 0.377 ppm Pt

*0.20% Ni-equivalent cut-off grade

The **Burwash** property, under option to Pacific Coast Nickel Corp. (www.pacificcoastnickel.com) from Strategic Metals Ltd., hosts nickel-copper-platinum group element (PGE) mineralization related to intrusions of the Late Triassic Kluane Mafic-Ultramafic Suite in southwest Yukon. Soil geochemistry and a helicopter-borne Versatile Time Domain Electromagnetic (VTEM) survey flown in 2007 defined numerous targets on the Burwash property. These were drill-tested by Pacific Coast in 2008 with five holes for a total of 466 m (Table 30).

Table 30. Selected 2008 drillhole results for Main Sill at the Burwash property.

Drillhole	Depth of Intersection (m)	Intersection*
08-03	4.37	42.57 m @ 0.16% Ni, 0.12% Cu, 0.170 g/t Pt, 0.075 g/t Pd
	56.08	18.29 m @ 0.15% Ni, 0.06% Cu, 0.149 g/t Pt, 0.105 g/t Pd
	75.40	8.12 m @ 0.14% Ni, 0.03% Cu, 0.135 g/t Pt, 0.108 g/t Pd
08-05	4.57	10.67 m @ 0.23% Ni, 0.06% Cu, 0.151 g/t Pt, 0.252 g/t Pd
	33.90	67.80 m @ 0.22% Ni, 0.07% Cu, 0.147 g/t Pt, 0.198 g/t Pd
	108.45	3.00 m @ 0.25% Ni, 0.17% Cu, 0.360 g/t Pt, 0.130 g/t Pd

*Insufficient data are available to determine whether intersections are true widths

SEDIMENTARY

In April and May 2008, a six-hole diamond drill program (1819 m) was conducted on the **NiMo** project, which includes the Deer and Rich claims of Southampton Ventures (www.southamptonventures.com) and Strategic Metals (www.strategicmetalsLtd.com). The drilling was followed by helicopter-borne VTEM and magnetic surveys flown over the Nick (Yukon MINFILE 106D 092) claims in July 2008. The properties cover a regionally extensive occurrence of Middle Devonian stratiform sedimentary exhalative massive sulphide mineralization enriched in nickel, molybdenum, vanadium, zinc, platinum and palladium.

BASE METALS – TUNGSTEN + MOLYBDENUM SKARN

North American Tungsten Corporation Ltd. (www.northamericantungsten.com) is conducting a definitive feasibility study on the **MacTung** deposit (Yukon MINFILE 105O 002; Fig. 20). The MacTung property, which is situated on the Northwest Territories/Yukon border in east-central Yukon, contains the largest tungsten deposit outside of China (Table 31). The skarn deposit is hosted in Lower Cambrian clastic rocks and limestone at the margin of a Cretaceous intrusion. A program of both infill drilling on the deposit and geotechnical drilling was conducted.

StrataGold Corp. (www.stratagold.com) conducted drilling on their **Mar-Tungsten** deposit (Yukon MINFILE 106D 027) to increase the resource on the property. A total of 34 diamond drillholes were completed in 2008



Figure 20. Geotechnical drilling at the Mac-Tung property.



Figure 21. Trench on the Mar-Tungsten property.

for a total of 4058 m. The diamond drill program extended the scheelite mineralization up-dip and along strike, and confirmed grade continuity through infill drilling, resulting in conversion of inferred resources into the indicated category. The mineralization is defined over an 800 m strike length and remains open down-dip and along strike to the north (Fig. 21). The Mar deposit is located within Stratagold's Dublin Gulch property, 50 km north of Mayo. In December, 2008, StrataGold announced a positive preliminary Economic Assessment (PEA) on the property and released an updated NI 43-101-compliant resource estimate (Table 32). The PEA estimates total mine production of 45 725 tonnes of WO_3 concentrate with an average grade of 58% WO_3 over an 11 year mine life.

Playfair Mining Ltd. (www.playfairmining.com) drilled the **Risby** tungsten deposit (Yukon MINFILE 105F 034) in 2008, extending the tungsten mineralization approximately 220 m along strike to the north of its NI 43-101-compliant inferred resource (Table 33). A total of 1600 m in seven holes (Table 34) encountered similar tungsten grades and widths as those found in the nearby deposit. These intercepts demonstrate a strong on-strike continuity of tungsten mineralization. The skarn deposit is hosted in Lower Paleozoic calcareous rocks that have been intruded by a mid-Cretaceous quartz monzonite pluton of the Cassiar Suite.

Table 34. Selected 2008 drill intersections for the Risby project.

Drillhole	Depth of intersection (m)	Intersection*
RT08-50	263.84	4.46 m @ 0.263% WO_3
and	274.03	8.53 m @ 0.366% WO_3
including	279.56	3.00 m @ 0.808% WO_3
RT08-51	275.70	2.40 m @ 0.775% WO_3
and	293.57	4.43 m @ 0.991% WO_3
including	295.10	2.00 m @ 1.650% WO_3
and	312.25	2.22 m @ 0.337% WO_3

*Intercept lengths are core lengths and not true widths

Table 31. NI 43-101-compliant resource for the MacTung property (2007).

Class	Tonnage	Grade (% WO_3)
indicated	33.029 Mt	0.88
inferred	11.857 Mt	0.78

Table 32. NI 43-101-compliant resource for the Mar-Tungsten deposit (2008).

Class	Tonnage	Grade* (% WO_3)
indicated	12.7 Mt	0.31
inferred	1.3 Mt	0.3

*Cut-off grade of 0.10% WO_3

Table 33. NI 43-101-compliant resource for Risby deposit (2007).

Class	Tonnage	Grade* (% WO_3)
inferred	6.386 Mt	0.462

*0.2% WO_3 cut-off grade

PORPHYRY/SHEETED VEIN

Table 35. NI 43-101-compliant resource for the Logtung deposit (Northern Dancer property; 2008).

Class	Tonnage	Grade
indicated	140.8 Mt	0.10% WO ₃ , 0.026% Mo
inferred	253.2 Mt	0.10% WO ₃ , 0.022% Mo

Largo Resources Ltd. (www.largoresources.com) completed a new block model and an updated mineral resource estimate incorporating all drilling results up to 2007 for the **Northern Dancer** property (Logtung deposit; Yukon MINFILE 105B 039). A recent NI 43-101-compliant resource estimate (Table 35) confirms the deposit is one of the world's largest known tungsten-molybdenum porphyry systems. Largo is conducting a scoping study (scheduled for release in 2009), ongoing exploration and engineering, and environmental studies on the project. The company completed a 38-hole 11 500 m drill program to expand and upgrade the mineral resource on the property. Excellent results have been received to date (Table 36) that will be used to further update the resource calculation as part of the scoping study.

Table 36. Selected 2008 drillhole results for the Northern Dancer property.

Drillhole	Depth of intersection (m)	Intersection
LT08-119	0.00	371.50 m @ 0.15% WO ₃ , 0.025% Mo
including	106.00	49.00 m @ 0.15% WO ₃ , 0.036% Mo
including	273.60	79.40 m @ 0.29% WO ₃ , 0.032% Mo
LT08-122	0.00	252.98 m @ 0.11% WO ₃ , 0.025% Mo
including	78.00	120.36 m @ 0.15% WO ₃ , 0.031% Mo
LT08-124	0.00	275.5 m @ 0.10% WO ₃ , 0.030% Mo
including	54.00	89.10 m @ 0.12% WO ₃ , 0.031% Mo
including	143.10	21.20 m @ 0.06% WO ₃ , 0.066% Mo
including	164.30	49.10 m @ 0.12% WO ₃ , 0.031% Mo



Figure 22. Technician Serge Bellemeure cutting core at the Jennings tungsten project. Photo courtesy of Agnico-Eagle Mines Ltd.

Agnico-Eagle Mines Ltd. (www.agnico-eagle.com) drilled eight diamond drillholes on its **Jennings** Project (Tootsee River; Yukon MINFILE 105B 089) in south Yukon during September and October 2008. The exploration program was directed toward drilling, prospecting, reconnaissance and interpretation of previously acquired data on the tungsten-molybdenum skarn/porphyry system (Fig. 22). The drill program totaled 4026 m, with drillhole lengths ranging from 420 to 635 m. Assay results are pending.

Prospector Consolidated Resources (www.prospectorresources.com) explored the **Kalzas** tungsten property (Yukon MINFILE 105M 066) in central Yukon, optioned from Copper Ridge Exploration (www.copper-ridge.com). Four diamond drillholes for a total of 505 m were drilled on the property (Table 37). The mineralization at Kalzas consists mainly of wolframite occurring in a broad, sheeted vein and stockwork complex overlying an inferred intrusion.

Table 37. Selected 2008 drillhole results for the Kalzas property.

Drillhole	Intersection
K-08-08	68 m @ 0.15% WO ₃
K-08-09	141.3 m @ 0.21% WO ₃
K-08-10	95 m @ 0.07% WO ₃
K-08-11	191.2 m @ 0.09% WO ₃

ACKNOWLEDGEMENTS

This report is based on public information gathered from a variety of sources. It includes information provided by companies through press releases, personal communication with exploration companies, and property visits conducted during the 2008 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: 2008 EXPLORATION PROJECTS

Project name	Optioner/Owner	MINFILE number	NTS	Work type	Primary commodity	Deposit
PRECIOUS METALS - GOLD						
Antimony	Strategic Metals Ltd.	116B 094	116B/08	AGP, GP	Au	porphyry/ sheeted vein
Arn	Auger Resources Ltd./ATAC Resources Ltd.	115F 048	115F/15	P, AGP, GP	Au	skarn/ replacement
Black Fox	Underworld Resources Inc./RyanWood Exploration Inc.	115O 014	115O/03	P, G	Au	vein/breccia
Boulevard	Northgate Minerals Ltd./Rimfire Minerals Corporation	115J 050	115J/13	GC, T, DD	Au	porphyry/ sheeted vein
Brimstone	Kreft, Bernie	new	115O/10	P, G, GC	Au	vein/breccia
Cheyenne	Logan Resources Ltd./RyanWood Exploration Inc.	116B 096	116B/08	G, C	Au	skarn/ replacement
Chopin	Northern Tiger Resources Inc.	115I 101	115I/12	P, GC, G	Au	vein/breccia
Dublin Gulch	StrataGold Corporation	106D 025	106D/4	DD	Au	porphyry/ sheeted vein
Echo	Northgate Minerals Ltd./Rimfire Minerals Corporation	new	115N/10, 15	G, GC	Au	porphyry/ sheeted vein
Eureka	Anfield Ventures Inc./Strategic Metals Ltd.	115O 057	115O/10	AGP, GP	Au	vein/breccia
Fisher	Mega Silver Inc./StrataGold Corporation	105M 022	105M/14	P, G, GC, T	Au	porphyry/ sheeted vein
Friday	Kreft, Bernie	115O 135	115O/10	P, GC	Au	vein/breccia
Goldy	Northern Freegold Resources	115I 112	115I/06	DD	Au	vein/breccia
Grew Creek	Emerick Resources Corp./Carlos, Al	105K 009	105K/2	GP, GC	Au	vein/breccia
Haines	RyanWood Exploration Inc.	115A 040	115A/13	G, GP, GC	Au	vein/breccia
Hartless Joe	Ferus Resources Ltd./ATAC Resources Ltd.	105D 203	105D/15	DD	Au	vein/breccia
Heidi	Logan Resources Ltd.	116A 037	116A/5	GC	Au	skarn/ replacement
Homestake	Monster Mining	105M 011	105M/14	GC, T, DD, RC/P	Au	vein/breccia
Ketza River	Yukon-Nevada Gold Corp.	105F 019	105F/9	DD, PF	Au	skarn/ replacement
Key	RyanWood Exploration Inc.	new	105M/14	G, GP, GC	Au	porphyry/ sheeted vein
Kirkland Creek	New Shoshoni Ventures Ltd.	115H 057	115H/10	DD	Au	vein/breccia
Laskey	Kreft, Bernie	115O 132	115O/10	GC, T	Au	vein/breccia
Log-Tom	1356139 Alberta Inc.	105C 028	105C/5	P, G, GP, GC, DD	Au	vein/breccia

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Appendix 1 (continued): 2008 EXPLORATION PROJECTS

Project name	Optioner/Owner	MINFILE number	NTS	Work type	Primary commodity	Deposit
Mike Lake	Dynamite Resources Ltd.	116A 012A	116A/5	DD	Au	skarn/ replacement
Myschka	Overland Resources Ltd.	105K 090	105K/16	G, GC	Au	porphyry/ sheeted vein
Nana	H. Coyne and Sons/McKeown, Sid	105D 076	105D/11	GC, DD	Au	skarn/ replacement
Nucleus	Northern Freegold Resources	115I 107	115I/6	DD	Au	porphyry/ sheeted vein
Rau	ATAC Resources Ltd.	106D 005	106D/1	P, G, DD	Au	skarn/ replacement
Ridge	Northern Freegold Resources	new	115I/6	DD	Au	vein/breccia
Rosy	Valere Mining Limited/ATAC Resources Ltd.	105C 024	105C/13	P, G, GC	Au	vein/breccia
Skukum Creek	Tagish Lake Gold Corp.	105D 022A	105D/3	PF	Au	vein/breccia
Sonora Gulch	Northern Tiger Resources Inc.	115J 008	115J/9	DD	Au	porphyry/ sheeted vein
Tinta Hill	Northern Freegold Resources	115I 058	115I/7	DD	Au	vein/breccia
Toni	Hulstein, Roger	116C 153	116C/2	GP, GC, T	Au	vein/breccia
VG (Vic)	Yukon-Shaanxi/Aurchem Exploration Ltd.	115I 068	115I/3	G	Au	vein/breccia
White Gold	Underworld Resources Inc./RyanWood Exploration Inc.	115O 011	115O/4	DD	Au	vein/breccia
PRECIOUS METALS - SILVER						
CMC Silver (Silver Hart)	CMC Metals Ltd.	105B 021	105B/7	T, BS, DD	Ag	vein/breccia
Connaught	Klondike Silver Corp./ATAC Resources Ltd.	115N 040	115N/15	GC, T	Ag	vein/breccia
Eagle	Mega Silver Inc.	105M 021	105M/14	AGP, GC	Ag	vein/breccia
Evelyn	Poulin, Bruno	105C 041	105C/14	T	Ag	vein/breccia
Hopeful	ATAC Resources Ltd./Berdahl, Ron	115P 047	115P/14	DD	Ag	vein/breccia
Inca	Incaplatau Explorations Ltd./Morgan, Tom	105O 015	105O/12	GC, RC/P	Ag	vein/breccia
Keno Hill	Alexco Resource Corp.	105M 001	105M/14	DD, U/GD, PF	Ag	vein/breccia
Mag	Kondike Silver Corp./ATAC	new	115N/15	GC, T	Ag	vein/breccia
Plata	Rockhaven Resources Ltd.	105N 003	105N/9	GC, T, DD	Ag	vein/breccia
Rancheria Silver	Tanana Exploration Inc.	various	105B	P, GC	Ag	skarn/ replacement
Stump	Klondike Silver Corp.	105F 056	105F/9	BS	Ag	vein/breccia
Wolf	International KRL Resources/Tarsis Capital Corp.	105B 140	105B/1	DD	Ag	skarn/ replacement

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Appendix 1 (continued): 2008 EXPLORATION PROJECTS

Project name	Optioner/Owner	MINFILE number	NTS	Work type	Primary commodity	Deposit
BASE METALS - ZINC-LEAD						
Andrew	Overland Resources Ltd./Berdahl, Ron	105K 089	105K/16	G, GC, DD	Zn-Pb	vein/breccia
Angie	Full Metal Minerals/RyanWood Exploration Inc.	105F 091	105F/15	GC	Zn-Pb	sediment associated
Bar (106C)	Full Metal Minerals/RyanWood Exploration Inc.	106C 026	106C/10	P, GC	Zn-Pb	Mississippi Valley Type
Blende	Blind Creek Resources/Eagle Plains Resources Ltd.	106D 064	106D/7	DD	Zn-Pb	vein/breccia
Bob	Strategic Metals Ltd.	105G 107	105G/6	AGP	Zn-Pb	Mississippi Valley Type
Clear Lake	Copper Ridge Exploration Inc./Kreft, Bernie	105L 045	105L/14	AGP	Zn-Pb	sediment associated
Corn	Full Metal Minerals/RyanWood Exploration Inc.	106C 019	106C/11	P, GC	Zn-Pb	Mississippi Valley Type
Cypress	Full Metal Minerals/RyanWood Exploration Inc.	106C 022	106C/7	GC	Zn-Pb	Mississippi Valley Type
Goz Creek	Tarsis Capital Corp.	106C 020	106C/7	P, G, GC, DD	Zn-Pb	Mississippi Valley Type
Groundhog	Rockhaven Resources Ltd.	105F 093	105F/10	P, G, AGP, GC	Zn-Pb	sediment associated
Marg	Yukon Gold Corporation Inc.	106D 009	106D/1	DD	Zn-Pb	volcanic associated
Michelle	Zinccorp Resources Inc.	116A 016	116A/13	DD	Zn-Pb	Mississippi Valley Type
Nebocat	Full Metal Minerals/RyanWood Exploration Inc.	105G 093	105G/6	GC, G	Zn-Pb	sediment associated
OG	Full Metal Minerals/RyanWood Exploration Inc.	116B 083	116B/13	GP, DD	Zn-Pb	Mississippi Valley Type
Selwyn Project	Selwyn Resources Ltd.	105I 012	105I/6	DD, PF	Zn-Pb	sediment associated
Tom	HudBay Minerals Inc.	105O 001	105O/1	scoping studies	Zn-Pb	sediment associated
Ultra	Morgan, Tom	115B 008	115B/16	P, GC, T	Zn-Pb	volcanic associated
Wolverine	Yukon Zinc Corporation	105G 072	105G/8	MD	Zn-Pb	volcanic associated
Zap	Rockhaven Resources Ltd.	106D 085	106D/8	DD	Zn-Pb	sediment associated

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Appendix 1 (continued): 2008 EXPLORATION PROJECTS

Project name	Optioner/Owner	MINFILE number	NTS	Work type	Primary commodity	Deposit
BASE METALS - COPPER						
Bond	Northern Tiger Resources Inc.	115I 076	115I/13	G, GC	Cu	porphyry/ sheeted vein
Bridget	RyanWood Exploration Inc.	115J 072	115J/15	GP, GC	Cu	porphyry/ sheeted vein
Carmacks Copper	Western Copper Corporation	115I 008	115I/7	DD, permitting	Cu	porphyry/ sheeted vein
Casino	Western Copper Corporation	115J 028	115J/10	DD	Cu	porphyry/ sheeted vein
Copper	BCGold Corp./RyanWood Exploration Inc.	new	115I/7	GP	Cu	porphyry/ sheeted vein
Cuprum	Manson Creek Resources Ltd.	105E 008	105E/4	GP	Cu	skarn/ replacement
Dad	Northern Tiger Resources Inc.	115I 026	115I/14	G, GC	Cu	porphyry/ sheeted vein
Del	Northern Tiger Resources Inc.	115I 095	115I/7	G, GC	Cu	vein/breccia
Eagle Eye South	Kerwin, Gloria	new	115F/16	GC	Cu	porphyry/ sheeted vein
Fairweather	Strategic Metals Ltd./RyanWood Exploration Inc.	105J 010	105J/13	AGP, GP, GC, DD	Cu	porphyry/ sheeted vein
Highway	Strategic Metals Ltd.	new	105C/1	DD	Cu	volcanic associated
Hopper	Strategic Metals Ltd.	115H 019	115H/7	P, GC	Cu	porphyry/ sheeted vein
Ironman	Vale Inco/Copper Ridge Exploration Inc.	116A 017	116A/15	DD	Cu	Wernecke Breccia
King Lake Copper	39231 Yukon Inc.	105D 104	105D/14	P, GC	Cu	porphyry/ sheeted vein
Led	Northern Tiger Resources Inc.	115 010	115I/7	G, GC	Cu	vein/breccia
Lewes River	Arcturus Ventures Inc.	105D 062	105D/10	GP	Cu	skarn/ replacement
Lobo Del Norte (Cowley)	Yankee Hat Minerals/Ernewein, Barry	105D 053, 059	105D/10	DD	Cu	skarn/ replacement
Lucky Joe	Copper Ridge Exploration Inc.	115O 051	115O/11, 12	G, GP, GC	Cu	porphyry/ sheeted vein
Mel (Dawson Range)	Northern Tiger Resources Inc.	new	115I/11	G, GC	Cu	porphyry/ sheeted vein
Minto	Capstone Mining Corp.	115I 021	115I/11	G, DD	Cu	IOCG
Mor	Tarsis Capital Corp.	105C 061	105C/1	GC, DD	Cu	volcanic associated
Peanut	BCGold Corp./RyanWood Exploration Inc.	new	115I/7	GP	Cu	porphyry/ sheeted vein
Pepper	BCGold Corp./RyanWood Exploration Inc.	new	115I/11	GP	Cu	porphyry/ sheeted vein

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DD - diamond drilling	GP - ground geophysics	P - prospecting	U/GD - underground development
		PF - prefeasibility	

Appendix 1 (continued): 2008 EXPLORATION PROJECTS

Project name	Optioner/Owner	MINFILE number	NTS	Work type	Primary commodity	Deposit
Shell Creek	Logan Resources Ltd.	116C 029	116C/9	GC	Cu	sediment associated
Spear	BCGold Corp./RyanWood Exploration Inc.	new	115I/11	GP	Cu	porphyry/ sheeted vein
Stoddart	Northern Freegold Resources	115I 050	115I/6	DD	Cu	porphyry/ sheeted vein
Timber	Strategic Metals Ltd.	105J 035	105J/4	AGP	Cu	porphyry/ sheeted vein
Toe	BCGold Corp./RyanWood Exploration Inc.	new	115I/11	GP	Cu	porphyry/ sheeted vein
WS Total	BCGold Corp./RyanWood Exploration Inc.	115I 006	115I/7	GP, DD	Cu	porphyry/ sheeted vein
BASE METALS - NICKEL ± PLATINUM GROUP ELEMENTS (PGE)						
Burwash	Pacific Coast Nickel Corp./Strategic Metals Ltd.	115G 100	115G/6	DD	Ni/PGE	mafic/ultramafic associated
Canalask	African Minerals Ltd./StrataGold Corporation	115F 045	115F/15	DD	Ni/PGE	mafic/ultramafic associated
Deer	Southhampton Resources/Strategic Metals Ltd.	116B 128	116B/9	DD	Ni/PGE	sediment associated
NiMo	Southhampton Resources/Strategic Metals Ltd.	new	106E/13	DD	Ni/PGE	sediment associated
Rich	Southhampton Resources/Strategic Metals Ltd.	new	116I/8	DD	Ni/PGE	sediment associated
Wellgreen	Northern Platinum Ltd.	115G 024	115G/5	DD	Ni/PGE	mafic/ultramafic associated
BASE METALS - TUNGSTEN						
Jennings	Agnico-Eagle Resources/North American Tungsten	105B 089	105B/1	P, G, GC, DD	W	porphyry/ sheeted vein
Kalzas	Prospector Consolidated Resources Inc./Copper Ridge Exploration Inc.	105M 066	105M/7	DD	W	porphyry/ sheeted vein
Kidlark	Yankee Hat Minerals	105F 097	105F/5	P, G, GP, GC, T	W	skarn/ replacement
MacTung	North American Tungsten	105O 002	105O/8	DD, PF	W	skarn/ replacement
Mar-Tungsten	StrataGold Corporation	106D 027	106D/4	DD	W	skarn/ replacement
Northern Dancer	Largo Resources Ltd./Strategic Metals Ltd.	105B 039	105B/4	DD, PF	W	porphyry/ sheeted vein
Risby	Playfair Mining Ltd.	105F 034	105F/14	DD	W	skarn/ replacement
Wau	Yankee Hat Minerals/ATAC Resources Ltd.	new	106D/1	G, DD	W	skarn/ replacement

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Appendix 1 (continued): 2008 EXPLORATION PROJECTS

Project name	Optioner/Owner	MINFILE number	NTS	Work type	Primary commodity	Deposit
BASE METALS - MOLYBDENUM						
Molygarchy	Manson Creek Resources Ltd./37999 Yukon Inc.	105E 024	105E/2	G, GP, GC	Mo	porphyry/ sheeted vein
BASE METALS - URANIUM						
Borealis	Copper Ridge Exploration Inc./ RyanWood Exploration Inc.	116B 098	116B/11	G, AGP, GC	U	porphyry/ sheeted vein
RARE EARTH ELEMENTS						
Lancer	Yankee Hat Minerals/Strategic Metals Ltd.	105F 080	105F/8	P, G, GC	REE	vein/breccia
REGIONAL PROGRAMS						
NTS 105B	Yankee Hat Minerals		105B	G, GP, GC		
NTS 105G	Yankee Hat Minerals		105G	G, GP, GC		
NTS 105K	Larocque, Norm		105K	P, GC, T		
NTS 105K	Woods, James		105K	P, GP, GC		
NTS 105K	Yankee Hat Minerals		105K	G, GP, GC		
NTS 105M	RyanWood Exploration Inc.		105M	GC		
NTS 105M	Yankee Hat Minerals		105M	G, GP, GC		
NTS 105O	RyanWood Exploration Inc.		105O	GC		
NTS 115O	RyanWood Exploration Inc.		115O	GC		
NTS 116C	Allan, Grant		116C	GC, T		
NTS 116C	Lilley, Edward		116C	P, GC		

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APPENDIX 2: 2008 DRILLING STATISTICS

Property	Optioner/Owner	# drillholes	metres
Diamond drilling			
Andrew	Overland Resources Ltd./Berdahl, Ron	134	23545
Blende	Blind Creek Resources/Eagle Plains Resources Ltd.	7	1047
Boulevard	Northgate Minerals Ltd./Rimfire Minerals Corporation	7	525
Burwash	Pacific Coast Nickel Corp./Strategic Metals Ltd.	5	466
Canalask	African Minerals Ltd./StrataGold Corporation		2800
Carmacks Copper	Western Copper Corporation	5	500
Casino	Western Copper Corporation	3	1163
CMC Silver (Silver Hart)	CMC Metals Ltd.		2000
Deer	Southampton Resources/Strategic Metals Ltd.	2	216
Dublin Gulch	StrataGold Corporation	15	4249
Fairweather	Strategic Metals Ltd./RyanWood Exploration Inc.	3	884
Goldy	Northern Freegold Resources	8	1500
Goz Creek	Tarsis Capital Corp.	7	773
Hartless Joe	Ferus Resources Ltd./ATAC Resources Ltd.	3	612
Highway	Strategic Metals Ltd.	1	215
Homestake	Monster Mining	11	1264
Hopeful	ATAC Resources Ltd./Berdahl, Ron	6	685
Ironman	Vale Inco/Copper Ridge Exploration Inc.	4	1031
Jennings	Agnico-Eagle Resources/North American Tungsten	8	4026
Kalzas	Prospector Consolidated Resources Inc./Copper Ridge Exploration Inc.	4	505
Keno Hill	Alexco Resource Corp.		10360
Ketza River	Yukon-Nevada Gold Corp.	223	30151
Kirkland Creek	New Shoshoni Ventures Ltd.	7	1158
Lobo Del Norte (Cowley)	Yankee Hat Minerals/Ernewein, Barry	21	2134
Log-Tom	1356139 Alberta Inc.	5	663
MacTung	North American Tungsten Corporation	55	4256
Mar-Tungsten	StrataGold Corporation	34	4058
Marg	Yukon Gold Corporation Inc.	10	3674
Michelle	ZincCorp Resources Inc.	26	3113
Mike Lake	Dynamite Resources Ltd.	68	10004
Minto	Capstone Mining Corp.	120	23840
Mor	Tarsis Capital Corp.	8	1703
Nana	H. Coyne and Sons/McKeown, Sid	4	1280
NiMo	Southampton Resources/Strategic Metals Ltd.	6	1819
Northern Dancer	Largo Resources Ltd./Strategic Metals Ltd.	38	11500
Nucleus	Northern Freegold Resources	53	13287
OG	Full Metal Minerals/RyanWood Exploration Inc.	8	2182
Plata	Rockhaven Resources Ltd.	51	4113
Rau	ATAC Resources Ltd.	18	3423

Appendix 2 (continued): 2008 DRILLING STATISTICS

Property	Optioner/Owner	# drillholes	metres
Rich	Southampton Resources/Strategic Metals Ltd.	2	909
Ridge	Northern Freegold Resources	9	1079
Risby	Playfair Mining Ltd.	7	1600
Selwyn Project	Selwyn Resources Ltd.	13	3857
Sonora Gulch	Northern Tiger Resources Inc.	10	2238
Stoddart	Northern Freegold Resources	10	2560
Tinta Hill	Northern Freegold Resources	17	3807
Wau	Yankee Hat Minerals/ATAC Resources Ltd.	3	437
Wellgreen	Northern Platinum Ltd.	12	4533
White Gold	Underworld Resources Inc./RyanWood Exploration Inc.	27	3431
Wolf	International KRL Resources/Tarsis Capital Corp.	5	1254
WS Total	BCGold Corp./Ryan, Shawn	5	1284
Zap	Rockhaven Resources Inc.	3	360
		1111	208073
Percussion/Reverse Circulation			
Bear Creek	Morgan, Tom	13	69
Forty Mile	Allan, Grant	16	119
Homestake	Monster Mining	36	1199
Inca	Incaplatau Explorations Ltd./Morgan, Tom	6	150
		71	1537

Yukon Placer Mining Overview, 2008

William LeBarge¹
Yukon Geological Survey

LeBarge, W., 2009. Yukon Placer Mining Overview, 2008. *In: Yukon Exploration and Geology 2007*, L.H. Weston, L.R. Blackburn and L.L. Lewis (eds.), Yukon Geological Survey, p. 39-42.

PLACER MINING

One hundred and twelve years after the discovery of gold in 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 Yukon – at today's prices, that would be worth more than \$10 billion.

In 2008, there were approximately 105 active placer mining operations, directly employing approximately 350 people. As usual, the industry saw a fair amount of transition: some operations moved to new drainages, others closed, several were sold and a few brand 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, resulting in a shift towards larger mining operations.

As in past years, weather played a factor in the mining process, as cool, rainy spring weather throughout Yukon inhibited the thawing of seasonal frost and delayed the start of active mining for many operators. This was however partially offset by warm weather in September and October which allowed many operators to mine well into the fall.

There are 10 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 placer 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 for 2008 was 49 968 crude ounces (1 554 180 g), compared to 63 929 crude ounces (1 988 431 g) in 2007. The value of this 2008 gold production was CDN\$36.9 million or US\$34.8 million (Fig. 2).

Approximately 85% of the Yukon's placer gold was produced in the Dawson Mining District, which includes the unglaciated drainages of Klondike River, Indian River, west Yukon (Fortymile and Sixtymile rivers) and lower Stewart River. The remaining gold came from the unglaciated Moosehorn Range in the Whitehorse Mining District, in addition to other placer mining areas in the glaciated Mayo and Whitehorse mining districts.

Reported placer gold production from Indian River drainages in 2008 decreased from 24 436 crude ounces (760 050 g) in 2007 to 14 650 crude ounces (455 666 g) in 2008. Most of the drop was from Dominion Creek, which was partially due to the cessation of mining by A-1Cats Ltd.

In Klondike area drainages, production decreased from 11 621 crude ounces (361 450 g) in 2007 to 11 029 crude ounces (343 040 g) in 2008. Notable decreases were reported from Bonanza and

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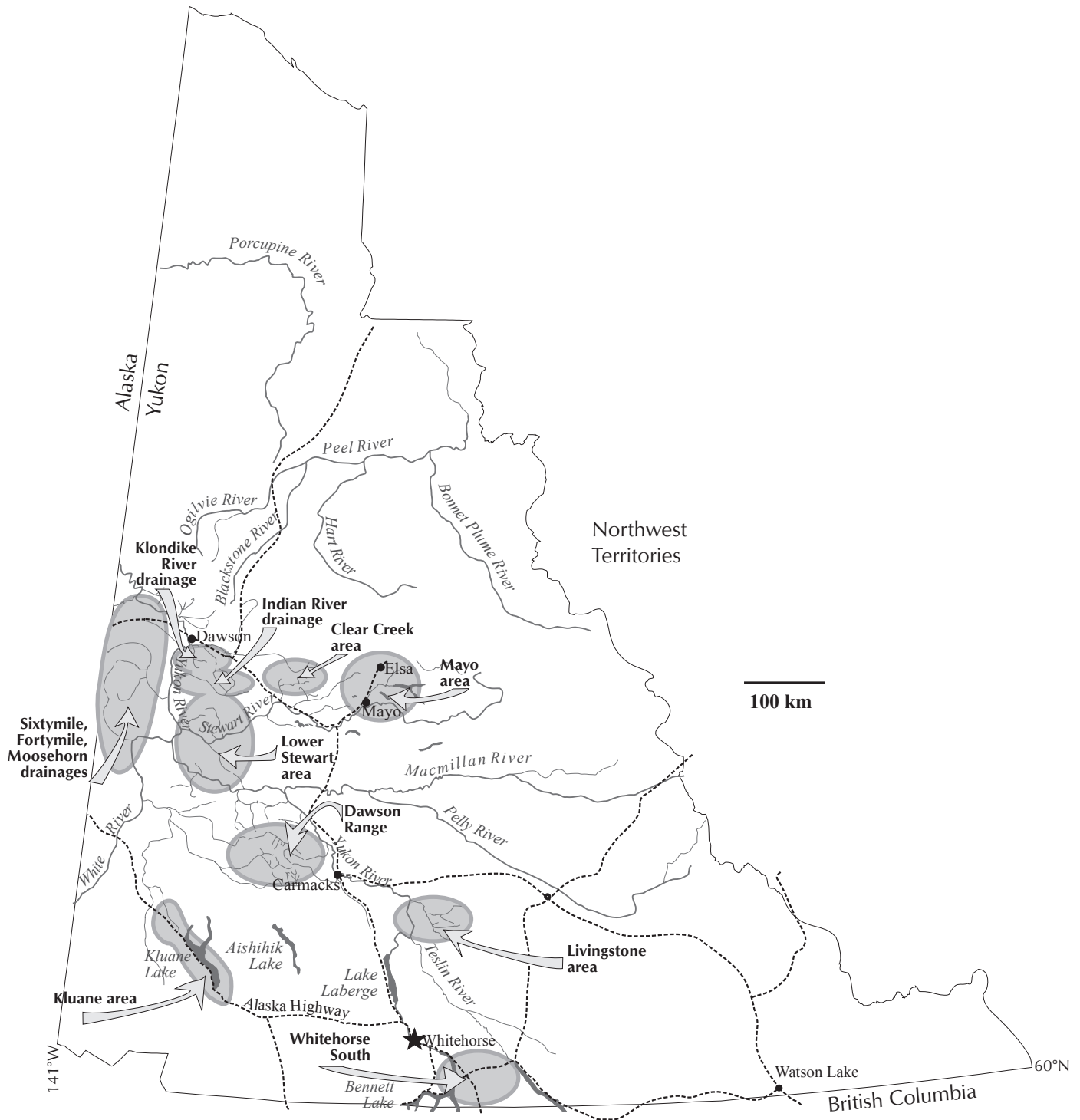


Figure 1. Yukon placer mining areas.

Hunker creeks, while production on Bear Creek more than doubled.

West Yukon (Sixtymile and Fortymile rivers and Moosehorn Range) placer gold production decreased from 14 914 crude ounces (463 880 g) in 2007 to 11 595 crude ounces (360 645 g) in 2008. The largest decrease was from Sixtymile River, whereas Matson Creek had a significant increase.

Production from operations in the Lower Stewart drainages was up in 2008, to a total of 5740 crude ounces (178 534 g) from 5424 crude ounces (168 700 g) in 2007. Production from Black Hills, Thistle and Kirkman creeks dropped substantially, but this was offset by large increases reported from Matson and Scroggie creeks and a new operation on Barker Creek.

Clear Creek drainages had an increase in gold that was reported over the year, from 363 crude ounces (11 290 g) in 2007 to 487 crude ounces (15 147 g) in 2008.

In the Dawson Range, reported placer gold production decreased from 912 crude ounces (28 370 g) in 2007 to 788 crude ounces (24 509 g) in 2008.

In the Mayo area, gold production decreased substantially from 2755 crude ounces (85 690 g) in 2007 to 1396 crude ounces (43 420 g) in 2008. A dramatic

decrease was seen in reported royalties from Duncan and Lightning creeks.

In the Klauane area, reported placer gold production nearly doubled from 887 crude ounces (27 590 g) to 1648 crude ounces (51 258 g). Production at Burwash Creek decreased, while Gladstone Creek increased. Royalties were reported for the first time from Frypan Creek, a Duke River tributary.

Little active mining took place in the Livingstone area, however on Little Violet Creek, 4.0 crude ounces (124 g) of gold were reported, down from 52 crude ounces (1600 g) the year before.

In the Whitehorse South area, no gold was reported in 2008, the same as in 2007.

PLACER EXPLORATION

One of the highlights of the 2008 season was the establishment of a significant mining operation on Barker Creek for the first time in many years. This new development had an effect on the southern Stewart River area in the form of an improved road network which connects Barker, Thistle, Ballarat and Kirkman creeks. This increased infrastructure will be beneficial to smaller operations and facilitate the exploration of nearby creeks.

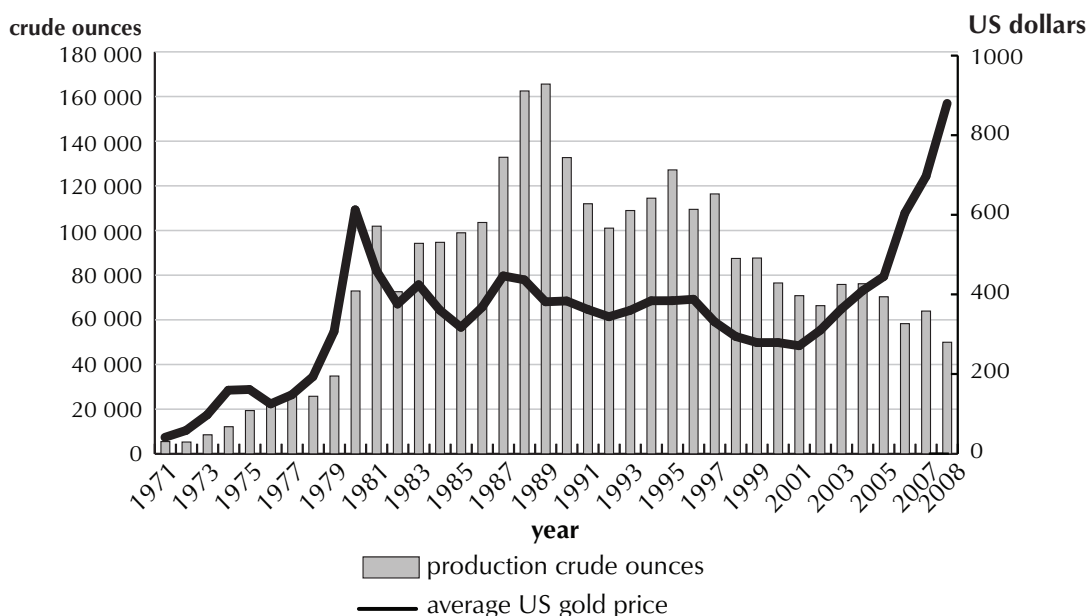


Figure 2. Yukon placer gold production figures and average US gold price, 1971-2008.

CONTACT US

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. Many recent publications and maps can be downloaded for free from our website at <http://www.geology.gov.yk.ca>. Information is also available at the Yukon Placer Secretariat, <http://www.yukonplacersetariat.ca/>. Publications on placer mining in the Yukon are available through the Yukon Geological Survey office at Room 102, Elijah Smith Building, 300 Main Street, Whitehorse, Yukon.

APERÇU DE L'EXPLOITATION DES PLACERS AU YUKON EN 2008

Cent douze ans après la découverte des premiers gisements d'or au Yukon, l'exploitation des placers demeure un secteur important de l'économie du territoire. 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 10 milliards de dollars au prix actuel de l'or.

En 2008, on a dénombré environ 105 sites d'exploitation sur des placers. Près de 350 personnes étaient employées directement sur ces placers. Comme à l'habitude, les transitions se sont avérées nombreuses dans cette industrie : certains sites ont été déplacés vers de nouveaux emplacements drainés, d'autres ont été fermés, plusieurs ont été vendus et quelques 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, ce qui entraîne une tendance vers de plus grandes exploitations.

Comme ce fut le cas au cours des dernières années, les conditions météorologiques ont joué un rôle important dans les activités minières, puisque les conditions fraîches et pluvieuses dans l'ensemble du Yukon au printemps ont inhibé le dégel saisonnier et retardé le début des activités

minières de nombreux exploitants. Cette situation a toutefois été partiellement contrebalancée par des conditions chaudes en septembre et en octobre, qui ont permis à de nombreux exploitants de poursuivre leurs activités plus tard à l'automne.

On compte dix zones d'exploitation de placers réparties dans l'ensemble des quatre districts miniers du Yukon. 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.

En date du 1er décembre 2008, la production d'or dans les placers du Yukon se chiffrait à 49 753 onces brutes (1 547 492 g) pour 2008 alors qu'elle s'élevait à 63 929 onces brutes (1 988 431 g) en 2007. La production d'or en 2008 est évaluée à 36,5 millions de dollars canadiens ou 34,9 millions de dollars américains.

Approximativement 85 % 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 les régions de Clear Creek, de Mayo, de la chaîne Dawson, de Kluane, de Livingstone et de Whitehorse Sud.

Un des faits marquants de la saison 2008 est l'établissement d'une exploitation minière importante dans le bassin du ruisseau Barker pour la première fois depuis de nombreuses années, ce qui a eu un effet sur la région du sud de la rivière Stewart sous forme d'une amélioration du réseau routier reliant les ruisseaux Barker, Thistle, Ballarat et Kirkman. Les petites exploitations pourront tirer profit de cette infrastructure améliorée, et celle-ci facilitera l'exploration des ruisseaux à proximité.

Yukon Oil and Gas Overview 2008

B. Adilman¹

Oil and Gas Resources

Energy, Mines and Resources, Government of Yukon

Adilman, B., 2009. Yukon Oil and Gas Overview 2008. *In: Yukon Exploration and Geology 2008*, L.H. Weston, L.R. Blackburn and L.L. Lewis (eds.), Yukon Geological Survey, p. 43-50.

ABSTRACT

In 2008, some interest was shown during Yukon's two oil and gas rights disposition processes, however, no bids were received. Companies continue to show interest in oil and gas resources in North Yukon.

Northern Cross Yukon has received Yukon Environmental Socio-economic Assessment Board (YESAB) approval for construction, exploration and drilling activities in the Eagle Plains basin; they have submitted another YESAB application for additional activity.

Yukon's Oil and Gas Royalty Regulations came into effect in February 2008. The Regulations authorize the government of Yukon to collect royalty for oil and gas recovered pursuant to Yukon oil and gas dispositions.

Production of natural gas yielded more than 65 000 10³m³ from two wells in southeast Yukon.

Other Oil and Gas Resources (OGR) activities in 2008 included the following: continued participation in the development of a Yukon Energy Strategy; on-going monitoring of the progress of the Mackenzie Gas Project; continued preparation for the proposed Alaska Highway Pipeline Project; on-going participation in several offshore oil and gas initiatives; continued consultation and cooperation with affected First Nations on a variety of oil and gas issues; making sure oil and gas interests are taken into account during the Land Use Planning process; and ongoing cooperation with the Yukon Geological Survey with field work and associated analytical work in order to discover potential source rocks and petroleum reservoir rocks.

RÉSUMÉ

En 2008, certaines sociétés ont montré de l'intérêt durant les deux processus de vente de droits sur le pétrole et le gaz au Yukon. Aucune soumission n'a toutefois été reçue. Des sociétés continuent de montrer de l'intérêt pour les ressources pétrolières et gazières dans le Nord du Yukon.

La société Northern Cross Yukon Ltd. a obtenu l'approbation de l'Office d'évaluation environnementale et socioéconomique du Yukon pour des activités de construction, d'exploration et de forage dans le bassin d'Eagle Plains et a soumis une autre demande à cet office pour d'autres activités.

Le Règlement sur les redevances sur le pétrole et le gaz du Yukon est entré en vigueur en février 2008 et autorise le gouvernement du Yukon à percevoir des redevances sur le pétrole et le gaz extraits conformément aux dispositions sur le pétrole et le gaz du Yukon.

Deux puits dans le sud-est du Yukon ont produit plus de 65 000 x 10³m³ de gaz naturel.

Parmi les autres activités axées sur les ressources pétrolières et gazières menées en 2008, il convient de souligner les suivantes: la participation continue à l'élaboration d'une stratégie en matière d'énergie pour le Yukon; la surveillance des progrès dans le cadre du projet gazier Mackenzie; la poursuite des travaux de préparation du projet proposé de gazoduc de la route de l'Alaska; la participation à plusieurs initiatives pétrolières et gazières en milieu extracôtier; la poursuite des consultations et de la collaboration avec les Premières nations concernées par toute une gamme de problèmes liés au pétrole et au gaz; la prise en considération des intérêts pétroliers et gaziers durant le processus de planification de l'utilisation des terres; la collaboration continue avec la Commission géologique du Yukon pour les travaux sur le terrain et les travaux d'analyse connexes menés à la recherche de potentielles roches mères et roches réservoirs de pétrole.

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INTRODUCTION

In 2008, the Oil and Gas Resources (OGR) branch of the Department of Energy, Mines and Resources continued its role of promoting Yukon's oil and gas industry. While industry activity was limited over the past year, OGR focused on preparations for future exploration and development in Yukon, specifically pipeline and drilling activities.

Yukon has eight onshore sedimentary basins containing an estimated 17 trillion cubic feet (Tcf) (480 billion m³) of natural gas and 772 million barrels (120 million m³) of oil (Government of Yukon, 2008; Fig. 1). Offshore estimates in the Beaufort Sea north of Yukon consist of an additional 40 Tcf (1.5 trillion m³) of natural gas and 4.5 billion barrels (720 billion m³) of oil (Government of Yukon, 2008), contributing to Yukon's vast and virtually untapped petroleum resources.

There were no new dispositions of oil and gas rights in 2008, however opportunities in southeast Yukon and the proposed construction of the Mackenzie and/or Alaska Highway pipelines hold promise for the 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 is in place in preparation for potential expansion of exploration and production. This regime, jointly crafted by Yukon and First Nation governments, applies to all Yukon lands. Although Yukon resources are remote, and pipeline infrastructure is presently lacking, OGR has created an attractive economic environmental and legislative framework that bodes well for future activity.

YUKON'S OIL AND GAS RIGHTS DISPOSITION PROCESS

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 Oil and Gas Resources branch runs two disposition processes annually, which are designed to be completed in approximately five months. Each process 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 the Oil and Gas Resources branch.

In 2007, 14 new permits were issued in northern Yukon totalling \$22.2 million in work commitments. No bids were received on posted locations in 2008.

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, allowing companies the opportunity to plan ahead; and
- a minimum work commitment which has been lowered from \$1 million to \$400 000.

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 64 750 10³m³ of natural gas in the period from January 2008 to October 2008 (Fig. 2)¹. The field is in the later stages of life, and gas production and reservoir pressure are declining slowly, whereas water cuts are increasing. Recovery factor to date is 54% of initial gas-in-place, which is considerably better than similar nearby fields in the basin.

¹www.emr.gov.yk.ca/pdf/Non-Confidential_Production.pdf

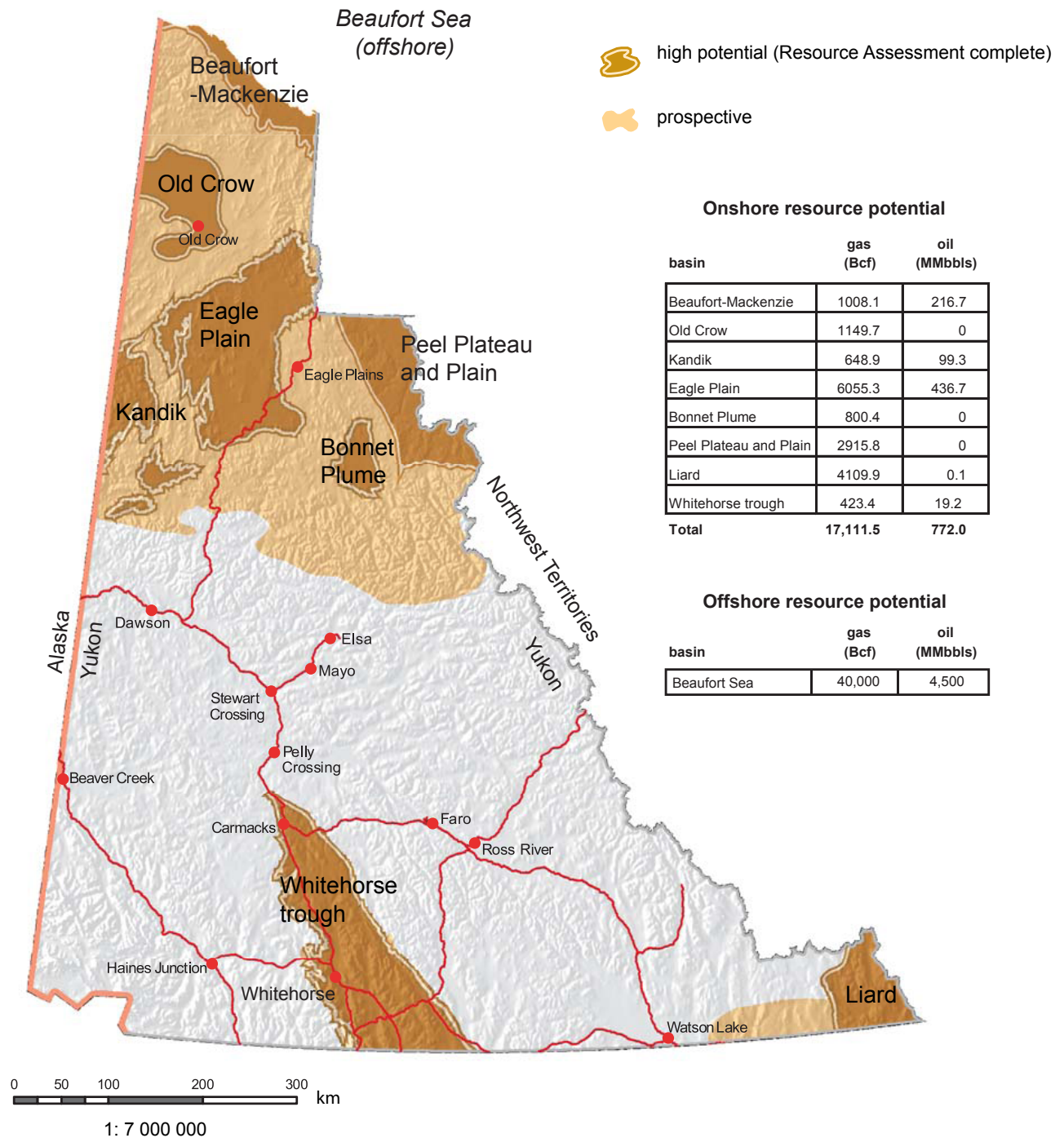
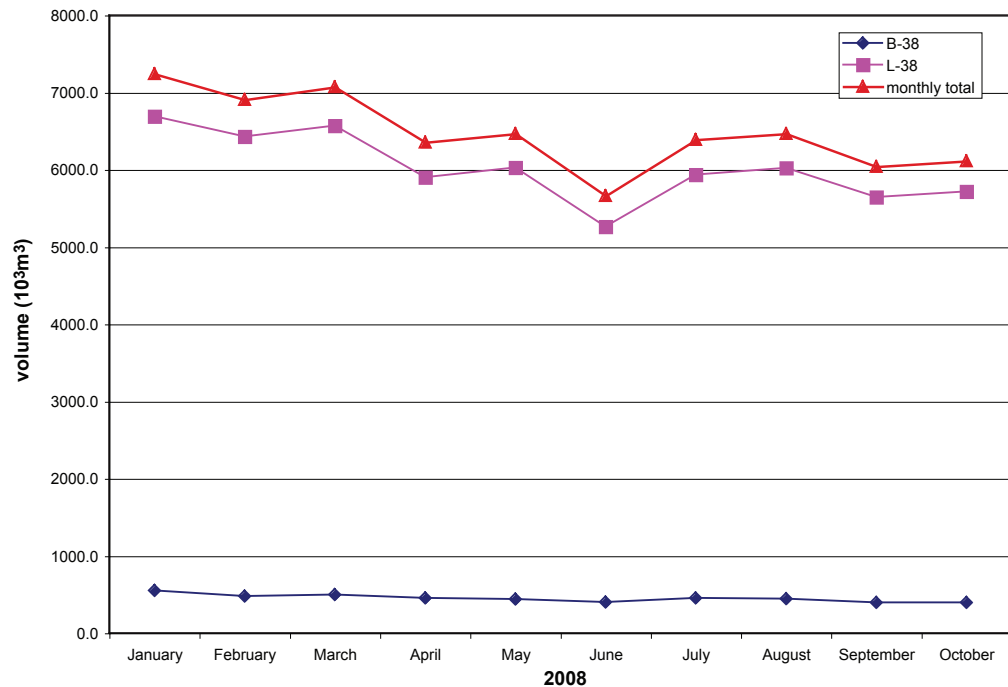


Figure 1. Yukon's oil and gas exploration regions.

Figure 2. Yukon natural gas production, from Kotaneelee field, southeast Yukon.



FIRST NATIONS

The Oil and Gas Resources branch continues to build strong working relationships with First Nations through the development of the common oil and gas regime and through regular consultation during the disposition and licensing processes. OGR supports the Aboriginal Pipeline Coalition (APC) 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. Canada, Yukon, and the APC are working cooperatively toward concluding a more stable long-term funding arrangement as First Nation engagement and participation is essential to the development and implementation of an efficient pipeline regulatory process.

PIPELINES

Both the Mackenzie Gas Project (MGP) and the Alaska Highway Pipeline Project (AHPP) offer enormous economic opportunities for the north (Fig. 3). 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 also continue with our neighbouring jurisdictions – Alaska, British Columbia, Northwest Territories and Alberta – to prepare for both projects.

AHPP will generate an estimated 375 000 person-years of employment over 24 years²; MGP estimates are 181 000 person-years over the same 24-year span³. The construction of these two projects will also inject billions of dollars into the North American economy. These projects would provide access for 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

TransCanada Alaska recently received a license from the State of Alaska, allowing it to access up to \$500 million in state assistance to offset the estimated \$1 billion cost of applying for US regulatory approval to build and operate the AHPP. As a condition of the licence, TransCanada will hold an open season within the next 18 months. An 'open season' is a limited window created by a pipeline company to identify gas producers and shippers interested in seeking carrier capacity on the line, if built, and to provide a willingness to commit their product at an economically feasible carrier price.

British Petroleum and ConocoPhillips have created a joint venture pipeline company called 'Denali' which intends to

²www.emr.gov.yk.ca/pdf/informetrica_econreport_02.pdf

³ www.itl.gov.nt.ca/pipeline/pdf/wright_mansell2004.pdf

file a competing application with the US Federal Energy Regulatory Commission (FERC) and the Canadian National Energy Board. It will also hold an open season in 18-24 months and has pre-filed with FERC in anticipation that a complete application will advance expeditiously when submitted.

Should the chosen route follow the Alaska Highway, this will be important to the interests of the Government of Yukon and to Yukoners. 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.

The Oil and Gas Resources Branch 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, composed of participants from Yukon, British Columbia and Alberta. This group was created in order to manage common issues expected to arise from the various inter-jurisdictional concerns over the Alaska Highway Pipeline Project. Yukon continues to urge the Canadian government to demonstrate that they are prepared with a streamlined, efficient regulatory process.



Figure 3. Northern natural gas pipeline options.

MACKENZIE GAS PROJECT

OGR's involvement with 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 Yukon gas would no longer be cut-off from this competitive market.

Oil and Gas Resources' intervention to this possible project included written submissions and presentations by OGR representatives at both the National Energy Board (NEB) and Joint Review Panel (JRP) hearings. Once the NEB concludes the MGP hearings process, it will submit a final report and recommendations to the federal minister responsible for northern pipelines. It is anticipated that a decision to proceed with the project, if approved, will occur in late 2009.

OGR's intervention in the JRP hearings has resulted in both the proponent (Imperial Oil) and Yukon committing to the enhancement of 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 maintain responsibility for oil and gas management and development in the Beaufort Sea. BP Exploration's \$1.2 billion successful bid in 2008 for exploration rights in the Beaufort Sea, following Imperial Oil/ExxonMobil's 2007 bid of \$585 million for similar rights, plus extensive Beaufort seismic work by GX Technology, are clear indicators that industry remains interested in the offshore, and that governments will need to respond to this renewed interest.

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, the Yukon

and federal governments have drafted a Memorandum of Agreement to identify Yukon's enhanced role in offshore oil and gas management. OGR continues to advance Yukon's offshore interests, including the following: governance, economic benefits, resource revenues, financial considerations, infrastructure, capacity development and sustainable development.

Yukon is actively participating with other governments and industry on a number of existing and proposed Beaufort Sea planning initiatives, including the Beaufort Sea Integrated Management Plan, and directly related to oil and gas, the Beaufort Basin Regional Environmental Assessment.

Taking an integrated management approach to all offshore planning is essential to ensuring an efficient and effective planning and decision-making process. OGR continues to work jointly with Indian and Northern Affairs Canada in undertaking a review of the call for nominations for the Beaufort Sea including the possibility of incorporating 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.

Yukon is pleased that the Government of Canada is engaged in improving the northern regulatory system, which has 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 and efficient.

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.

OIL AND GAS ROYALTY REGULATIONS

The Yukon's Oil and Gas Royalty Regulations were promulgated in February 2008. The regulations authorize the Government of Yukon to collect royalty for oil and gas recovered from Yukon oil and gas dispositions.

The Yukon royalty regime is based on an *ad valorem* (according to value) system with the objectives of transparency and simplicity of administration for both government and industry.

The Government of Yukon's royalty rate is between 10% and 25% of the gross produced value of oil, gas and field condensate. The actual royalty rate paid by producers will vary depending on the market price of oil and gas. As an added incentive for industry, a lower royalty rate of 2.5% is applied on the initial production.

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 and good potential for an economic oil and gas discovery. If the area is further developed, it will also mean a significant economic boost to the residents in the area.

In areas where land claims remain unsettled, Yukon requires consent of the affected Yukon First Nations prior to disposition of oil and gas rights or authorization of oil and gas activities. Significant progress has been made in order to achieve an oil and gas consent agreement with Liard First Nation. 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.

Current efforts are also focused on obtaining Ross River Dena Council consent. If consent is provided by these two First Nations (Liard, and Ross River Dene), the Government of Yukon will begin consultations regarding potential infringement of aboriginal rights with all six First Nations who assert claims within the southeast Yukon. Throughout the disposition and licensing process, the Government of Yukon will be consulting with affected First Nations about proposed oil and gas activities.

YUKON GEOLOGICAL SURVEY

In 2008, Yukon Geological Survey geologists continued oil and gas related research studies on three projects. The focus of two of these projects is in northern Yukon. Field investigations were completed during the 2008 field season in the Whitehorse trough, southern Yukon.

Grant Lowey completed field investigations of the stratigraphy, sedimentology and hydrocarbon potential of the Laberge Group in Whitehorse trough and undertook a detailed study of the petroleum source rock potential of the Bonnet Plume Basin.

The Government of Yukon continued its partnership with the Geological Survey of Canada, the Northwest Territories Geosciences Office, and industry and university affiliates to form a working relationship under the title 'Regional Geosciences Studies and Petroleum Potential, Peel Plateau and Plain, Northwest Territories and Yukon'. This four-year project is in its final stages. A volume and accompanying digital atlas, summarizing the research conducted over the last four years, is due to be released in 2009. The project focused on gaining a better understanding of the petroleum potential of the Peel Plateau and Plain in north Yukon and adjacent Northwest Territories. As part of this partnership, Tammy Allen and Tiffani Fraser of the Yukon Geological Survey examined Upper Paleozoic and Cretaceous strata to better determine their potential as source rocks and reservoir rocks.

OTHER ACTIVITIES

The Oil and Gas Resources branch continues to assist 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 continues to contribute to the development of a Yukon Climate Change Action Plan.

OGR has completed an Energy to Mines Report, which examines the possibility of developing Yukon natural gas resources to generate electricity at selected mine and other end-use sites. The study considers using natural gas produced at the Eagle Plain field as a fuel source, and delivering it by pipeline to the point of use. The study concluded that natural gas is likely a better economic alternative than electricity delivered from the Yukon

Energy grid, or from on-site diesel-powered electric generation.

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

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Yukon Mining Incentives Program, 2008

Steve Traynor¹
Yukon Geological Survey

Traynor, S., 2009. Yukon Mining Incentives Program, 2008. *In: Yukon Exploration and Geology 2008*, L.H. Weston, L.R. Blackburn and L.L. Lewis (eds.), Yukon Geological Survey, p. 51-54.

The Yukon Mining Incentives Program (YMIP) is designed to promote and enhance mineral prospecting and exploration activities in Yukon by providing a portion of the risk capital required to locate and explore mineral deposits.

A total of 58 applications for funding were received by the submission deadline for the 2008 season. Contribution agreements totaling \$774 500 were subsequently issued to 45 successful applicants. Proposals approved for funding included 5 under the Grassroots-Prospecting module, 10 under the Focused Regional module and 30 under the Target Evaluation module.

The trend of the last few years has resulted in placer gold exploration and testing programs accounting for approximately 25% of the projects approved for YMIP funding. This year was no exception and 12 projects, all targeting gold, received approval. Of the remaining 33 projects approved for funding under various hard rock modules, 16 targeted vein-type gold mineralization; 7 were for Cu (\pm Au) porphyry targets; 6 focused on Zn-Pb mineralization in a variety of settings; 3 targeted silver; and 1 focused on uranium (Fig. 1).

There is significant anecdotal and testimonial evidence attesting to the value of mining incentives programs such as YMIP, unfortunately much of the analysis of the benefits of these programs has been restricted to annual comparisons that permit only limited recognition of long-term trends.

In 2006, the Yukon Exploration Activity Database was conceived and developed as an integrated tool to facilitate the collection, analysis and presentation of Yukon exploration, development and mining activity data. This system now contains detailed data covering the period from 2000 to 2008 and has proved to be an important aid in the recognition and interpretation of broader trends within the Yukon's mining industry.

In response to declining levels of exploration spending in the late 1990s, the Yukon government increased funding to YMIP in 2000 (Fig. 2). From 2000 to 2003, projects receiving YMIP funding accounted for 40% of all grassroots exploration. Much of this exploration was undertaken by Yukon prospectors, who during the course of this work, accumulated impressive inventories of early stage exploration targets.

With the upsurge in exploration spending during the past few years, and the mining industry's need for new grassroots targets, Yukon-based prospectors found that they were able to benefit from this increased activity through the negotiation of property option agreements. Analysis of property agreements negotiated during the last six years shows a strong positive correlation between grassroots exploration spending and the numbers of negotiated property agreements (Fig. 3). In 2007, when grassroots exploration spending peaked, a total of 18 property agreements were signed on projects that were generated or advanced, in part, with funding received through the Yukon Mining Incentives Program.

The importance of YMIP's role in generating early stage exploration targets has become increasingly evident in the course of analyzing multiple years of exploration activity data. This analysis has also lead to the recognition of the significant impact this program is having on advanced stages of

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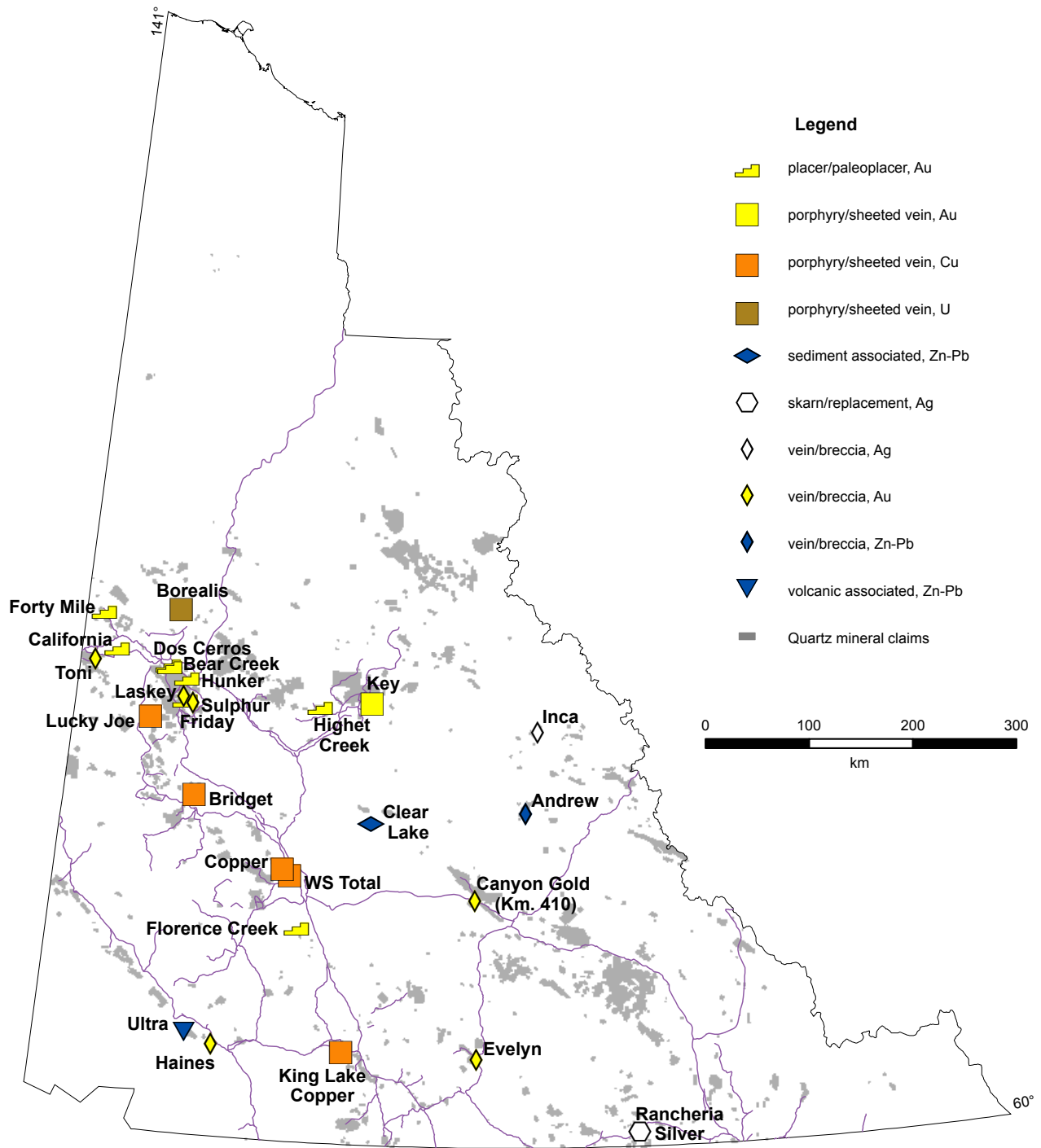


Figure 1. Yukon exploration projects funded by the Yukon Mining Incentives Program (YMIP) for 2008.

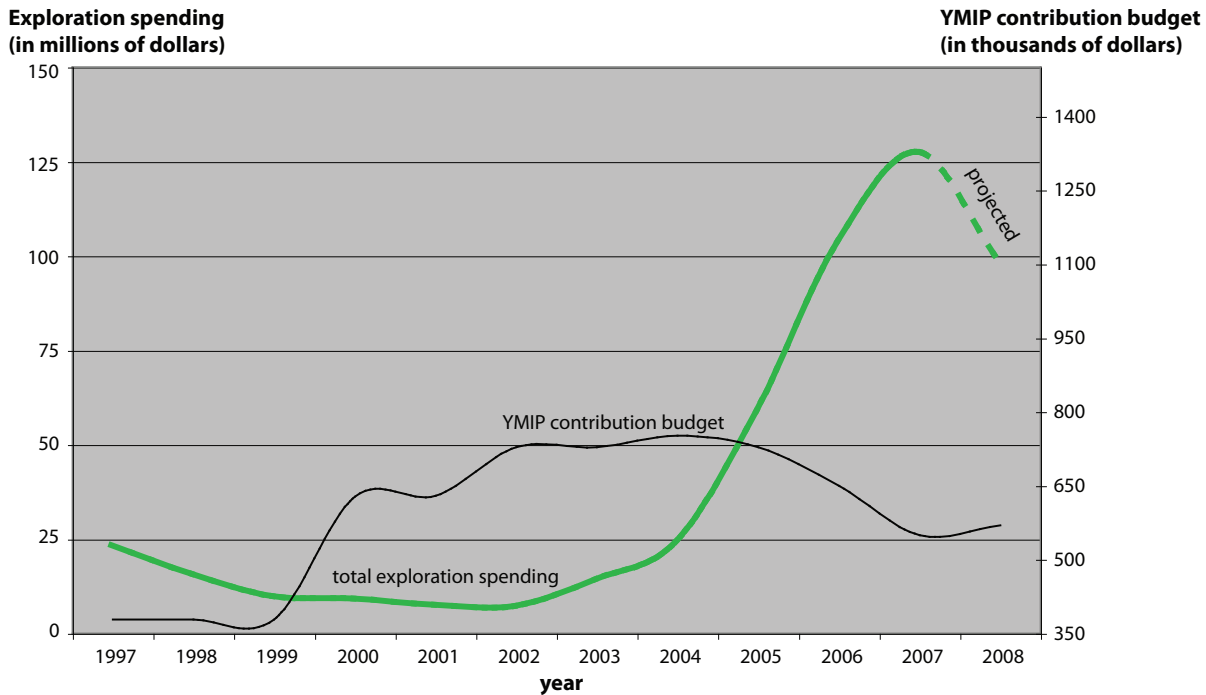


Figure 2. Yukon Mining Incentives Program funding since program inception. The graph depicts contribution budgets versus total exploration spending.

exploration. In the past eight years, one out of every three projects that received some portion of funding through YMIP was optioned following staking. YMIP-funded projects have also accounted for half of all known property agreements negotiated. Furthermore, out of all projects approved for funding through YMIP during this period, one out of every ten has been advanced to the stage of drilling.

The impact of recent world wide events and market realities will inevitably have some effect on mineral exploration and development in Canada. With companies reviewing their levels of discretionary expenditures on exploration, governments that work to improve their local investment climate will be better able to sustain mineral exploration and development activities in their

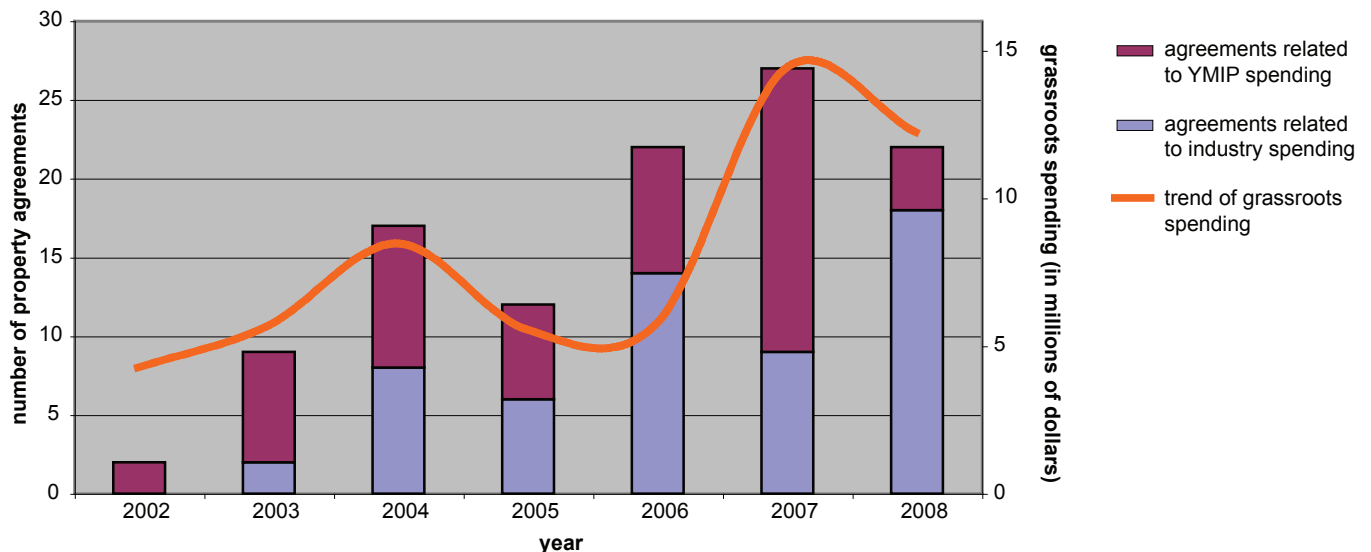


Figure 3. Property agreements related to YMIP and industry spending.

jurisdictions by providing financial incentives to attract available risk capital.

During periods of prosperity and through those inevitable times of economic challenge, programs such as YMIP play a fundamentally important role in early stage project generation, as well as the development of projects entering more advanced stages of exploration. Across Canada, the Government of Yukon is a leader in their commitment to providing economic incentives to mining exploration and development through the Yukon Mining Incentives Program.

RÉSUMÉ

Le Programme d'encouragement des activités minières au Yukon (Yukon Mining Incentives Program - YMIP) vise à promouvoir et à améliorer les activités de prospection et d'exploration minière au Yukon en fournissant une partie du capital de risque nécessaire pour localiser et explorer les gisements minéraux.

Au total, 58 demandes de financement ont été reçues avant la date butoir pour la saison 2008. Les accords de contribution ont permis à 45 demandeurs d'obtenir 774 500 \$ au total. Parmi les demandes approuvées, 5 ont obtenu un soutien dans le cadre du programme d'exploration primaire et de prospection, 10 dans le cadre du programme régional d'exploration des régions sous explorées et 30 dans le cadre du programme d'évaluation de cibles.

La tendance des dernières années a eu pour effet que les programmes d'essai et d'exploration d'or placérien comptent pour environ 25 % des projets approuvés en vue d'un financement dans le cadre du YMIP. Cette année ne constitue pas une exception puisque 12 projets axés sur l'or ont été approuvés. Parmi les 33 autres projets approuvés dans le cadre de divers modules relatifs aux roches métamorphiques, 16 sont axés sur la minéralisation aurifère filonienne, 7 sur le porphyre Cu (\pm Au), 6 sur la minéralisation Zn-Pb dans divers milieux, 3 sur l'argent et 1 sur l'uranium.

Robert E. Leckie Awards for Outstanding Reclamation Practices

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St. Amand, J., 2009. Robert E. Leckie Awards for Outstanding Reclamation Practices. *In: Yukon Exploration and Geology 2008*, L.H. Weston, L.R. Blackburn and L.L. Lewis (eds.), Yukon Geological Survey, p. 55-58.

QUARTZ RECLAMATION

SELWYN RESOURCES LTD.

Selwyn Resources Ltd. focused significant attention on reclamation at its active Selwyn lead-zinc project (Howard's Pass) in eastern Yukon, in 2008. The aggressive bio-engineering of slopes has been extended to many more areas of the property. The company has stabilized roads, creek banks and the airstrip by transplanting live willow from the property in an innovative manner that is proving very successful (Fig. 1). In addition, the completion of numerous baseline studies has allowed the company to make informed decisions on issues with potential environmental impacts.



Figure 1. Bio-engineering in the Don Valley: live willows are being planted to stabilize the banks of the road.

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Selwyn's commitment to local communities and the ongoing education of youth in environmental studies demonstrates how the company's progressive environmental and socio-economic policies and practices are incorporated into its operations. Selwyn truly demonstrates excellence in environmental stewardship, social responsibility, leadership and innovation, which encompasses all that this award stands for.

HONOURABLE MENTION: International KRL Resources Corporation has been operating on the NOR property, located 395 km northeast of Dawson City. The company has consistently adhered to best management practices, and works cooperatively with the district Natural Resource Officer to surpass the requirements of its permit.

International KRL identified and removed an old site abandoned in the 1970s. Site reclamation included burning tent frames and removing fuel drums and barrels (Fig. 2). The company demonstrates a genuine desire to take responsibility for past practices of others, expending time and money to do so.



Figure 2. Reclamation and restoration of an abandoned camp site from the 1970s. Black areas show where tent frames were burned. All that remains on-site is core (core boxes are shown in middle of photo).

PLACER RECLAMATION

ROSS MINING LTD.

Ross Mining Limited continues to carry out exceptional restoration work on its Dominion Creek claims, the largest placer mining operation in Yukon. Extensive use of topsoil has allowed for rapid re-vegetation of parts of the property. Mined areas have been transformed into a rich-living ecosystem with newly created ponds and waterways that form a haven for moose, fox, geese, ducks and swans (Fig. 3).

Jon Rudolf, president of Ross Mining Ltd., has introduced the idea of ethical gold to Yukon. His company Mammoth Tusk Gold offers the Ethical Gold Certification Program. This certification is rooted in values of sustainability, environmental and social responsibility, and fair practices. The chain of custody must be certified from unearthing, to smelting, to delivery for sale.

Ross Mining demonstrates excellence in environmental stewardship, social responsibility, leadership and innovation. The founding of Mammoth Tusk Gold has opened a new arena where Yukon and placer mining can truly shine.



Figure 3. Placer mining continues at the Ross Mining operation next to reclaimed areas. Numbers 1 to 5 represent areas that have been reclaimed or are in the process of being reclaimed. Number 1 is the oldest and number 5 is the youngest.

HONOURABLE MENTION: Since 2004, HC Mining Limited has been operating on Moosehorn Creek, a tributary of Henderson Creek, in the Dawson mining district. Hayden Cowan, the owner, is in the process of applying for Ethical Gold Certification.

The restoration measures used by HC Mining Ltd. go beyond 'best practices' in mining reclamation. The very steep overburden piles, which blocked passage across the valley, have been reduced to gentle slopes (Fig. 4). The

creek bank has been armoured along its length, and a settling pond is in place for catchment of any sediment while slopes stabilize. Top soil has been spread to enable entrapment of water and airborne seed, which will encourage rapid re-vegetation.

HC Mining is commended for its efforts in accelerating the re-establishment of this valley for use by wildlife and the public.



Figure 4. Re-sloped and contoured overburden piles along the creek allow for safe passage of migrating wildlife.

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Overview of Yukon Geological Survey: 2008-09

Carolyn Relf¹
Yukon Geological Survey

Relf, C., 2009. Overview of Yukon Geological Survey: 2008-09. *In: Yukon Exploration and Geology 2008*, L.H. Weston, L.R. Blackburn and L.L. Lewis (eds.), Yukon Geological Survey, p. 61-64.

INTRODUCTION

As new director of the Yukon Geological Survey (YGS, Fig. 1) I would like to take this opportunity to give you my impressions of the survey and share some thoughts on where we are going as an organization. If I had to summarize how it feels to be part of YGS in one word, I would choose this one: "lucky". Brevity is not my strongest point, however, so I am going to use more than one word to elaborate a bit on the survey and its strengths.

YGS, like all geological surveys in Canada, has undergone significant changes over the past decade. Following federal devolution, the survey merged and grew under Grant Abbott's direction into a



Figure 1. Yukon Geological Survey staff standing in front of the native copper slab from the White River area at MacBride Museum. (front row, left to right) Aubrey Sicotte, Rosie Cobbett, Carolyn Relf, Lara Lewis and Leyla Weston. (second row, left to right) Grant Abbott, Kristen Kennedy, Rachelle Dufour, Carrie Labonte, Karen MacFarlane, Olwyn Bruce, Tammy Allen and Mike Burke. (third row, left to right) Tiffani Fraser, Rod Hill, Steve Israel, Panya Lipovsky, Bailey Staffen, Maurice Colpron, Don Murphy, Lee Pigage, Jeff Bond, Robert Deklerk, Bill Lebarge and Karen Pelletier. (back row, left to right) Steve Traynor, Charlie Roots and Grant Lowey.

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single organization with a clear mandate and a vision for excellence. During his last year as director, Grant made some organizational changes that clearly defined the functional areas of the survey and streamlined operations. Following the re-organization, he sought and received approval to hire the new director (me) four months before his retirement date. This transition period was an excellent idea as it allowed me to spend time with Grant asking all manner of questions¹ about the survey's scientific program, its administrative and financial workings, and our clients. I am very grateful to Grant for buffering me during my first few months and hope I can fill his shoes adequately. Fortunately for the whole survey, he has returned on a part-time basis as a Project Geologist; his unwritten duties will include being an ongoing source of advice and corporate memory.

There were other staff changes at YGS this past year. In the spring, our Economic Geologist, Ken Galambos, took an extended leave of absence to work as a consultant in the mineral exploration industry. In the fall, the Head of our Technical Services Section, Diane Emond, was accepted into Yukon College's practical nursing program. Their absence is being felt, and I would like to take this opportunity to thank them for their contributions to the survey and wish them success in their respective career paths. In August, Karen MacFarlane from the Northwest Territories Geoscience Office joined YGS on an 18-month assignment. Karen is working with our Data Management and Minerals staff on a project that will upgrade and streamline our corporate databases (MINFILE, Mineral Exploration Activity, Placer and Publications).

A SNAPSHOT OF YGS

The Yukon Geological Survey is part of the Department of Energy, Mines and Resources (EMR), which is responsible for managing and supporting the sustainable development of Yukon's energy and natural resources. The mandate of YGS is to provide the geoscience information that will support both the resource management policies of government and investment decisions by industry. The information we provide also supports land use planning initiatives and the development and maintenance of

Yukon's physical infrastructure. Funding for our activities comes from Yukon government and from Indian and Northern Affairs Canada (through their Strategic Investments in Northern Economic Development initiative).

The survey comprises four work units (Fig. 2), each responsible for different aspects of our mandate. The current activities of staff in each unit are described separately in this volume (see Relf, this volume); I have limited myself in this paper to giving a brief overview of each unit's responsibilities and a description of how they are integrated.

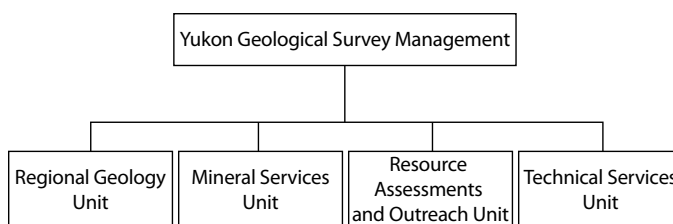


Figure 2. Simplified organizational chart, Yukon Geological Survey.

REGIONAL GEOLOGY UNIT

The Regional Geology Unit undertakes bedrock and surficial mapping and associated thematic investigations such as structural, metamorphic, geochemical and geochronological studies. The maps provide a framework for mineral and hydrocarbon exploration, regional tectonic and stratigraphic correlations, and allow interpretation of Yukon's protracted bedrock and surficial geologic histories. Included among the activities of this group are studies of permafrost, which contribute to climate change monitoring and the prediction and mitigation of landslides. Staff in this unit are Don Murphy (Head), Maurice Colpron, Steve Israel, Jeff Bond, Panya Lipovsky and Grant Abbott. Charlie Roots, a Geological Survey of Canada employee, is co-located with us and is a key part of the mapping group. In addition, we currently have one vacant mapping position.

¹Shortly after my arrival in Whitehorse it was pointed out to me that Grant has a certain expression, known as the 'look', wherein he gazes at you over the top of his glasses with his eyebrows raised. The 'look' appears to be code for "what was I thinking when I hired you?" During my question-intensive overlap period with Grant, I was recipient of the 'look' 17 times. I don't know whether that's good or bad, but luckily I think it's too late for YGS to change its mind about me.

MINERAL SERVICES UNIT

The Mineral Services Unit provides information and advice to governments, industry, the general public and Yukon First Nations on Yukon's mineral resources and ongoing exploration and development activities. Staff monitor results of mineral exploration programs, track placer production, administer the Yukon Mining Incentive Program (YMIP), and liaise with staff in other branches of EMR such as Mining Lands (to track exploration expenditures and trends) and Client Services and Inspections (e.g. to share data on placer mining activities). Mineral Services maintains Yukon's MINFILE, Placer, and Mineral Exploration Activities databases. In addition, Mineral Services contributes regularly to various media that include articles and brochures describing the current status on Yukon's mineral deposits and exploration activities. Staff include Mike Burke (Head), Bill Leberge, Steve Traynor, Rob Deklerk and Karen MacFarlane (on assignment from Northwest Territories Geoscience Office).

RESOURCE ASSESSMENTS AND OUTREACH UNIT

Resources Assessments and Outreach staff deliver a range of activities and programs. A core part of the unit's responsibilities includes completing geoscience studies in order to appropriately assess Yukon's potential hydrocarbon and mineral resources. Such studies support our ongoing land use planning processes by providing information about a planning area's potential economic values, and help the Yukon government and Yukon First Nations make sound resource management policies and decisions. In addition to assessments, this unit administers Yukon's Mineral and Petroleum Environmental Research Group (MPERG), allocating grants for environmental research with applicability to resource development.

Outreach activities of YGS are varied, targeting both the general public and Yukon's schools. Our outreach program is coordinated by the Resource Assessments and Outreach Unit, however, all members of our staff contribute to the survey's outreach and public education efforts.

Staff in this unit are Lee Pigage (Head), Karen Pelletier, Grant Lowey, Tammy Allen and Tiffani Fraser. Currently, our Mineral Assessment Geologist position is vacant.

TECHNICAL SERVICES UNIT

The Technical Services Unit provides services both internally to YGS staff and to external clients. Internally, they provide expertise in database development and data management, GIS and cartography support, and technical editing of publications (including editing of this volume²). External services include the maintenance of our website and its various web-based applications, sales of maps and publications, and general 'front-line' services to clients. Staff include Lara Lewis (Acting Head), Olwyn Bruce, Aubrey Sicotte, Bailey Staffen, Leyla Weston and Rachelle Dufour. We hope to fill the Head of Technical Services position early in 2009.

YUKON GEOLOGICAL SURVEY MANAGEMENT

Rod Hill (Operations Manager), Carrie Labonte (Administrative Coordinator) and I (Director) coordinate and support the work of all four units at YGS. Collectively, we manage administrative, financial and human resource responsibilities, liaise with other Yukon government branches and departments, and network with external partners (governments and universities). Implicit among the list of management-related duties is the fact that we are accessible to all clients who may have questions about the survey or any of its activities.

FUNDING, PROGRAM DELIVERY AND OVERSIGHT

Yukon Geological Survey activities are funded from a number of sources. We have a core operating budget which funds the bulk of our program activities, with the exception of mineral and petroleum resource assessments for which dedicated funds are allocated. Grants under YMIP and MPERG are managed by YGS as well; this year we allocated \$605,000 for YMIP, and \$50,000 for MPERG grants. The latter program was delivered collaboratively with other Yukon government departments, Yukon First Nations, industry and non-government organizations.

While YGS is the primary organization dedicated to the delivery of public geoscience in Yukon, we are not the only organization. Between 2005 and 2009, the Department of Indian and Northern Affairs Canada (INAC) provided YGS with funds for geoscience projects

²For example, Technical Services will be editing this paper. I'll be curious to see whether my footnote on Grant Abbott's 'look' survives the editors' pen. If it doesn't, this footnote won't make a lot of sense to readers.

through their Strategic Investments in Northern Economic Development (SINED) program. YGS used the funds to fill gaps in regional geophysical coverage (mainly aeromagnetic), to update portions of Yukon's regional stream sediment geochemistry database, and to support targeted mapping. A list of SINED-funded projects is provided in a separate paper (Relf, this volume).

In February 2008, the Federal Government announced a program called Geo-mapping for Energy and Minerals (GEM), which is aimed at collecting and distributing geoscience data to support the development of mineral and energy resources in Canada's North. Originally announced as a two-year program, a subsequent announcement in August by the Prime Minister extended the program to 2013. While GEM program funds will be spent by the Geological Survey of Canada (GSC), GEM projects in Yukon will be jointly planned and co-delivered with YGS. Following six months of meetings and correspondence with GSC, we have developed a plan for Yukon GEM projects, which was presented to our Technical Liaison Committee in November for their feedback. GEM projects are described briefly in a separate contribution (Relf, this volume).

In addition to GSC collaboration, YGS has research partnerships established with the British Columbia Geological Survey, Alaska Geological Survey and a number of universities. Activities include joint research projects and co-supervision of, and support for, student thesis projects.

The way in which we set program priorities and define annual workplans is complex. Some activities, such as mineral and energy resource assessments, are defined to address specific needs of Yukon and Yukon First Nations

governments. These assessments support resource management decisions, development of government policy and commitments made under the Umbrella Final Agreement. Other activities are defined following consultation with our Technical Liaison Committee, who provides an industry perspective on geoscience needs in Yukon. Our commitment to the GSC to collaborate on GEM program activities represents an opportunity to maximize return by sharing field expenses and integrating our expertise. University collaborations are also advantageous: we can provide learning opportunities for undergraduate and graduate students, and, in turn, the universities have the expertise and analytical capacity that we lack.

WHAT'S NEXT?

Fifteen years ago, Grant Abbott initiated a long-term planning cycle for YGS. The planning meetings, held every five years, provide a planning template that helps to set priorities for annual work. This spring will mark five years since the last planning meeting. We have started preparing for our 2009 planning session by taking a critical look at our current work commitments and our staff capacity and demographics. When we meet this spring we will discuss Yukon's geoscience gaps and needs that will cover the next five to ten years. Our main goals include trying to anticipate our various clients' needs, keeping up with latest trends in information management and delivery, and predicting how our staff capacity might change over the next decade. The planning will focus beyond 2013, as that is when our current GEM-related commitments will end. The planning document will be made publicly available and we would greatly appreciate any feedback.

Summary of Yukon Geological Survey's 2008-2009 activities

Carolyn Relf¹
Yukon Geological Survey

Relf, C., 2009. Summary of Yukon Geological Survey's 2008-2009 activities. *In: Yukon Exploration and Geology 2008*, L.H. Weston, L.R. Blackburn and L.L. Lewis (eds.), Yukon Geological Survey, p. 65-75.

ABSTRACT

Yukon Geological Survey (YGS) is delivering 16 field-based projects this fiscal year, including three regional mapping projects, two sedimentary basin studies, five geophysical surveys and five student projects. YGS also provided support for several external collaborators and undertook visits to 29 communities and schools. In addition to field-based activities, staff initiated the development of a new corporate database for managing our various data sets and administered the Yukon Mining Incentives and Mineral and Petroleum Environmental Research Group programs (YMIP and MPERG, respectively).

Following the announcement of the federal GEM (Geo-mapping for Energy and Minerals) program, YGS has been investing significant time providing input to the Geological Survey of Canada on Yukon's geoscience priorities, to ensure the program addresses our clients' needs. Information on Yukon-based GEM activities was presented at the Yukon Geoscience Forum and will be updated in January 2009 at Mineral Exploration Roundup in Vancouver.

RÉSUMÉ

La Commission géologique du Yukon (CGY) a mis en œuvre 16 projets sur le terrain au cours de la présente année financière, y compris trois projets de cartographie régionale, deux études de bassins sédimentaires, cinq levés géophysiques et cinq projets étudiants. La CGY a également fourni du soutien à plusieurs collaborateurs externes et elle a effectué des visites dans 29 communautés et écoles.

Outre les activités sur le terrain, le personnel de la CGY a lancé les travaux d'élaboration d'une nouvelle base de données pour la gestion des divers jeux de données de la CGY et il a dirigé le Programme d'encouragement des activités minières au Yukon (Yukon Mining Incentives Program - YMIP) ainsi que le groupe de recherche environnementale sur les minéraux et le pétrole (Mineral and Petroleum Environmental Research Group - MPERG).

À la suite de l'annonce du programme de géocartographie de l'énergie et des minéraux (programme de GEM), la CGY a travaillé activement à la communication des priorités géoscientifiques du Yukon à la Commission géologique du Canada, ce qui permettra d'assurer que le programme satisfera les besoins des clients de la CGY. Des renseignements sur les activités du programme de GEM menées au Yukon ont été présentés lors du Forum géoscientifique du Yukon et seront mis à jour lors de la conférence sur l'exploration minérale de 2009 (Mineral Exploration Roundup 2009) à Vancouver.

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INTRODUCTION

Yukon Geological Survey (YGS) had a busy field season in 2008, carrying out field work across the territory and providing support to a number of external researchers working in Yukon. Several new maps and reports were released in 2008 (see the list of new releases at the end of this volume) and a major information management project was initiated. Forty-five exploration projects were approved for funding under the Yukon Mining Incentive Program (YMIP) and 5 projects received funding from the Mining and Petroleum Environmental Research Group (MPERG). This year, YGS awarded the first annual Bradshaw Memorial Scholarship to Derek Turner of Simon Fraser University, British Columbia. The scholarship, named after YGS geologist Geoff Bradshaw, provides funds to both Canadian and international students enrolled in a graduate program in earth sciences at a Canadian university and whose focus of study is in Yukon.

Following the federal government's announcement of new funding for geological mapping this year (Geo-mapping for Energy and Minerals; or GEM program), YGS has been pursuing discussions with the Geological Survey of Canada (GSC) to define and scope out projects that meet the needs of stakeholders in Yukon's exploration and development sector, as well as addressing the program outcomes defined by the federal government. As of early December, four proposals had been submitted to the GSC

for Yukon-based projects; decisions regarding whether these projects will proceed, and at what level of funding, are anticipated by the end of December.

YGS project activities are presented in the following pages in tabular form. The tables briefly outline project status and current activities; more detailed descriptions of projects may be found elsewhere in this volume (entries that are highlighted are linked to the relevant paper), or can be viewed on the YGS website (www.geology.gov.yk.ca).

FIELD ACTIVITIES

MAPPING

During the 2008 field season, YGS staff undertook five field projects (Table 1). These included regional bedrock and surficial mapping and associated thematic studies centred in southwestern Yukon, as well as two studies focused on energy potential in sedimentary basins of northern Yukon. Locations of these projects are shown in Figure 1.

THEMATIC STUDIES

A variety of thematic studies are being carried out across Yukon by YGS staff in partnership with colleagues from other organizations (Table 2). Locations of these projects are shown in Figure 2.

Table 1. Mapping projects.

Project	Participants	Summary of activities
Windy-McKinley	Don Murphy, Maurice Colpron (YGS), Cees van Staal (GSC)	Year 3 of a multi-year mapping project: 2008 activities included 1:50 000 bedrock mapping and associated geochronologic and geochemical studies. Project scope has expanded such that Windy-McKinley is the core around which a larger, multi-disciplinary YGS-GSC-BCGS 'Edges' project evolved; Edges will examine the geologic histories and mineral potential of accreted terranes of the northern Cordillera and the tectonically modified edges of those terranes. See Murphy <i>et al.</i> (this volume) for more details.
Stevenson Ridge	Jeff Bond, Panya Lipovsky (YGS)	Year 2 of a multi-year mapping project: 2008 activities included 1:50 000 surficial mapping. Project goals include unravelling early to mid-Pleistocene glacial history along the southern margin of Beringia; evaluating regional placer gold potential and documenting discontinuous permafrost (with implications for landslide hazards and feasibility studies of potential rail link routes).
Kluane Ranges	Steve Israel (YGS)	Final season of 1:50 000 bedrock mapping in Kluane Ranges. Project focus: resolution of regional tectonic and stratigraphic questions within Wrangellia and adjacent Alexander terrane; and assessment of mineral potential (magnetic nickel-copper-PGE, VMS, skarn, porphyry) of the area.
Peel Plateau	Tammy Allen, Tiffani Fraser (YGS)	Final wrap-up field work on joint NWT-Yukon Peel Plateau and Plain project. Activities focused on examination and collection of samples from Upper Paleozoic Imperial and Tuttle formations to better characterize their source and reservoir potential.
Bonnet Plume Basin	Grant Lowey (YGS)	Year 1 of a 2-year study of oil and gas potential of Bonnet Plume basin. Field activities included measurement of stratigraphic sections and sample collection for Rock-Eval, organic geochemistry, etc. See Lowey (this volume) for more details.

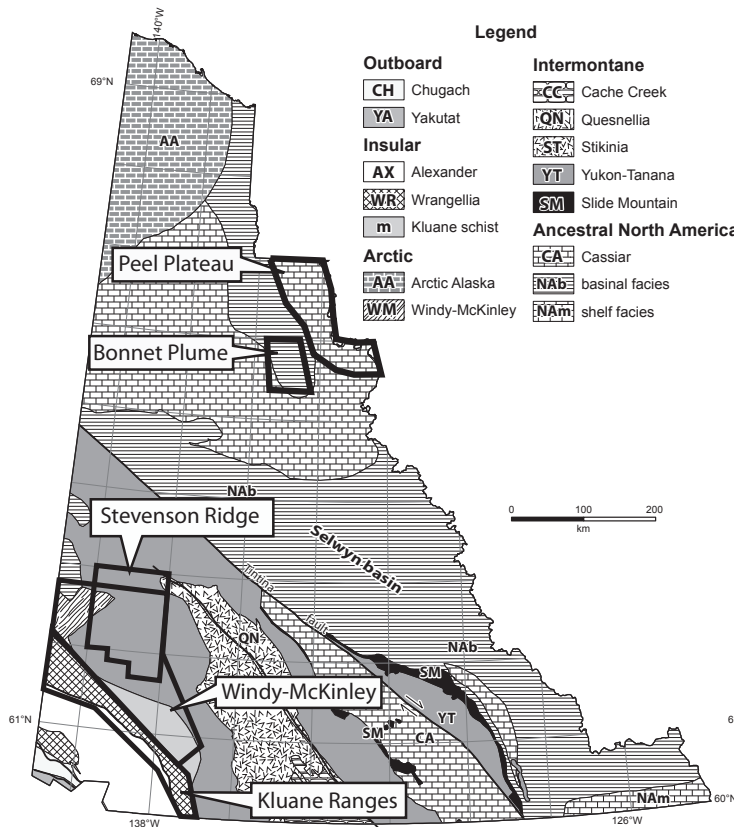


Figure 1. Location of mapping projects.

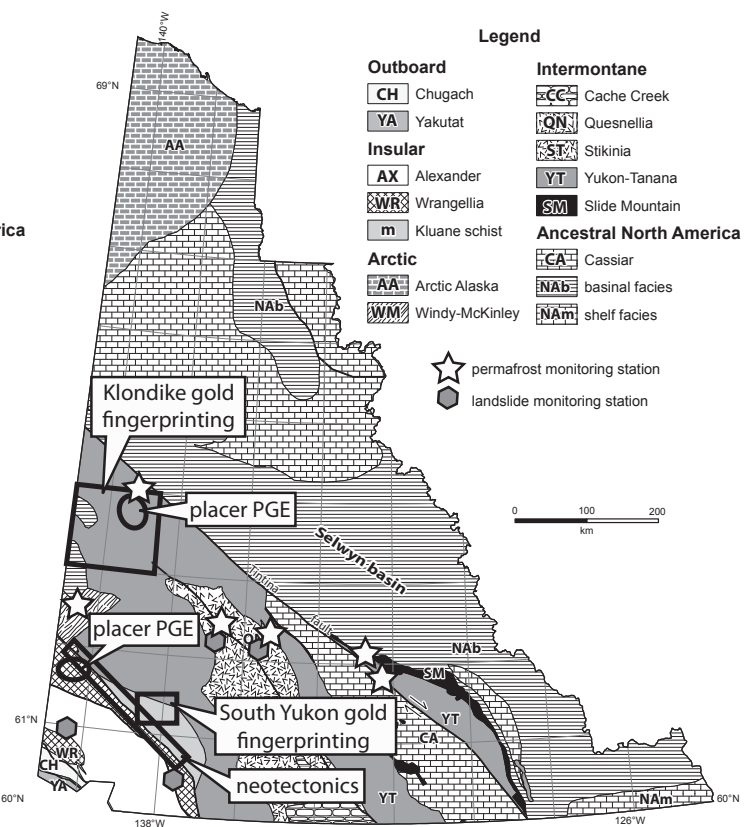


Figure 2. Location of thematic studies.

Table 2. Thematic studies.

Project	Participants	Summary of activities
PGE placer	Bill LeBarge (YGS), Yana Fedortchouk (Dalhousie)	Ongoing study of PGE placer potential of Yukon creeks; 2008 activities included collection of samples from Burwash, Dollis and Scroggie creeks and separation of heavy minerals for analysis at Dalhousie University.
Gold geochemistry	Bill LeBarge (YGS), Rob Chapman (Leeds)	Ongoing study of geochemical signatures of placer gold grains from Indian River (Klondike area) and southern Yukon. Analysis being undertaken at University of Leeds (collaboration with Rob Chapman).
SW Yukon neotectonics	Panya Lipovsky, Don Murphy, Steve Israel, Jeff Bond (YGS), Stéphan Mazotti (GSC), John Clague (SFU), Peter Haeussler (USGS)	Ongoing multi-disciplinary studies to constrain locations and slip rates of Denali and Duke River fault systems. 2008 activities included: detailed GPS measurements to determine relative displacement across the Denali fault (Mazotti); sediment coring along Denali fault (Clague); detailed mapping along Duke River fault (Cobbett; see below); and trenching of sediments across Denali fault to determine relative ages of previous slip events.
Permafrost monitoring	Panya Lipovsky (YGS)	Ongoing monitoring. 2008 activities included collection of temperature data from seven permafrost monitoring stations in southern Yukon (see Lipovsky, this volume), as well as compilation of borehole data along Alaska Highway corridor.
Landslide monitoring	Panya Lipovsky (YGS)	Ongoing monitoring of landslide hazards in several locations in Yukon, including Mount Steele, Kusawa Lake, Carmacks and Little Salmon Lake area.

STUDENT PROJECTS

Support was provided by YGS for the field components of eight graduate thesis projects this year. The studies (Fig. 3) are described in Table 3.

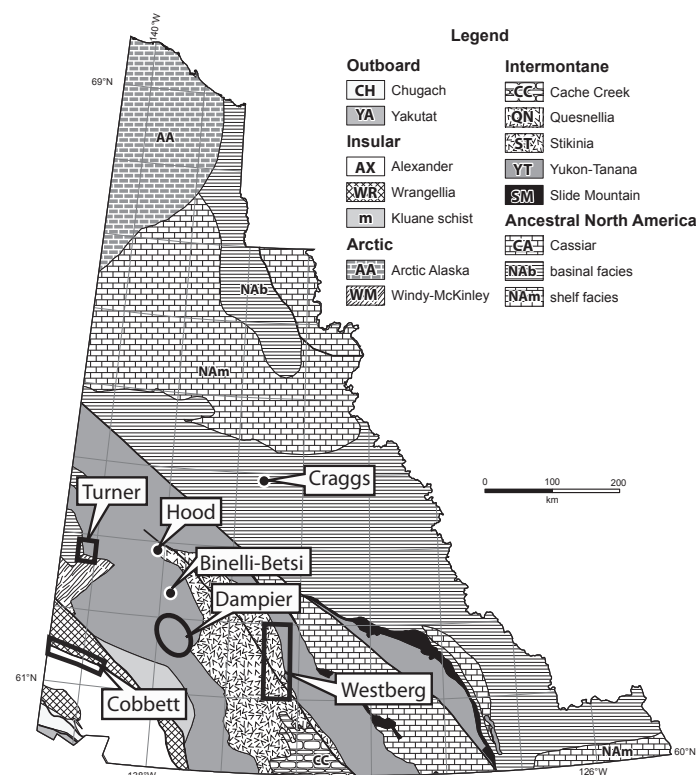


Figure 3. Location of student projects.

Table 3. Student projects.

Project	Participants	Summary of activities
Laberge/Quiet lakes	Elizabeth Westberg (SFU)	Year 2 of fieldwork for MSc thesis supervised by Maurice Colpron (YGS) and Dan Gibson (SFU). Study focuses on documenting tectonothermal history of a portion of Yukon-Tanana terrane. See Westberg, this volume.
SW Yukon glacial history	Derek Turner (SFU)	Year 1 of field work for PhD thesis supervised by Brent Ward (SFU) and Jeff Bond (YGS). Study focuses on stratigraphy of sediments associated with the penultimate Pleistocene glaciation.
Duke River fault	Rosie Cobbett	Year 1 of field work for MSc thesis supervised by Steve Israel (YGS), Cees van Staal (GSC) and Jim Mortenson (UBC). Study examines displacement history of Duke River fault which separates Wrangellia and Alexander terranes.
Central Yukon soil study	Lesley Dampier (SFU and UNBC)	Year 1 of field work for MSc thesis supervised by John Clague (SFU), Paul Sanborn (UNBC) and Jeff Bond (YGS). Study compares modern and Pleistocene soil horizons in upland sites in the Dawson Range. See Dampier, this volume.
Minto deposit	Shawn Hood (UBC)	Year 1 of field work for MSc thesis supervised by Maurice Colpron (YGS) and Ken Hickey (Mineral Deposit Research Unit, UBC). Study focuses on the role of deformation in concentrating Cu and Au at the Minto deposit. Study supported by Capstone Mining Corp. See Hood, this volume.
Dawson Range Au, Ag	Thierry Binelli-Betsi (UNB)	Year 2 of field work for PhD thesis supervised by Dave Lentz (UNB), sponsored by Northern Freegold Resources Ltd. Study focuses on defining regional and local controls on the distribution of mineralized veins.
Keno Hill	Simon Craggs (UNB)	Year 1 of field work for PhD thesis supervised by Dave Lentz (UNB), sponsored by Alexco. Study focuses on structural evolution of Ag-Pb veins.

GEOPHYSICAL SURVEYS

Four geophysical surveys are planned, or have been completed this fiscal year (Fig. 4). Geophysical surveys funded by YGS are managed by the GSC’s Regional Geophysics Section and are jointly released by GSC and YGS. The data collected will support new and ongoing bedrock mapping. Table 4 summarizes the status of each survey.

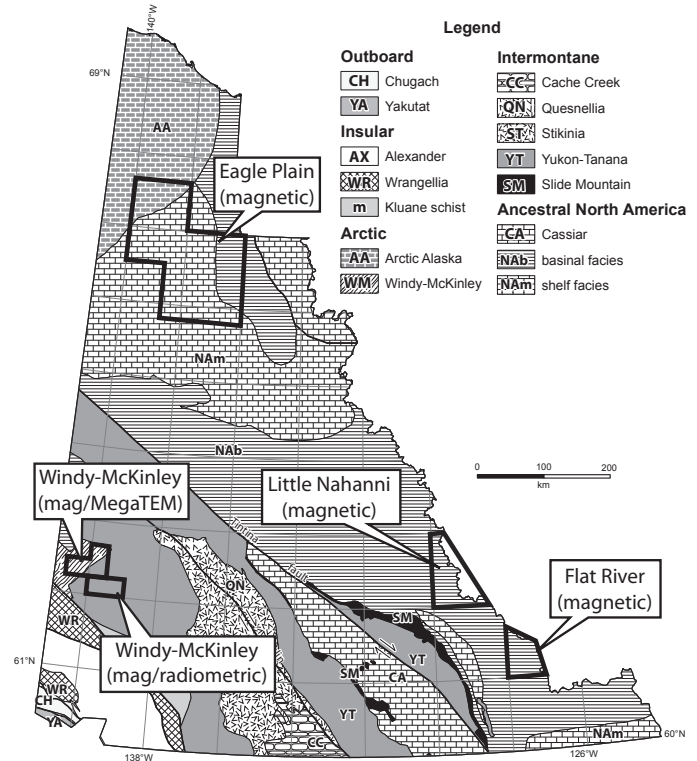


Figure 4. Location of geophysical surveys.

Table 4. Geophysical surveys.

Project	Participants	Summary of activities
Windy-McKinley Mag-EM	YGS, GSC	Combined aeromagnetic/MegaTEM™ survey over a poorly exposed volcanic package interpreted to correlate with rocks of the Delta VMS District of Alaska. Survey funded by INAC (SINED) and GSC (GEM); data collection completed.
Windy-McKinley Mag-Rad	YGS, GSC	Combined aeromagnetic/radiometric survey to delineate distribution and compositional variations of Cretaceous to Tertiary felsic-intermediate volcanic package and to facilitate exploration for epithermal and magmatic hydrothermal mineralization. Survey funded by INAC (SINED); data collection completed.
Eagle Plain Mag	YGS, GSC	Aeromagnetic survey over Eagle Plain scheduled to be flown between January and March 2009. Data will support ongoing bedrock geology compilation under GEM. Survey funded by INAC (SINED).
Little Nahanni-Flat River Mag	YGS, GSC	Aeromagnetic survey over Little Nahanni and Flat River map sheets, scheduled to be flown between January and March 2009. Data will fill gaps in existing regional magnetic coverage. Survey funded by INAC (SINED) and YGS.

PROJECT WRITE-UPS AND COMPILATION WORK

Several YGS projects have completed the data collection phase and are in the synthesis/write-up stage (Fig. 5). An update of these projects is provided in Table 5.

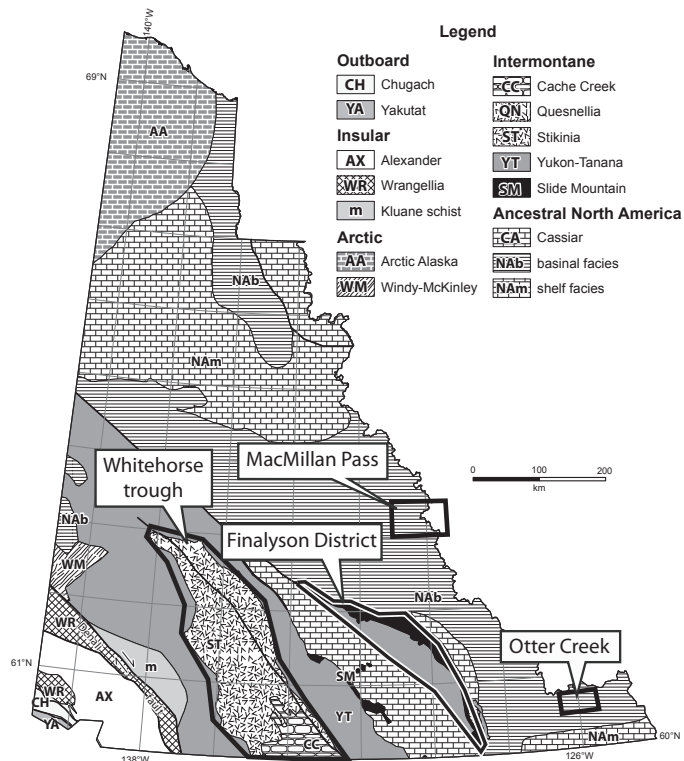


Figure 5. Location of project write-ups and compilation work.

Table 5. Project write-ups and compilation work.

Project	Participants	Summary of activities
Otter Creek	Lee Pigage (YGS)	Two 1:50 000 scale bedrock geology maps released in November 2008 (Toolbally and Pool Creek). Accompanying Bulletin under technical review; anticipate release early 2009.
Glenlyon/Whitehorse trough	Maurice Colpron, Grant Lowey (YGS), Don White, Steve Gordey (GSC)	Paper on Petroleum source rock potential of Whitehorse trough (Lowey <i>et al.</i> , in press) submitted to Bulletin of Canadian Petroleum Geology. Publications underway include Open File geology maps of Whitehorse trough (Colpron), a paper interpreting the seismic section across the basin (Colpron and White), a structural interpretation of the basin (Colpron <i>et al.</i>) and a YGS Bulletin on Whitehorse trough (contributions by Lowey, Colpron and others).
Finlayson District	Don Murphy (YGS)	First draft of Finlayson District bedrock compilation complete; writing initiated on accompanying Bulletin.
MacMillan Pass	Grant Abbott (YGS)	Synthesis of six 1:50 000 scale bedrock geology maps (Niddery Lake) underway; work initiated on accompanying Bulletin.
Yukon Bedrock Geology	Maurice Colpron, Lee Pigage, Don Murphy, Steve Israel, Olwyn Bruce (YGS), Steve Gordey (GSC)	Yukon-wide digital bedrock geology compilation. Project entails upgrading of Gordey and Makepeace (1999) map, incorporating geologic data generated by YGS since 1999 and upgrading of accompanying geodatabase.
Yukon Surficial Geology	Jeff Bond, Panya Lipovsky, Aubrey Sicotte (YGS)	Yukon-wide digital surficial geology compilation. Project entails digitizing of existing Yukon surficial geology maps and integration into a common legend.

STUDIES IN SUPPORT OF LAND USE PLANNING

YGS carries out resource assessment studies in support of Yukon's Land Use Planning (LUP) process. Currently, two studies are underway (Table 6).

Table 6. *Studies in support of land use planning.*

Project	Participants	Summary of activities
Dawson region placer potential	Bill Lebarge (YGS)	Compilation of various data layers (drainage, surficial geology, mineral occurrences, placer production data, etc.) to support assessment of placer potential in Dawson region. Dawson LUP.
Peel aggregate inventory	Kristen Kennedy (YGS)	Map-based inventory of aggregate resources in Peel watershed area, based on air photo interpretation and available subsurface data. Peel LUP.

ON-GOING STUDENT RESEARCH

Several YGS-supported thesis students who have completed the field component of their projects are currently undertaking analytical work and writing up their studies (Table 7).

Table 7. *On-going student research.*

Project	Participants	Summary of activities
Borehole study	Megan James (U of O)	Writing up MSc thesis supervised by Panya Lipovsky (YGS) and Toni Lewkowicz (U of O). Project examines recent changes in permafrost recorded in boreholes along Alaska Hwy in SE Yukon.
Eagle Plain	Kristen Kennedy (U of A)	Final stages of MSc thesis supervised by Duane Froese (U of A). Study examines development of the Eagle Plain flood channel during late Laurentide glaciation.
Wheaton Valley study	Amber Church (SFU)	Final stages of MSc thesis supervised by John Clague (SFU) and Jeff Bond (YGS). Project focused on periglacial-related mass wasting in upper part of Wheaton Valley drainage. See Church, this volume.
Wernecke Supergroup	Francesca Furlanetto (SFU)	Working on MSc thesis supervised by Derek Thorkelson (SFU). Study involves comparison of detrital ages from sediments of Wernecke Supergroup and correlative units in the Cordillera. See Furlanetto, this volume.
Petrogenesis of Cretaceous granites	Kirsten Rasmussen (UBC)	PhD in final stages of completion; supervised by Jim Mortenson (UBC). Project contributes to a larger study of the age and petrogenesis of Cretaceous plutons and their role in the generation of gold and tungsten deposits in the north Cordillera.
Ages of west Laurentia overlap sequences	Luke Beranek (UBC)	Ongoing PhD supervised by Jim Mortensen (UBC). Study entails dating of detrital zircons across North American continental margin–Slide Mountain–Yukon–Tanana terranes and examining the implications for timing of terrane collision.
Wheaton River glacier biogeochemistry	Monica Bruckner (Montana State)	Final stages of MSc thesis supervised by Mark Skidmore (Montana State University) and Jeff Bond (YGS). Study characterizes biogeochemistry of meltwater from the Wheaton River glacier.
Aquatic ecosystems SW Yukon	Joan Bunbury (U of O)	Working on PhD thesis supervised by Konrad Gajewski (U of O). Studying impacts of White River eruption on aquatic ecosystems in SW Yukon. See Bunbury, this volume.

SINED FUNDING

Indian and Northern Affairs Canada (INAC) has provided funding to YGS over the last four years to support geoscience work that contributes to economic development in the territory. The funds are part of INAC's 2005 to 2009 Strategic Investment in Northern Economic Development (SINED) program. Table 8 shows a summary of the projects undertaken with SINED resources during the funding period, and the deliverables generated to date, as well as those that are anticipated.

GEM PROJECT PLANS 2008 TO 2013

Following the announcement of the Government of Canada's Geo-mapping for Energy and Minerals (GEM) program, YGS and GSC have been discussing potential collaborative projects that would fulfil both the program outcomes identified by GSC (such as increased exploration success rates) and address the needs of YGS clients in the resource development sector. GEM projects will fall under one of two GSC programs: GEM Minerals or GEM Energy, each of which will focus on generating new geologic information that will stimulate investment in resource exploration and development.

Table 8. SINED funding.

Project	SINED	Status	Products to date
2005-06			
Aeromag survey of Wernecke Mountains	\$820 000	Survey flown winter 2006	GSC OF 5412 to 5424/YGS OF 2008-6 to 18
Stream sediment survey of Flat River sheet	\$82 000	Survey completed	GSC OF 5329/YGS OF 2006-18
Digitization of surficial geology maps	\$100 000	Completed; maps available on request	Yukon surficial geology compilation underway
2006-07			
Re-analysis of archived stream sediment samples	\$35 000	Samples from NTS sheets 105G, 105J analysed	GSC OF 5696, 5694; YGS OF 2008-3, 2008-4
Stream sediment survey (Kandik Basin)	\$161 000	Survey completed	GSC OF 5319, 5695/YGS OF 2006-17, 2008-2
Digitization of surficial geology maps	\$110 000	Completed; maps available on request	Yukon surficial geology compilation underway
2007-08			
Re-analysis of archived stream sediment samples	\$39 000	Samples from NTS sheets 105H, 105I analysed, QA/QC underway	
Airborne geophysics in Windy-McKinley area	\$688 000	Survey deferred to fall 2008	
Mapping in Windy-McKinley area	\$100 000	Bedrock and surficial mapping completed July 2007	YGS Open File 2007-9
Aeromag survey of Eagle Plain	\$384 000	Survey deferred to winter 2009	
2008-09			
Re-analysis of archived stream sediment samples	\$39 000	NTS sheet 105N work underway: GSC Open File anticipated spring 2009	
Aeromag survey of Eagle Plain	\$504 000	Survey contract awarded for winter 2009	
Aeromag survey of Kandik Basin	\$315 000	Funds redirected to Eagle Plain survey in winter 2009	
Airborne geophysics in Windy-McKinley area	\$398 000	Mag-EM and Mag-radiometric surveys flown fall 2008	
Mapping in Windy-McKinley area	\$100 000	Field work completed July 2008	YGS Open File 2009-1
Peel area aggregate inventory	\$35 000	Work underway	
Bedrock mapping, Francis River (Selwyn)	\$90 000	Reconnaissance completed; ramping up to begin summer 2009	Full project plan complete; ramp-up spring 2009

Four Yukon projects have been defined to date, two of which were initiated this fiscal year, and two of which, if approved, will start in 2009/2010. The projects were defined based on the following criteria: geoscience knowledge gaps identified by YGS staff; client needs as defined by the YGS Technical Liaison Committee; priorities identified in consultation with GSC over the past two years; and the capacities of each partner. At the time this paper was written, project proposals and budgets were under review by GSC management; project approval and resource allocation decisions are anticipated by late December. More up-to-date information on the status of each project is anticipated early in 2009 and will be available through GSC or YGS.

The four Yukon-based GEM project proposals are described briefly below.

EDGES PROJECT (GEM MINERALS)

Project co-leads: Bert Struik (GSC), Don Murphy (YGS), Joanne Nelson (BCGS)

Proposed project duration: 2008 to 2013

The Edges project will examine the geologic history and mineral potential of the most exotic terranes of the northern Cordillera: the Insular (Wrangellia and Alexander) and Cache Creek terranes. Individual studies will include not only the mineral potential of the terranes themselves, but will examine the metallogeny of the regions at the edges of both the peri-Laurentian and exotic terranes where accretionary processes (arc magmatism, deformation, etc.) have modified them.

Project activities include bedrock mapping, geophysical surveys and thematic research such as innovative metallogenically oriented isotopic studies, litho geochemistry and tectonic synthesis. Areas targeted for study within Yukon include the Windy-McKinley area, Kluane Ranges, McQuesten, and Stevenson Ridge (Fig. 6). Windy-McKinley and Kluane Ranges mapping projects, already underway, are the core around which the Yukon component of the Edges Project has been built. Other 2008 to 2009 Edges activities include an aeromagnetic survey of the McQuesten area (planned for winter/spring 2009; see Fig. 6) and two geophysical surveys in the Windy-McKinley area.

During the course of the Edges Project, a number of workshops and field trips are planned which will provide clients an opportunity to offer feedback to project participants and to see the geologic problems being addressed in a field environment.

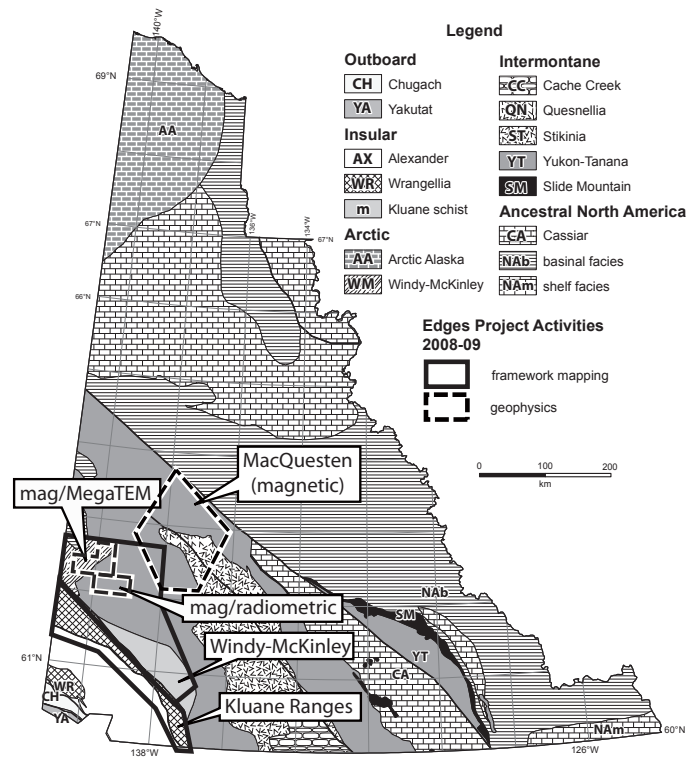


Figure 6. Location of studies in support of land use planning.

YUKON ENERGY PROJECT (GEM ENERGY)

Project lead: Larry Lane (GSC)

Proposed project duration: 2008 to 2013

The Yukon Energy Project will focus a number of different activities in five of Yukon’s sedimentary basins, with the intent to better understand the petroleum systems of the basins and upgrade existing hydrocarbon resource assessments for each. The basins of interest are Eagle Plain, Peel Plateau, Bonnet Plume, Liard basin and Whitehorse trough. Individual activities in each basin range from updating bedrock geology maps, generation of cross sections, stratigraphic and sedimentologic studies, generation of new Rock-Eval and vitrinite reflectance, and scanning existing geological and geophysical reports to allow better access to industry data.

COAL RIVER MAPPING PROJECT (GEM MINERALS)

Project co-leads: Charlie Roots (YGS), Grant Abbott (YGS)

Proposed project duration: 2009 to 2010

Coal River mapping project is a tightly focussed, one-year project designed to upgrade stratigraphic and structural relations in NTS map sheet 95D and integrate recently acquired aeromagnetic data into the existing bedrock map. Coal River area is prospective for several deposit types including SEDEX, MVT and a variety of Cretaceous intrusion-related metal deposits. An additional component of the proposed project entails surficial mapping of the eastern part of the map sheet, where no surficial geology map currently exists. The surficial map will provide a framework for drift prospecting in the area.

WERNECKE–MACKENZIE MOUNTAINS COOPERATIVE MAPPING PROJECT (GEM MINERALS)

Project co-leads: Charlie Roots (GSC), Steve Israel (YGS), Edith Martel (NWT Geoscience Office)

Proposed project duration: 2009 to 2013

The Wernecke–Mackenzie mountains cooperative mapping project area straddles the border between Yukon and NWT (NTS 106B and 106C) and is underlain by Proterozoic and Paleozoic sedimentary rocks of ancestral North America. The rocks host numerous stratabound base metal occurrences (Cu, Fe, Pb, Zn), as well as breccia zones with IOCG+U potential, but the regional stratigraphic and structural framework for the area is poorly understood. This project proposes to upgrade existing bedrock geology maps and undertake targeted thematic studies that will document local and regional mineralizing systems, examine basin architecture, and address outstanding stratigraphic and structural questions. In addition to bedrock mapping, the proposed study includes a component of surficial mapping that will aid in the interpretation of new regional stream sediment geochemical data and support drift prospecting.

The status of GEM project proposals will be shared publicly in January 2009 when more detailed information on project activities and planned deliverables is available.

PROGRAMS

YUKON MINING INCENTIVES PROGRAM

The Yukon Mining Incentives Program (YMIP) supports mineral prospecting and exploration activities in Yukon by providing a portion of the risk capital required to locate and evaluate mineral occurrences. YMIP is administered by Steve Traynor. This fiscal year, \$774 500 was committed to 45 projects. Funded projects include five under the Grassroots – Prospecting module (2 placer and 3 hardrock projects); 11 under the Focused Regional module (1 placer and 10 bedrock projects); and thirty under the Target Evaluation module (11 placer and 19 hardrock projects).

MINING AND PETROLEUM ENVIRONMENTAL RESEARCH GROUP

The Mining and Petroleum Environmental Research Group (MPERG) is a cooperative working group comprising government agencies, environmental and resource development companies, Yukon First Nations and non-government organizations (NGOs). The program's mandate is to support and promote research to address environmental issues for mining and petroleum development in Yukon. MPERG funds are administered by Karen Pelletier.

MPERG provided funds for five projects in 2008 to 2009. Deliverables are briefly described below:

1. A fact sheet for Yukoners that explains the properties of uranium and provides information on modern uranium exploration and mining techniques.
2. A study of the factors which influence ecological recovery rates along seismic lines.
3. A comparative analysis of the factors that influence the success of re-vegetation projects based in part on previous MPERG studies.
4. An expanded study, building on findings from 2007, of the biological uptake of naturally occurring selenium (Se) in aquatic life in selected Yukon Rivers.
5. An evaluation of the Brewery Creek mine from initial permitting and assessment through to closure/ remediation to better understand heap-leach mining in northern environments.

OUTREACH

YGS serves a wide range of clients that include the mineral and petroleum exploration sectors, prospectors, placer miners, Yukon First Nations, Land Use Planning Commissions and the general public. Regular interaction with our clients is important to us as it provides an opportunity to keep them informed of our activities and products, and allows us to receive feedback regarding their concerns, interests and information needs.

Mike Burke visited all major Yukon exploration projects this year, monitoring progress at each site and collecting information for the YGS annual report of exploration highlights (see Burke, this volume). Bill Lebarge visited placer operations, collecting data for the Placer database and maintaining contacts among operators (see Lebarge, this volume). The professional contacts maintained by Mineral Services staff provide valuable information on exploration trends and issues that influence YGS workplans.

Another target group for outreach is Yukon residents. YGS staff undertake a variety of outreach and public education activities each year, coordinated by Karen Pelletier. In 2008, YGS staff visited 29 schools and communities, presenting lectures, leading walking tours and taking part in open houses. Demand for such activities continues to increase.

Finally, Lee Pigage liaised with the Peel Land Use Planning Commission, providing information on the mineral and hydrocarbon potential of the Peel planning area and providing updates to YGS staff and management on the status of Yukon's land use plans. He also monitored activities associated with the North Yukon and Dawson land use plans.

INFORMATION MANAGEMENT AND DISTRIBUTION

YGS Technical Services group manages data and oversees the distribution of information via the web and through publications. Current YGS data reside in a number of databases which were built on different platforms (Oracle, Access, Excel) at different times. A project was initiated this year to build a single corporate database in which to house all data; this will eliminate duplication of fields between the databases, standardize information and streamline data entry, data creation and data delivery. It will also prepare us to move our web services from ArcIMS to ArcGIS Server, which will enable access to YGS data via web mapping services, web feature services, Google Earth and Microsoft Virtual Earth. We will continue to support our on-line Map Maker application as well.

Olwyn Bruce, Aubrey Scotte and Karen MacFarlane are spearheading this project. It is anticipated that the entire project will take about two years to complete, with the database build being the first step and the web transition to follow. Testing, documentation and training of staff and clients will be part of the process. In the meantime, existing YGS databases are being maintained and the data they contain are being updated regularly. Rob Deklerk continued to manage the MINFILE database. Four new mineral occurrences were added this year and four map sheets were updated to reflect recently released assessment reports. An extract of MINFILE data in Access format is scheduled for release in late January, 2009. Future updates of the data will be available for download via the web or on request.

Variations in the depth and thickness of the White River Ash in lakes of the southwest Yukon

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ABSTRACT

The purpose of this study is to document the depth and thickness of the White River Ash in lakes across the southwest Yukon for use in paleoenvironmental impact studies. Sediment cores were sampled from seven lakes located within the plume of the eastern lobe of the White River Ash (1147 cal. years BP). Site locations are between 92 and 254 km from Mount Churchill, Alaska, the probable source for the White River Ash. Based on magnetic susceptibility measurements, the depth of the sediment above the ash layer in the lakes ranges between 38 and 98 cm; these differences are due to factors associated with sedimentation rates. The thickness of the ash ranges between 0.1 and 32 cm and typically increases with proximity to the source vent. These results can be used in paleoenvironmental studies to assist in the interpretation of the impact of volcanic ash events.

RÉSUMÉ

Le but de cette étude est d'obtenir des données sur l'épaisseur des centres de la rivière White dans les lacs du sud-ouest du Yukon aux fins d'utilisation dans le cadre d'études d'impact paléoenvironnemental. Nous avons examiné les carottes de sédiments prélevées dans sept lacs situés dans le panache du lobe est des cendres de la rivière White (1147 cal. BP) afin de déterminer les différences de profondeur et d'épaisseur de la couche de cendres. Les sites d'échantillonnage sont situés entre 92 et 254 km du mont Churchill (Alaska), une source possible des cendres de la rivière White. Selon des mesures de la susceptibilité magnétique, la profondeur des sédiments au-dessus de la couche de cendres dans les lacs varie entre 38 et 98 cm et dépend de facteurs liés au taux de sédimentation. L'épaisseur des cendres varie entre 0,1 et 32 cm et augmente habituellement à proximité de la source. Ces résultats peuvent être utilisés dans les études paléoenvironnementales pour faciliter l'interprétation des répercussions des épisodes de cendres volcaniques.

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INTRODUCTION

THE WHITE RIVER ASH EVENT

The eastern lobe of the White River Ash is the result of a volcanic eruption that deposited an enormous volume of tephra over southern Yukon 1147 cal. yrs. BP (Fig. 1; Clague *et al.*, 1995; West and Donaldson, 2001). Evidence of the eruption occurs in peat profiles as far east as Great Slave Lake, Northwest Territories (Robinson, 2001), and recent work suggests that traces can be found northeast to Great Bear Lake (Lerbekmo, 2008). Early studies of the widespread tephra layer suggested different possible sources for the tephra, such as Mount Natazhat (Hayes, 1892), Mount Bona (Hanson, 1965), or a vent under the Klutlan Glacier (Lerbekmo and Campbell, 1969; Fig. 2). More recently, Mount Churchill, Alaska, a stratovolcano in

the Wrangell volcanic field 40 km from the Yukon-Alaska border was determined to be the likely source (McGimsey *et al.*, 1992; Richter *et al.*, 1995). However, Lerbekmo (2008) recently reprised the idea that a vent under the Klutlan Glacier is the source.

Explosive volcanic eruptions such as the White River Ash event eject large quantities of ash into the atmosphere that become deposited in both terrestrial and aquatic environments. Tephra is incorporated into lake sediments by falling directly on the lake surface, and through deposition within the watershed and transportation to the lake via runoff. Evidence suggests the eruption that produced the White River Ash occurred in late autumn or early winter (West and Donaldson, 2001), therefore, the tephra would have been deposited on frozen lake surfaces and would not have been incorporated into the

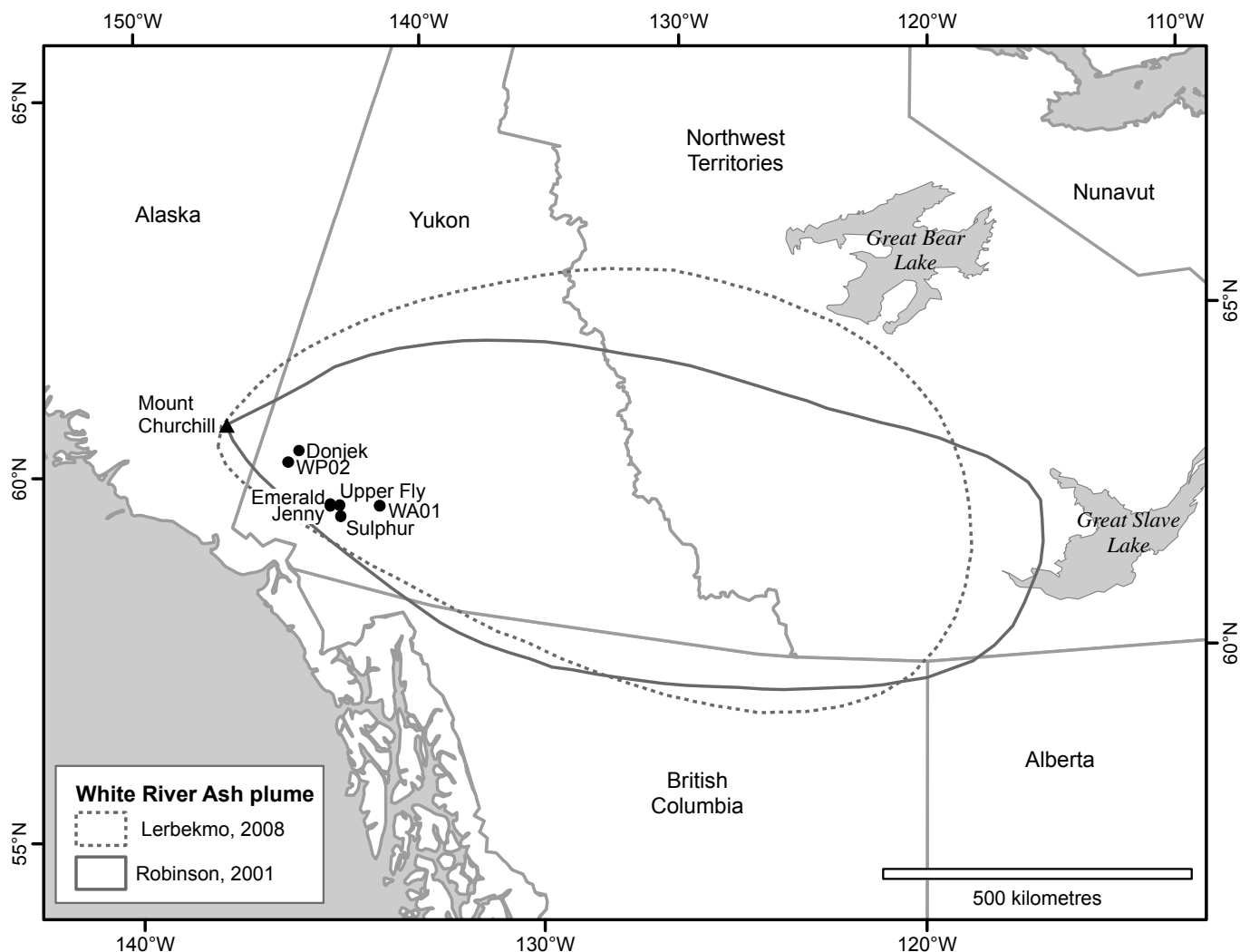


Figure 1. The extent of the eastern lobe of the White River Ash after (Robinson, 2001) and (Lerbekmo, 2008). Location of the seven study lakes and Mount Churchill are provided for reference.

sediments until the spring melt. The ashfall would have impacted both the aquatic and terrestrial communities in the region, though the extent of the impact would be a function of the quantity of ash deposited in a given site. Therefore, this event provides a 'natural experiment' to evaluate the impact of this catastrophic event on ecosystems through the analysis of fossils in lake sediments.

The objective of this study is to assess the variations in depth and thickness of the White River Ash from seven lakes in southwest Yukon. The results from this study can then be used in paleoenvironmental studies to aid in the interpretation of the impact of these types of events on terrestrial and aquatic ecosystems.

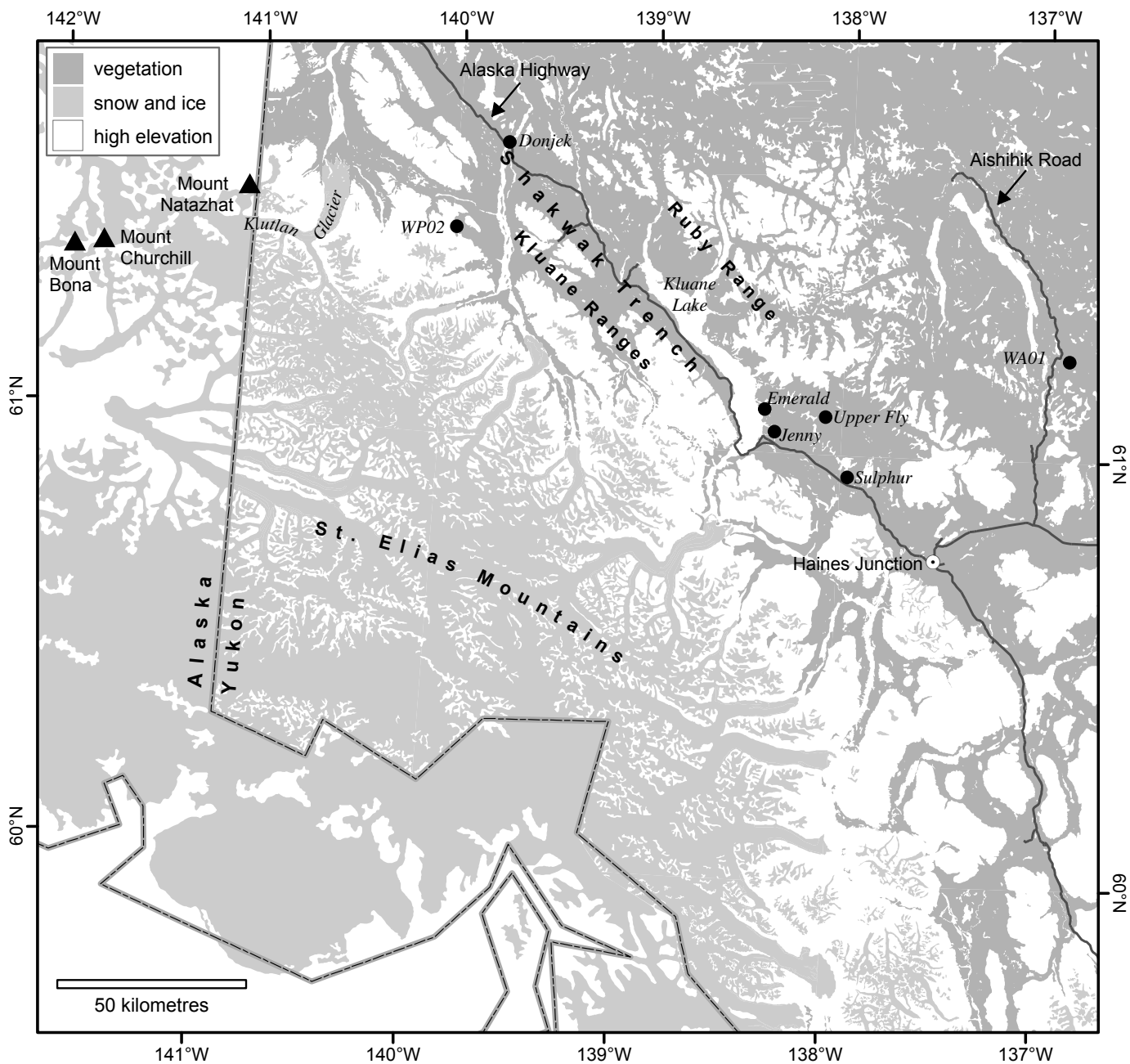


Figure 2. Map showing more detailed locations of the seven lakes. Mount Churchill, Mount Natazhat, Mount Bona and the Klutlan Glacier are provided for reference.

REGIONAL SETTING

The southwest Yukon is located in the rainshadow of the St. Elias Mountains resulting in a semi-arid climate with total precipitation values <300 mm annually (Environment Canada, 2004). Mean annual daily temperatures are below 0°C, and discontinuous permafrost is widespread throughout the region, particularly at higher elevations (National Atlas Information Service, 1995). Dominant trees in this part of the boreal forest are white spruce (*Picea glauca*), balsam poplar (*Populus balsamifera*) and trembling aspen (*Populus tremuloides*; Johnson and Raup, 1964); bogs with stands of black spruce (*Picea mariana*) can be found further north. Natural grasslands are interspersed with open forest stands, particularly in the vicinity of Kluane Lake and in the Aishihik Lake region (Vetter, 2000). Alpine-tundra types including dwarf birch (*Betula*), willow (*Salix* spp.), grasses (Gramineae) and sedges (Cyperaceae) are found at higher elevations.

The region is geologically complex and is underlain by a variety of bedrock types including intrusive bodies composed of granodiorite, quartz diorite, quartz monozite and granite. Gneiss and volcanic rock are also present, and till is abundant, particularly in the Kluane Lake region (Gabrielese *et al.*, 1977; Fulton, 1995).

Seven sediment cores recovered from lakes located within the eastern lobe of the White River Ash plume were used for this study (Figs. 1, 2). Lakes vary in their ionic composition, but are generally bicarbonate rich and dominated by either calcium or magnesium, with higher ionic concentrations occurring near Kluane Lake. Surface areas of the lakes vary between 0.1 and 143 ha, and core collection depth ranged between 2.5 and 11 m (Table 1). Both Sulphur Lake (Sulphur) and Upper Fly Lake (Upper Fly) lack an obvious inflow, yet both have a stream outflow, whereas the other sites are kettle lakes with only

groundwater inputs. Vegetation surrounding the lakes varies. Sulphur Lake WA01 (WA01), Emerald Lake (Emerald), Jenny Lake (Jenny), and Donjek Kettle (Donjek) are situated in the boreal forest; Upper Fly is in the forest-tundra transition zone; and Lake WP02 (WP02) is located in alpine tundra.

METHODS

FIELD METHODS

Lake sediment cores were collected from Emerald and Donjek in August 1996; Sulphur and Upper Fly in July/August 1997; Jenny in May 2003; WP02 in July 2006; and WA01 in July 2008. All sediment cores were retrieved using a modified Livingstone piston sampler and the unconsolidated uppermost sediments were extruded into plastic bags in the field. The length of the core that is extruded in this manner depends on the cohesiveness of the sediments and varies from site to site (Fig. 3). The remainder of the cores were extruded, wrapped in plastic wrap and aluminum foil and transported back to Ottawa where magnetic susceptibility was measured. Only the uppermost sections of the lake sediment cores are discussed in this study.

LABORATORY METHODS

Magnetic susceptibility

Magnetic susceptibility is a non-destructive sediment logging technique that measures the ability of the sediments to be magnetized; values typically reveal the amount of magnetic minerals that are present within the sediments (Dearing, 1994). Increases in concentrations of magnetic minerals in lake sediment cores are generally interpreted as periods of increased erosion in the

watershed. For example, greater precipitation would transport inorganic allochthonous material to the lake, which would then become incorporated into the sediments (Lowe and Walker, 1997). Other material that causes high magnetic concentrations in lake sediments includes volcanic ash, due to the presence of magnetite, a common mineral that dominates magnetic

Table 1. Location, surface area, core collection depth, and distance from Mount Churchill for the seven study lakes.

Lake	Latitude (°N)	Longitude (°W)	Elevation (m)	Surface area (ha)	Core collection depth (m)	Distance from Mount Churchill (km)
WP02	61.48	140.00	1463	0.65	4.0	92.6
Donjek	61.69	139.76	732	0.6	6.0	110.1
Emerald	61.07	138.37	820	8.4	7.0	181.6
Jenny	61.04	138.36	817	19.9	4.0	183.0
Upper Fly	61.09	138.09	1326	10.5	4.0	196.2
Sulphur	60.95	137.98	854	142.6	11.0	205.7
WA01	61.25	136.93	991	0.1	2.5	254.7

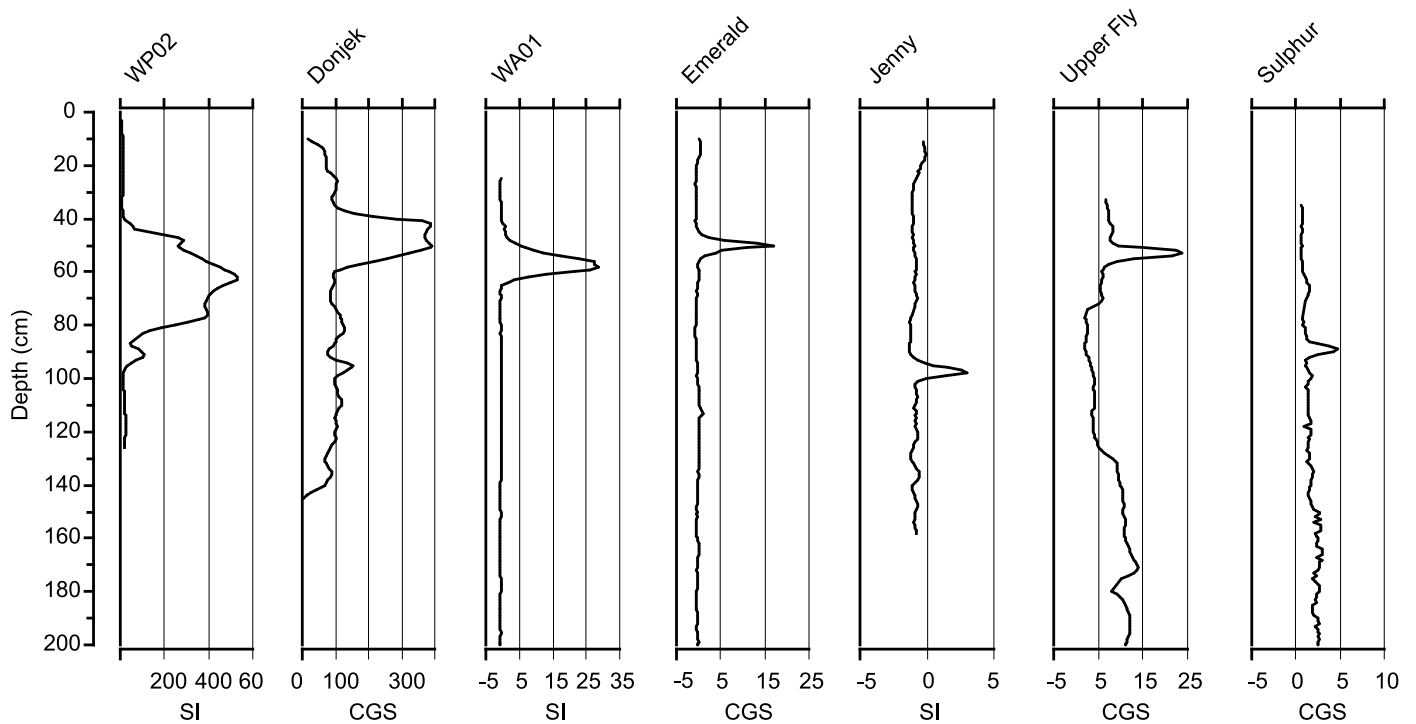


Figure 3. Magnetic susceptibility profiles for the seven study lakes. Note that different units were used.

susceptibility measurements when present in a sample (Dearing, 1994).

A Bartington MS2C Core Sensor with a 6 cm-internal diameter was used to measure magnetic susceptibility at 1 cm intervals on the seven lake-sediment cores. Whole cores were fed through a loop sensor and the meter computed susceptibility values as a weighted mean of the individual measurements (Nowaczyk, 2001). Units are dimensionless and the base units are either in centimetres, grams, seconds (CGS) or metres, kilograms, seconds (International System of Units; SI). Although the values are slightly different, for the purposes of this study the interpretation of the results is not affected.

RESULTS

MAGNETIC SUSCEPTIBILITY OF SEDIMENT IN SOUTHWEST YUKON LAKES

In all seven lake-sediment cores, maximum values of magnetic susceptibility occur where the White River Ash is present (Fig. 3). Both WP02 and Donjek have very high maximum values (533 SI units and 392 CGS units, respectively), followed by more moderate maximum values at WA01 (28.7 SI units), Upper Fly (23.7 CGS units) and Emerald (17 CGS units), and low maximum values at Sulphur (4.81 CGS units) and Jenny (2.97 SI units). All sites have low magnetic-susceptibility values in the portions of the cores where there is no volcanic ash. WP02 and Donjek have the highest minimum values (6.7 SI units and 6.2 CGS units, respectively), Upper Fly and Sulphur have small, positive values (1.9 CGS units and 1.6 CGS units, respectively), whereas Jenny, Emerald, and WA01 have negative values (-1.4 SI units, -0.7 CGS units and -0.8 SI units, respectively). Prior to the ash deposition, magnetic concentrations appear more variable throughout the cores from Donjek and Upper Fly, whereas the remaining sites show stable, low magnetic concentrations aside from where the White River tephra is present.

WHITE RIVER ASH DEPTH IN SOUTHWEST YUKON LAKES

The White River Ash layer is shallowest in Donjek with only 38 cm of sediment accumulation over the past 1200 years (Table 2). Comparable sediment accumulation rates above the ash are found at Upper Fly (54 cm), Emerald (51 cm), WP02 (50 cm), and WA01 (51 cm), whereas Sulphur (90 cm) and Jenny (98 cm) have almost twice the accumulation.

WHITE RIVER ASH THICKNESS IN SOUTHWEST YUKON LAKES

The thickest layers of White River Ash found in lake sediments from these sites are at WP02 (32 cm) and Donjek (27 cm; Table 2). WA01 has 11 cm of ash, whereas Jenny, Emerald, and Upper Fly all have less than 1 cm (0.3, 0.3 and 0.1 cm, respectively). Sulphur has no visible ash layer, however the magnetic susceptibility values indicate an increase coinciding with the timing of the White River Ash (Lacourse and Gajewski, 2000). Note that the estimate of ash thickness is not exact due to the averaging of the magnetic signal by the sensor.

Table 2. Depth and thickness of the White River Ash found in the sediment cores of the seven lakes. Ash depth is based on magnetic susceptibility measurements (1 cm resolution) and ash thickness is based on magnetic susceptibility measurements and visual inspection.

Lake	Ash depth (cm)		Ash thickness (cm)
	Start	Finish	
WP02	50	82	32.0
Donjek	38	61	27.0
Emerald	50	51	0.3
Jenny	98	99	0.3
Upper Fly	53	54	0.1
Sulphur	89	90	Not visible
WA01	51	62	11.0

DISCUSSION

MAGNETIC CONCENTRATIONS IN LAKE SEDIMENTS

Carbonate lake sediments at Jenny, Emerald and WA01 result in weak, negative magnetic susceptibility values due to the diamagnetic behaviour of calcium carbonate (e.g., precipitated calcite, ostracodes and molluscs) found in the sediment (Fig. 2; Dearing, 1994). The weak, positive values throughout the cores at the other sites suggest paramagnetic sediments that include minerals that contain iron (e.g., biotite, olivine; Dearing, 1994).

The White River Ash is ferrimagnetic based on the strong, positive susceptibility values at all sites; this is due to the presence of the mineral magnetite that comprises 2.1% of the weight of the White River Ash (Lerbekmo and Campbell, 1969). Very high (*i.e.*, >300 regardless of unit) magnetic concentrations at Donjek and WP02 are the result of the volume of White River Ash that occurs in the sediments at those sites (Fig. 3), as large bulk samples record higher values than small samples of the same material (Dearing, 1994). Magnetic concentrations of the White River Ash at the other sites are lower and are a reflection of the reduced amount of ash in those sediments. The particularly low values at Jenny and Sulphur lakes may be a result of the large surface area at those two sites, where the ash becomes more diluted in the sediments than it would at the lakes with a smaller surface area.

WHITE RIVER ASH THICKNESS AND DISTANCE FROM THE SOURCE

The thickness of the White River Ash layer in lake sediments is expected to decrease with increasing distance from the source. This holds true for six of the seven lakes, but not for WA01, which has an 11 cm thick ash layer and is located the furthest from the source in this study (Tables 1, 2). WA01 is a bowl-shaped kettle lake with a very small surface area (0.1 ha) surrounded by steep slopes. As the tephra was deposited it would have become concentrated in a small area at the bottom of the lake (referred to as sediment focusing). In addition, as the snow on the surrounding slopes melted in the spring, any ash within the basin would have been washed into the lake, thereby increasing the amount accumulated in the sediments. A lake sediment core collected from a slightly larger lake with less steep slopes across the Aishihik Road from WA01 revealed no visible ash layer, suggesting the

importance of the morphology of the lake and surrounding basin to the ash layer thickness at WA01.

WHITE RIVER ASH DEPTH AND SEDIMENTATION RATES

The amount of lake sediment that has accumulated above the White River Ash is comparable at five of the seven sites, indicating similar sediment accumulation rates over the past 1200 years (Fig. 3 and Table 2). Greater sedimentation rates have occurred at both Jenny and Sulphur since the White River Ash event, and may be due to larger sediment input to the sites as well as sediment focusing. The steep-sided bathymetry of Sulphur Lake causes accumulated material within the sediment to move downslope to the bottom of the lake where the core sample was collected within an 11 m-deep section. A similar situation exists at Jenny Lake, however it is more likely the result of the steep slope alongside the lake close to the area where the core was collected. During periods of increased precipitation or snowmelt, inorganic allochthonous material becomes entrained and deposited in the lake and eventually forms part of the sediments.

CONCLUSIONS

Magnetic susceptibility in lake sediments is highest where the White River Ash is present, and greater volumes of ash result in much higher magnetic susceptibility measurements. The thickness of the White River Ash typically decreases with increasing distance from the source vent, and lake sedimentation over the past 1200 years is fairly consistent between the sites. However, sediment focusing can increase the amount of ash incorporated into the sediments of a given site. The findings from this study will be considered in a paleoenvironmental study exploring the impact of the White River Ash event on aquatic ecosystems in the region.

ACKNOWLEDGEMENTS

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Cryostratigraphic record of permafrost degradation and recovery following historic surface disturbances, Klondike area, Yukon

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ABSTRACT

Cryostratigraphic investigation of near-surface permafrost at a site in the southern Klondike goldfields has revealed three ages of permafrost disturbance and recovery which potentially span the last century. In an undisturbed forest, the base of the modern active layer is stable with a suspended ice/sediment cryofacies at the contact. A recently burned site (2004) shows that the degrading contact has not yet stabilized. An earlier disturbance from the 1970s shows evidence of aggradation (upward shift) of the permafrost table following limited vegetation succession. Underlying all three sites is an older disturbance corresponding to a thaw depth of ~2 m, predating the 1970s disturbance; it is likely that this represents an early 20th century disturbance associated with the deforestation of the valley during the gold rush era. Permafrost has recovered significantly since that time as the boreal forest and understory vegetation was re-established, underscoring the role of vegetation cover in permafrost disturbance and recovery.

RÉSUMÉ

Une étude cryostratigraphique du pergélisol peu profond des champs aurifères du sud du Klondike dévoile trois périodes de dégradation et de récupération du permafrost durant le vingtième siècle. Le contact actuel du pergélisol avec la couche active dans une forêt non perturbée est stable avec une cryostructure riche en glace. Un site récemment incendié (2004) a un contact typique d'une dégradation active. Une perturbation datant des années 1970 montre une récupération du pergélisol après reprise de la végétation. Les trois sites présentent une perturbation plus ancienne, antérieure aux années 1970, correspondant à un dégel ayant atteint ~2 m de profondeur. Cet accroissement important de la couche active résulte probablement d'une perturbation liée à la déforestation de la vallée durant la ruée vers l'or, au début du vingtième siècle. Le pergélisol a significativement récupéré depuis, avec la reprise de la forêt boréale et de la végétation basse. Cette reconstitution des événements souligne le rôle du couvert végétal dans la perturbation et la récupération du pergélisol.

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INTRODUCTION

The potential impacts of future climate warming on permafrost are poorly understood. Several recent modelling efforts have predicted widespread melting-to-near-disappearance of permafrost in the coming century across much of the northern hemisphere (e.g. Lawrence and Slater, 2005). Seemingly inconsistent with these predictions is evidence for the long-term survival of permafrost within several metres of the surface for more than 700 000 years, a timeframe which includes past interglaciations that were warmer and of longer duration than the Holocene (Froese *et al.*, 2008). The presence of this ancient ice indicates that permafrost can survive in a warmer climate, but leaves open the question of how has it survived? And what properties of the overlying insulating cover of vegetation, sediment and ice contribute to its resilience?

This paper presents preliminary results of a cryostratigraphic characterization of Klondike permafrost where thermal disturbance occurred due to the removal of peat and vegetation cover following a recent fire, mining activities and deforestation over the past century. We use a new technique for permafrost characterization – computed tomography (CT) scanning – to image permafrost cores and establish the ice characteristics of the near-subsurface permafrost. This, in turn, allows us to interpret the dynamical history of permafrost over the last century and better understand degradation and subsequent aggradation of the permafrost table following re-establishment of vegetation cover.

The Klondike goldfields provide an exceptional site to study the dynamics of permafrost given that the area has been subject to several periods of disturbance from mining activities dating to the late 19th century. During the gold rush era (ca. 1896 to 1910) deforestation of valleys occurred to support the growing need for wood for a variety of uses, ranging from cribbing, flume and trestle construction, cabins, and melting of permafrost in shafts; as well, understory moss was collected in many areas for fuel, as well as a source to insulate cabins (Morse, 2003). Subsequently, with the transition to large-scale dredging after 1905, ground was stripped and thawed for gold recovery in valley bottoms (Green, 1977). In addition to the areas that were mined, disturbances resulted from industrial development: roads, railways, telegraph lines and ditches were significant features developed during this era (Hogan and Skuce, 1992a, 1992b, 1993). Many of these sites were abandoned shortly

after construction, but some persisted through the following half-century until large-scale mining largely ended in the 1960s (Green, 1977). More localized disturbances of areas that had not been affected by dredging occurred through the last 40 years. Furthermore, forest fires impacted large areas of the Klondike. This rich history of a hundred years of anthropogenic and natural permafrost disturbances provides the possibility to use these perturbations of varying age and severity to develop a model of permafrost degradation and recovery as an analogue for future climate change.

STUDY AREA

The Dominion Creek study area contains several sites with differing ages of disturbance within a few hundred square metres (Fig. 1). The original environment is a gently sloping (4-5°) pediment surface developed on loessal silts along the north side of the Dominion Creek valley. These loessal silts accumulated during the Pleistocene from the transport and deposition of wind-blown silt. Upslope, the surface grades into the colluvial mantle along the valley margin. The area was largely deforested during the early 20th century, as witnessed by the presence of stumps of mature trees in the recent-growth forest. As well, old-timer workings are present in the area, conspicuous from tailings piles and historic artefacts recovered by present-day mining (A. Sailer, pers. comm., 2008).

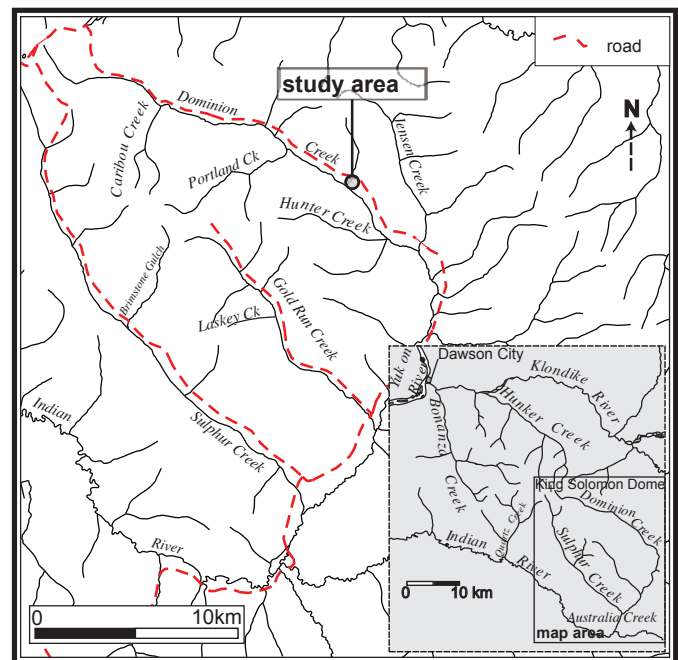


Figure 1. Location of the study site.

Mechanized mining at the site since the 1960s has generated several local disturbances of the surface vegetation cover. Three roads are present throughout the forest, where trees were cut or uprooted, and the peat cover was deeply compacted or perhaps ripped up by the tracks. Some ruts were created where surface water was channelled and has induced degradation of the permafrost. These road tracks are present in the woods of the studied area (Fig. 2a). In 2004, a large fire affected several areas of the Klondike along the Dominion Creek valley. One of the burned areas is along the same geomorphic surface adjacent to the road sites (Fig. 3). A combination of burning and bulldozer firebreaks disturbed the forest and provide three types of closely adjacent field conditions: (i) fire-disturbed areas where peat cover was removed (firebreak); (ii) fire-disturbed areas where peat cover persisted and only tree and shrub cover was affected (Fig. 2b); and (iii) undisturbed sites where forest cover was unaffected by the fire.



Figure 2. Studied sites: (a) vehicle tracks; and (b) 2004 fire.

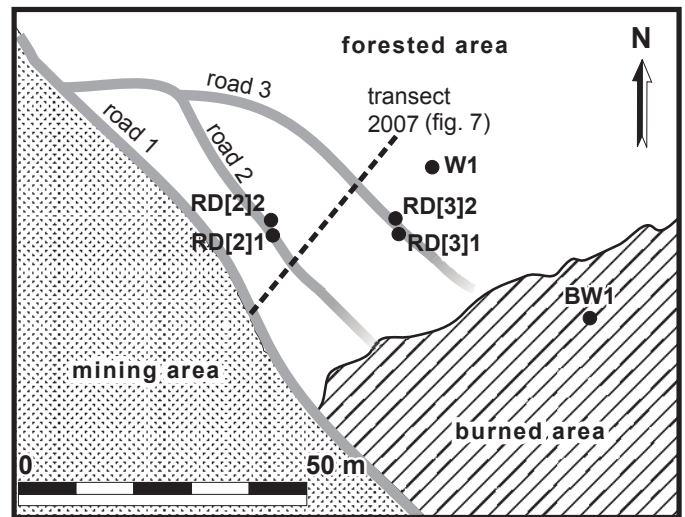


Figure 3. Studied sites, active layer transect survey and borehole location.

To summarize, three generations of degradation/recovery of permafrost are present: (i) a wooded area which recovered from deforestation, probably dating from the early 20th century; (ii) bulldozer tracks from the late 1960s to early 1970s where vegetation is still recovering from the disturbance; and (iii) burned areas associated with the 2004 fire where degradation is ongoing (Fig. 3).

METHODS

In order to understand the dynamics of permafrost and its recovery following disturbance, multiple techniques were used, including active layer probing to determine actual end of summer thaw depth, recovery of permafrost cores and CT scanning to determine the properties of shallow permafrost, and hand augering where permafrost was not encountered with the probe. As well, approximate ages of disturbances were confirmed with tree-ring analyses, dating from late 1960s to early 1970s.

ACTIVE LAYER PROBING

Active layer thickness is an important property in understanding permafrost dynamics and determining rates of degradation and recovery. Following a perturbation, permafrost thaws from the top and the active layer increases as the thermal disturbance extends further into the ground. Active layer depths were assessed in September 2007 using a graduated metal rod, inserted vertically into the ground until the permafrost was encountered. In July 2008, a hand auger was used to reach a depth of 5.10 m at sites where permafrost was not encountered.

SAMPLING

Six boreholes were drilled from early June to mid-July 2008 for permafrost sampling using a light, portable drill (see Calmels *et al.*, 2005). Mounted on a small Stihl™ engine with a high-speed transmission, 1 m connecting steel rods terminate in a 10 cm diameter core barrel with a carbide bit with set diamonds. This system allowed cutting through isolated stones or even boulders, which would have not been possible with a conventional CRREL coring kit. Core sections were recovered, wrapped with plastic, stored frozen in a freezer and returned to the University of Alberta, Edmonton, Alberta, where they were untouched prior to CT scan imaging.

CORE IMAGING BY CT SCANNING

Imaging was done using a Toshiba Aquilion medical scanner at the Alberta Research Council in Edmonton, AB. Based on the principles of radiography, CT scanning (computed tomography scanning) provides a non-destructive examination of materials at the micro level, and provides imaging through mapping of density contrast. This technique allows a detailed interpretation down to the millimetre-scale of ice lenses, as well as individual gas bubbles and their orientation, in order to establish the processes that took place during freezing of the permafrost. Furthermore, diagenetic changes such as water migration, gas segregation in bubbles and cavities, and volume-change related deformations may be inferred. The advantages of CT scanning in permafrost studies are discussed in detail by Calmels and Allard (2004, 2008).

The Toshiba Aquilion medical scanner has a spatial resolution of 0.35 mm for transverse sections, and

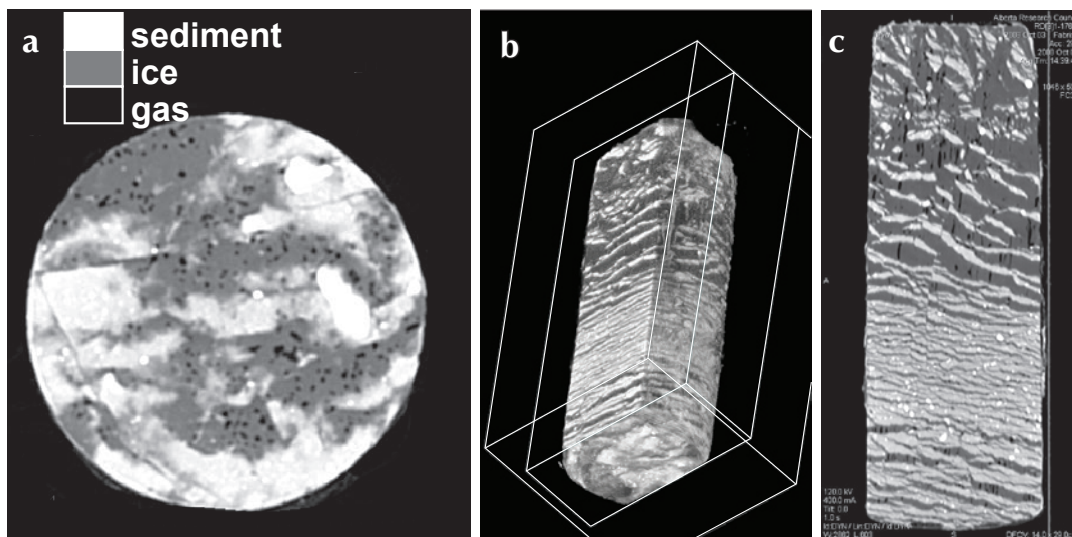
0.5 mm for longitudinal sections. The cores were taken out of the freezer for the few minutes needed for the analyses and were otherwise kept in their sealed bags. The system produces a series of transverse slices (Fig. 4a). Medical software is used to process a 3-D reconstruction from the slices (Fig. 4b), and thereafter to extract any longitudinal sections across the slice series (Fig. 4c). Typically, images are in grey tones, showing the complete spectrum of densities; lower density materials appear in dark colours or tones, and higher density materials are expressed in light colours. Using image processing, it is also possible to select narrow ranges of the spectrum of density, so that it is possible to image selected components individually (*i.e.* ice, gas or soil). Ultimately, the ice and gas volumetric contents can be estimated from the CT scan images using medical imaging software such as Osiris™.

RESULTS

ACTIVE LAYER SURVEY

Active layer probing in September 2007 showed that in undisturbed woods, where the peat cover was 36 cm thick, and the slope was gentle (4-5°), active layer thickness was about 42 cm (Fig. 5b). In the upper forested area, where the slope was steeper and the soil dryer, active layer thickness exceeded 150 cm (Fig. 5a). This largely reflects changes in moisture associated with the steeper slope resulting in a thinner peat cover and, as a result, a thinner insulating surface layer. In the area associated with the 2004 fire, the thaw front reached a depth of 85 to 86 cm, with or without the overlying peat

Figure 4. Three modes of imaging scanner data. Core is 10 cm in diameter. (a) Transverse slice; (b) 3-D reconstruction; (c) Longitudinal section. Soil is white, ice is grey and gas is black.



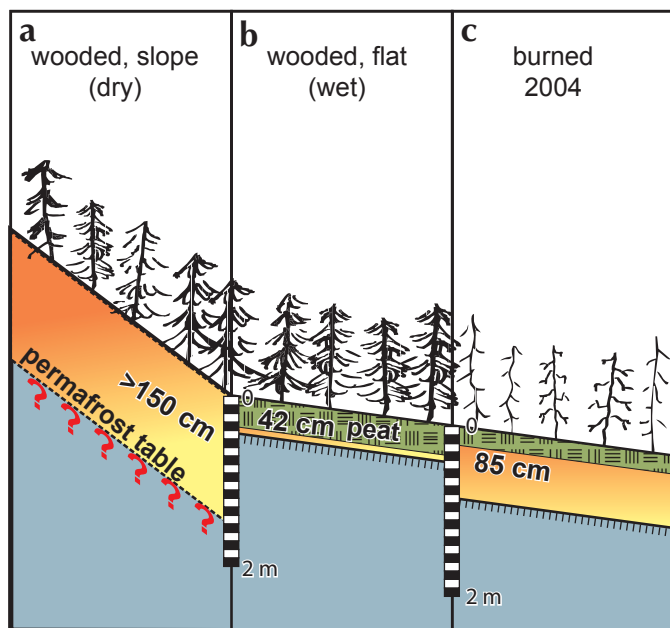


Figure 5. Active layer depths in wooded and fire disturbed areas.

cover (Fig. 5c). Where the peat remained, its surface was burned, and its average thickness was 20 cm or slightly less. In these degrading sites, the peat did not seem to have a major influence on ground thermal conditions. Due to the impact of the fire in the past three years, the active layer had approximately doubled from 42 to 86 cm, suggesting a melting rate of nearly 15 cm/year for the permafrost.

A second active-layer survey was completed 30 m outside of the 2004 burned area on the same geomorphic surface

from the undisturbed wooded area (Fig. 6); it intersected three bulldozer trails dating back to the late 1960s to early 1970s. Each bulldozer trail consisted of two parallel tracks with a raised area in the middle. Active layer thicknesses ranged from 42 to 76 cm in the undisturbed wooded areas. The wooded area at road three has similar active layer thicknesses as those observed at the undisturbed wooded areas. On road two, the thawing front reached 86 cm. A more degraded road, road one, probably of the same origin and age as the other two roads has an active layer thickness of more than 170 cm. In July, 2008, additional probing with an auger was completed on road 1 to a depth of 5.1 m. The surface of road 1 was particularly wet, likely as a result of channelled surface runoff. Considering the present depth and the magnitude of permafrost table depth in the area, it is probable that the top of the permafrost is about six metres deep.

GEOCRYOSTRATIGRAPHIC OBSERVATIONS

The following section presents preliminary observations of ice and gas content within sampled core; sedimentary parameters are still being analysed. Six permafrost cores were recovered in the study area at W1, RD[2]1, RD[2]2, RD[3]1, RD[3]2, and BW1 (Fig. 3). In 2004, five boreholes W1, RD[2]1, RD[2]2, RD[3]1 and RD[3]2 were completed in the wooded, mainly undisturbed area, while a sixth, BW1, was located 36 m away in a burned area. The first five were collected in a line slightly oblique to the transect shown in Figure 6, which begins at the wooded area (borehole W1), crosses the bulldozer tracks on ‘road three’ (boreholes RD[3]1 and RD[3]2), and ‘road two’ (RD[2]1 and RD[2]2), and ends in the middle of the track on ‘road one.’

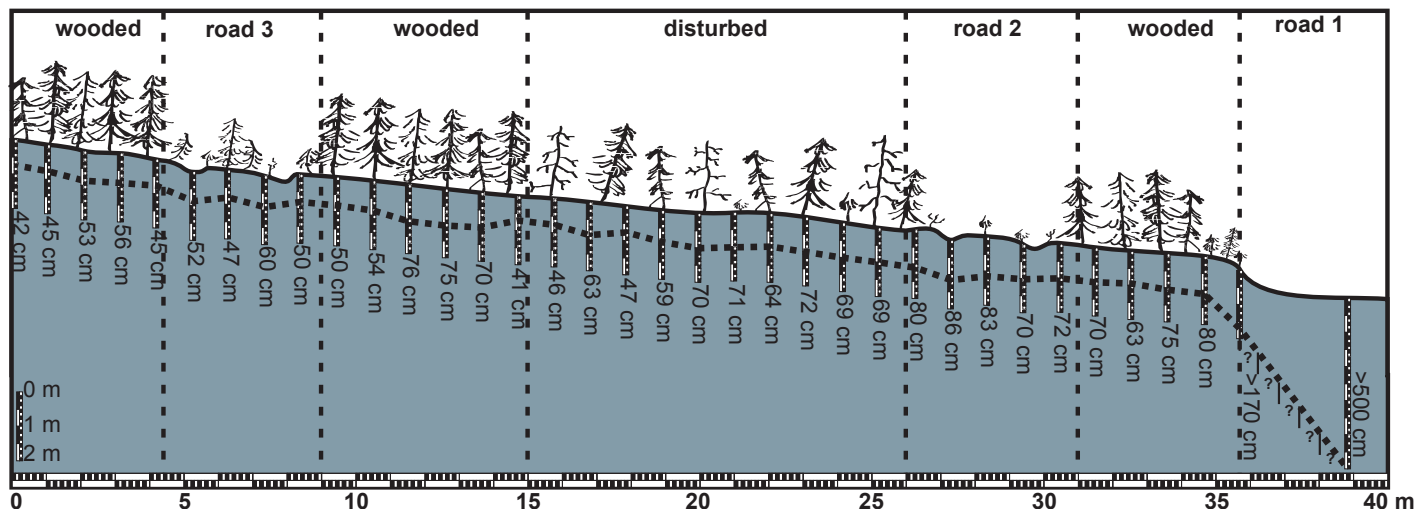


Figure 6. Active layer conditions in forested site along a transect crossing the 1970s roads.

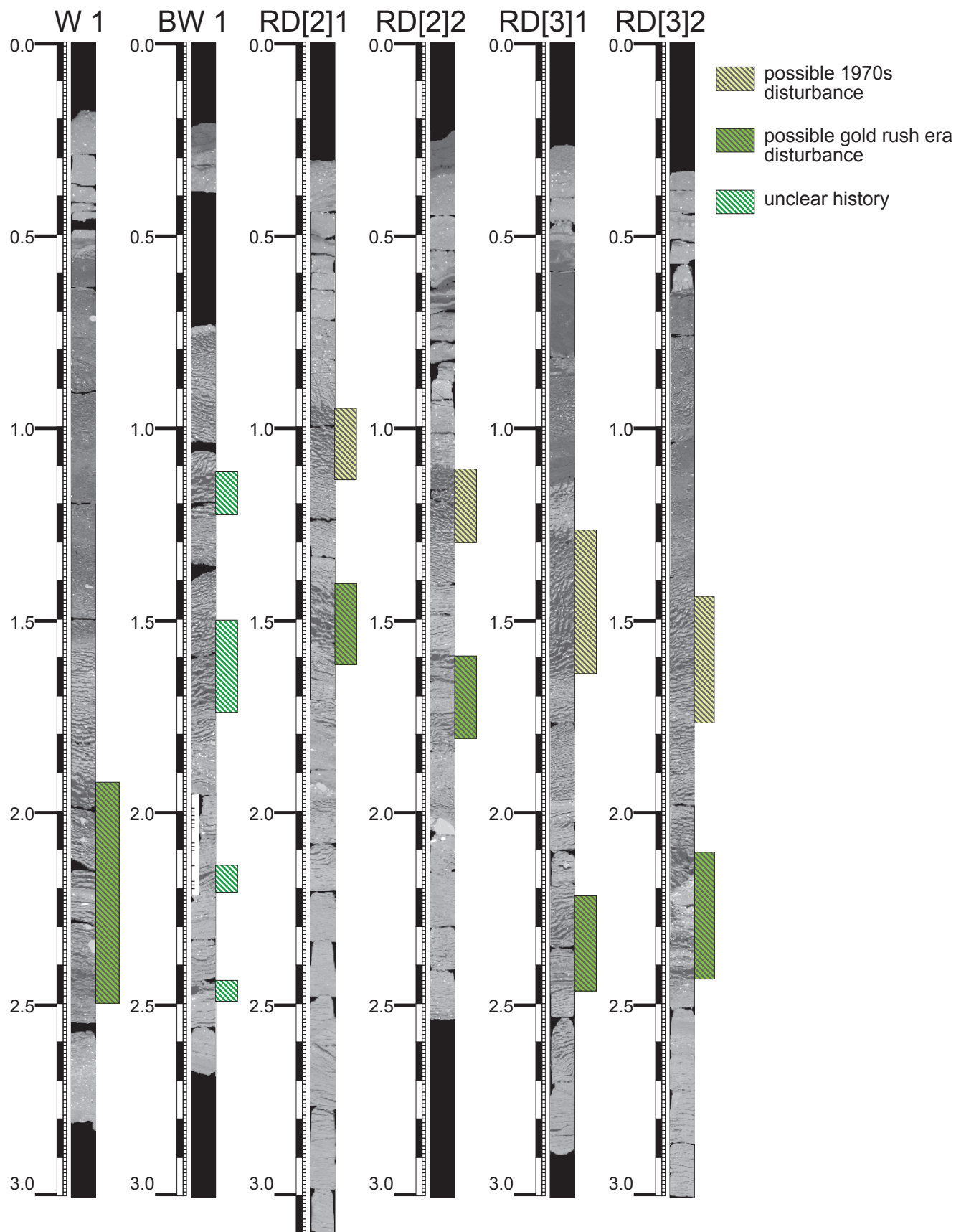


Figure 7. Geocryological profiles of the cores for each site. Depth is in metres.

Figure 7 shows the complete geocryological profiles of each core. It is important to note that the cores are not oriented. All of the cores share some geocryological similarities. The sedimentary and geomorphologic characteristics of the area provide a context for these shared features. The sediment is largely a sandy-silt with rare pebbles and coarse-sediment lenses. In the studied sites, the cryostructures are related mainly to segregational ice. When freezing progresses in mineral or organic soils, cryosuction causes the migration and subsequent freezing of pore water from the unfrozen soil to the freezing front, which results in the formation of discrete layers or lenses (Mackay, 1971; Williams, 1979; Gilpin, 1980; Williams and Smith, 1989; Konrad, 1990; IPA, 2005). This phenomenon, called ice segregation, is well developed in fine-grained sediments with good moisture availability. The segregation ice usually develops downward when permafrost progress from the surface, but can also form when the upper boundary surface of permafrost progresses upward into the active layer, forming aggradational ice (French, 1996).

Cryostructures

Four main cryostructures are present in our geocryological profiles. We partially follow Murton and French (1994) in our classification; we do not consider structureless units and have added an organic-rich cryostructure to our classification system.

(i) Layered

A layered cryostructure is most commonly encountered in our cores (Fig. 8a). It consists of an alternation of continuous bands of ice with continuous sediment layers. As shown in Figure 7, the layered cryostructure is common in all cores and has ice-layer thicknesses ranging from <1 mm to 2 cm, with an average of 5 to 6 mm. The layering is subhorizontal and ice lensing is slightly tilted; even without orientation of the samples, we can reasonably assume that tilting is subparallel with, or influenced by, the slope, and freezing has propagated mainly parallel to the slope surface. Two forms of the layered cryostructures are observed: parallel wavy and non-parallel wavy.

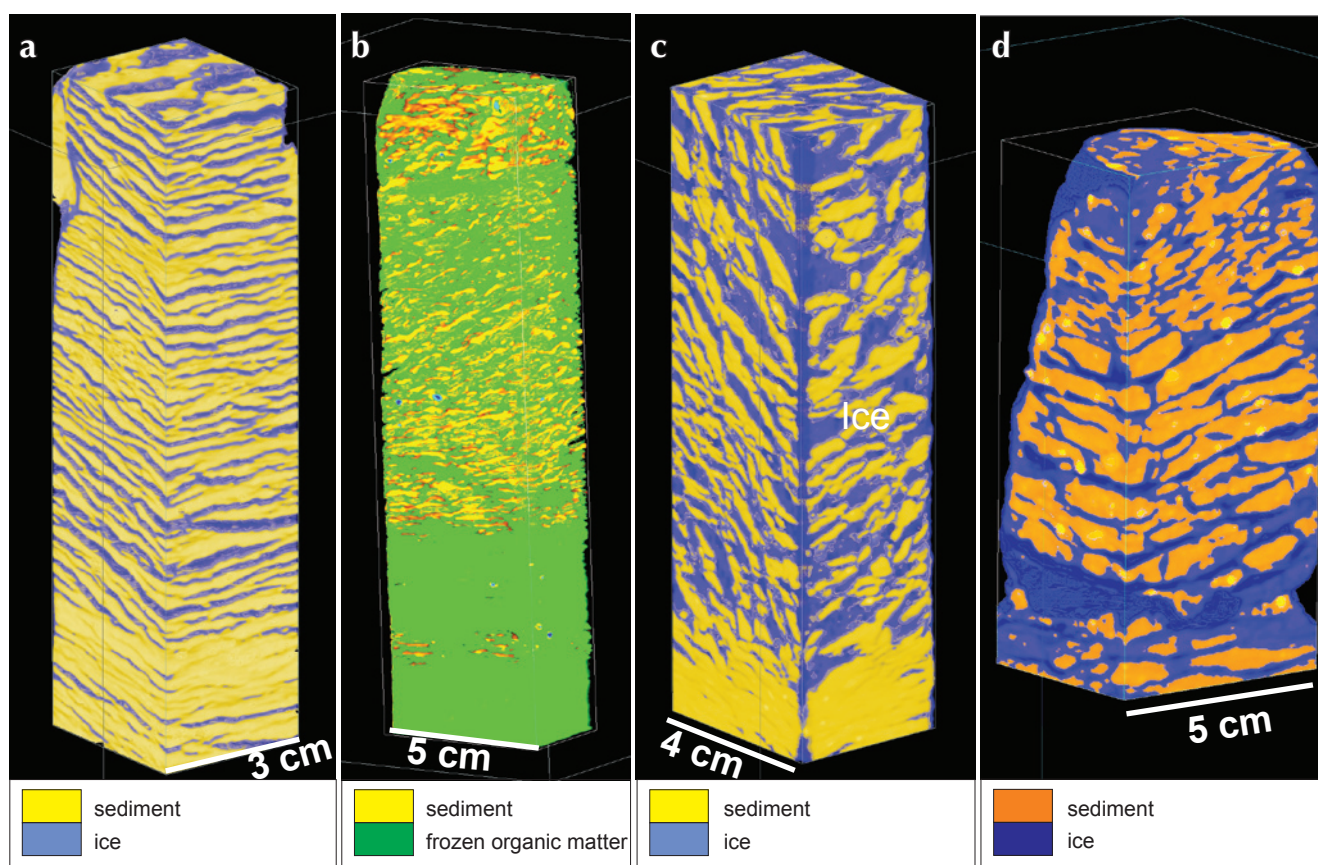


Figure 8. Cryostructures observed in boreholes revealed by CT scanning of permafrost cores: (a) layered; (b) organic rich; (c) suspended; and (d) reticulate.

A layered cryostructure can be related to ice-wedges, segregational ice, intrusive ice, buried glaciers or ice bodies. At our sites, only ice segregation is involved in the genesis of this cryostructure. The combination of freezing rate and water availability influence ice-lensing and the thickness of the ice and sediment layers. The relatively thin ice layers suggest relatively modest water supply or a rapid freezing rate.

(ii) Organic-rich

Frozen organic-rich zones are encountered along some of our profiles (Fig. 8b). The organic-rich cryostructure is present in cores RD[3]1 from 50 to 115 cm, in RD[3]2 from ~65 to 130 cm, and to a lesser degree in W1 from 50 to 130 cm where the organic material is mixed within the sediment. The organic-rich cryostructure is largely absent in cores BW1, RD[2]1 and RD[2]2. The proximity of sites RD[3]1, RD[3]1 and W1 suggests that this organic-rich zone is restricted to individual cores and does not represent a cryostructure with a great lateral extent. Several processes may produce the organic concentration, and its origin is not clear. The accumulation of organic matter may have formed when the surface of the site existed as a topographic depression or a small thermokarst pond where organic sedimentation took place. These zones are particularly ice rich due to their high porosity. Organic matter, such as peat, has a density similar to that of ice, and appears dark grey on CT scans. The frozen peat can be distinguished from pure ice by its mineral content, and it appears slightly brighter, with distinct sediment beds and lenses on CT scans.

(iii) Suspended

A suspended cryostructure is characterized by aggregates or sediment particles suspended in an ice matrix, with ice content exceeding sediment content (Fig. 8c). The suspended cryostructure is often encountered in massive ice and also in the uppermost 10 cm of permafrost (*i.e.* directly underlying the active layer, Mackay, 1972; Murton and French, 1994) where aggradational ice is forming (Yershov, 1998). In such conditions, the thermal gradient is low and ice lensing is fed by the perched water available on the permafrost table. In general, this type of cryostructure likely reflects a lower thermal regime favouring ice segregation, as well as greater water supply favouring segregational ice growth (Yershov, 1998).

In our cores, the cryostructures were not always homogeneous and show variation in ice content within a single cryostratigraphic unit. Ice lenses range from a few millimetres to 2 cm. The thickness of the cryostructure

ranges from approximately 20 to 40 cm and is present in all cores. It is interesting to note that in our cores, the gas content is greatest in these thick ice layers. Generally, the gas content consists of elongated cylindrical bubbles extending from the sediment into the ice. The association of this gas feature with thick lenses of segregational ice suggests they could be characteristic of lower freezing rates.

(iv) Reticulate

A reticulate cryostructure consists of a three-dimensional network of vertical and horizontal ice veins isolating sediment blocks (Fig. 8d). It can be regular, containing rectangular or rhombic sediment blocks, or irregular containing irregularly shaped blocks. The structure is only encountered in BW1 core, from ~196 to 210 cm, and can be considered rare at our sites. This could reflect the low moisture content or other sediment properties in this particular location. Mackay (1974) suggests that reticulate ice veins grow in horizontal and vertical shrinkage cracks with much of the water coming from the adjacent material in a semi-closed freezing system, rather than from migration of water in an open system.

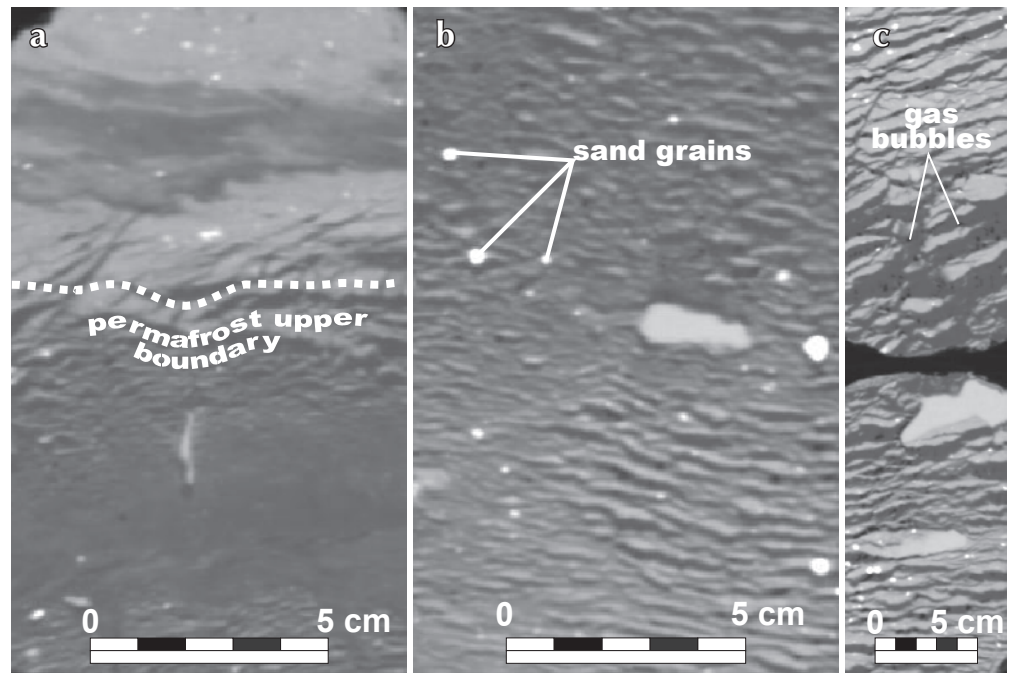
Cryostratigraphy of sites

The geocryological description of each site, with respect to their cryostructures, is presented below. The undisturbed site is described first, then the recently disturbed site, and finally the 1970s disturbed sites.

(i) W1, the forested site

W1 is a control site intended to represent an undisturbed, wooded site. Nevertheless, the presence of stumps and artefacts of the gold rush era in the area suggests it was disturbed in the early 20th century. Core W1 reaches a depth of 2.83 m. It has a surface cover of 5 cm of moss above 15 cm of humified peat. The thawing front was immediately below the organic layer in July 2008. Active layer samples have thin (1 mm or less) ice lenses in a sandy-silt matrix. The permafrost table was encountered at 51 to 58 cm depth, marked by an organic-rich zone where distinct ice lensing occurs below 58 cm (Fig. 9a). The diffuse nature of the upper boundary of the permafrost suggests a stable thermal equilibrium between the active layer and the permafrost table with few changes in recent time. This would indicate relatively constant surface conditions, with depth fluctuations of the permafrost being mainly controlled by climate. At a depth of approximately 150 cm, a fine, wavy layered cryostructure is present with millimetre-thick sediment

Figure 9. Cryostructures in core W1 (forested site): (a) upper boundary of permafrost; (b) layered cryostructure; and (c) suspended cryostructure.



and ice layering (Fig. 9b). Below 150 cm, a larger layered cryostructure is present to a depth of 200 cm where it grades to a suspended structure with the highest ice content observed in the profile (Fig. 7, 9c). Below this zone, the cryostructure grades to layered and thinly layered/lenticular transitional facies to a depth of approximately 260 cm where ice lenses are rare to absent. Sand, pebble and clasts (up to ~7 cm) are present in a fine-grained sediment matrix. Overall, one very ice-rich zone (suspended cryostructure) is present at around 2 m depth, and the upper permafrost boundary suggests that no disturbance occurred during recent decades.

(ii) BW1, the 2004 burned site

Core BW1 was taken to a depth of 2.64 m and was collected to study the impact of the recent fire on the geocryological profile. The organic cover was burned and consists of an 8 cm-thick moss layer above 12 cm of dark humified peat. The thickness of the unfrozen ground at the time of sampling was 28 cm, including the organic cover. Active layer samples collected between 40 and 73 cm of depth were disturbed during the drilling process and were discarded. The permafrost table was noted at 76 cm, marked by a sharp contact (Fig. 10a, upper part), suggesting that the active layer is still increasing since the 2004 fire. The cryostructure is mainly non-parallel, wavy layered with tilted ice lenses (Fig 10a, lower part). Two major ice-rich zones include a suspended cryostructure at ~ 115 cm and 160 cm depth; two other minor ones are

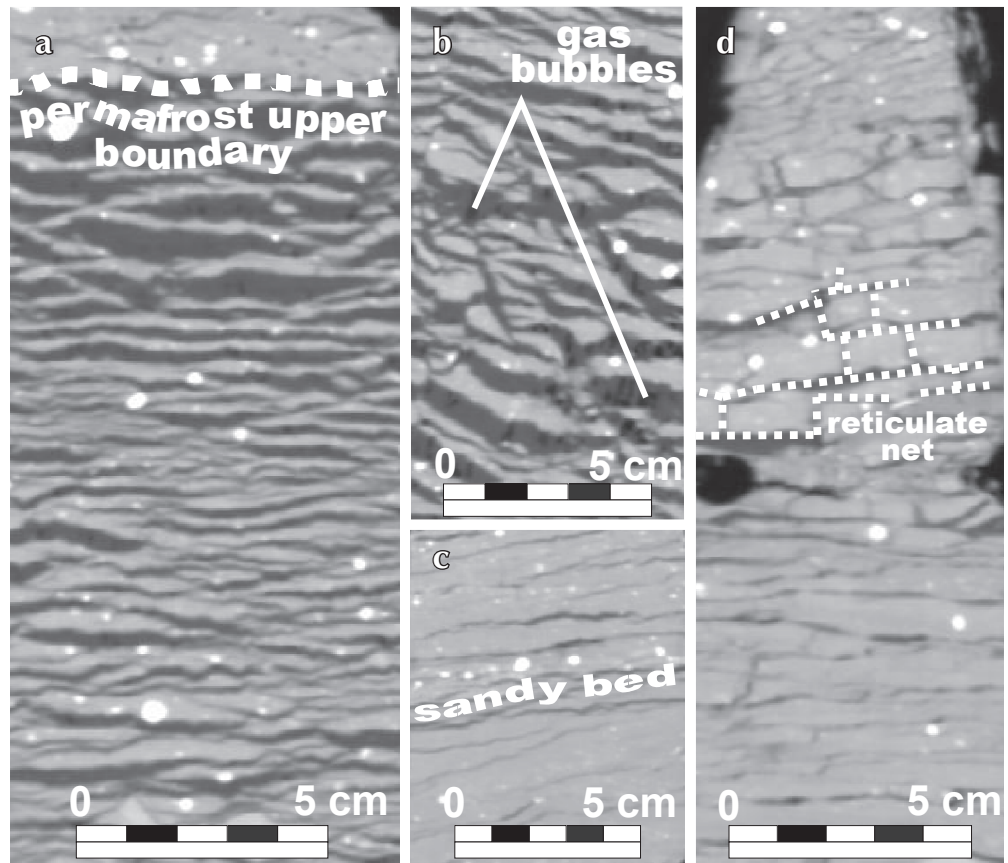
present at ~215 cm and 245 cm (Fig. 7). Usually, gas bubbles are observable within thick ice layers, but less common where ice lenses are thinner (Fig. 10b). Some beds of coarse particles are observed within the silty matrix. The orientation of this bed is tilted similar to the ice lensing (Fig. 10c), reflecting the general slope of the terrain. With the decrease in ice content with depth in the profile, other mixed cryostructures are observed such as the regular reticulate facies at 260 cm depth (Fig. 10d). Overall, two noticeable very ice-rich zones (suspended cryostructure) are present between 115 and 175 cm. The actual thaw discontinuity over the geocryological facies suggests that the active-layer thickness is still deepening in response to the 2004 fire disturbance.

(iii) RD[2]&[3], the late 1960s - early 1970s roads

The 'roads' are paths left by tracked vehicles in the early 1970s (A. Sailer, pers. comm., 2007), consisting of two depressed ruts separated by a higher, vegetated mound (Fig. 2a). Boreholes RD[2]1 and RD[3]1 were drilled in the ruts of the roads, whereas boreholes RD[2]2 and RD[3]2 were drilled in the vegetated mounds between the ruts to assess variability in the degradation and recovery processes.

Boreholes RD[2]1 and RD[2]2 have a depth of 3.09 and 2.54 m, respectively. The organic cover for both sites consists of 10 to 12 cm-thick moss cover above 15 cm of humified peat. The thawing front was directly below the organic layer between 27 and 30 cm, whereas the

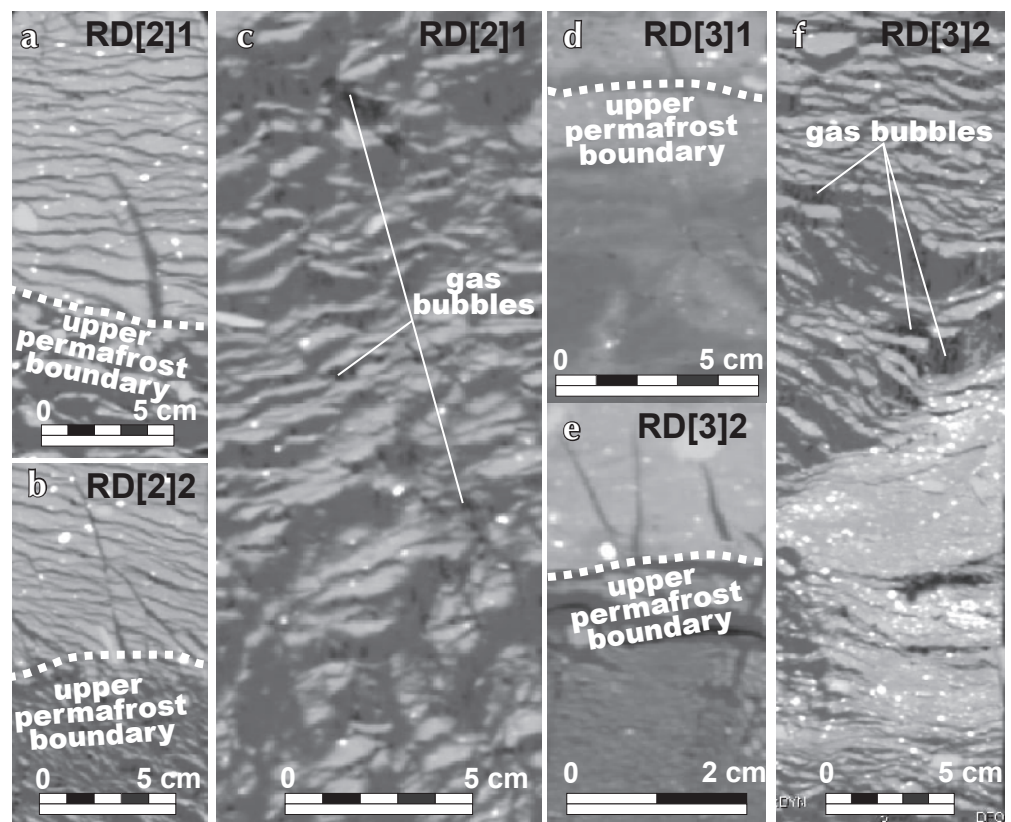
Figure 10. Cryostructures in core BW1 (2004 burned site): (a) upper boundary of permafrost above wavy layered cryostructure; (b) suspended cryostructure; (c) sandy beds; and (d) reticulate cryostructure.



permafrost table was at 95 and 110 cm for RD[2]1 and RD[2]2, respectively (Fig. 11a and 11b respectively). For both cores, the top of the modern permafrost table is ice rich and has a suspended cryostructure (Fig. 7, 11c). Some nearly vertical ice-veins propagate from the permafrost table into the active layer, probably due to the shrinkage of the sediment under the action of the cryodessication induced by the rising of the permafrost table (Mackay, 1972, 1974; Yershov, 1998; Williams, 1995). Below the upper permafrost boundary, the cryostructure is non-parallel wavy layered and is underlain by a lower ice-rich zone at 140 and 155 cm depth for RD[2]1 and RD[2]2, respectively (Fig. 7). Below these ice-rich zones, a layered cryostructure is present and the ice content decreases. Sand lenses, pebbles and small boulders occur infrequently in the profile, though distinct coarser layers are present at 192 and 208 cm for RD[2]1 and RD[2]2, respectively. The geocryological and sedimentary profiles of these two cores are consistent with a slight vertical offset of 15 cm, corresponding to the difference in surface profile between the ruts and the centre mound. RD[2] has two ice-rich zones at approximately 100 cm and 150 cm depth.

Cores RD[3]1 and RD[3]2 have depths of 2.84 and 2.99 m, respectively. The organic cover for both sites (27 cm for RD[3]1, 25 cm for RD[3]2) consists of a 6 to 8 cm-thick moss cover above 17 to 20 cm of humified peat. The thawing front was noted between 33 and 35 cm depth. The permafrost table was observed at 51 and 66 cm for RD[3]1 and RD[3]2, respectively, marked by a one centimetre-thick, sub-horizontal ice lens and vertical ice-veins above an organic-rich cryostructure. Some vertical ice veins are present in RD[2] cores and extend from the permafrost table; this zone is ice rich in both RD[2] and RD[1] cores. RD[2] cores have a higher organic content (Fig. 11d,e). The organic-rich level occurring just below the permafrost table probably prevented the formation of a suspended cryofacies. Below this depth, an ice-rich suspended cryostructure occurs at 130 (RD[3]1) and 145 cm (RD[3]2) depths. Below these levels, a layered cryostructure is present, overlying a suspended ice-rich zone at approximately 210 and 220 cm depths for RD[3]1 and RD[3]2, respectively (Fig. 11f). Below this last ice-rich zone, the layered structure is present, and the ice content decreases with depth. The geocryological and sedimentary profiles of the two cores are consistent, again with a gap of ~15 cm

Figure 11. Cryostructures in core RD[2]1, RD[2]2, RD[3]1, and RD[3]2 (1970s road sites). (a) Upper permafrost boundary overlying a suspended cryostructure (RD[2]1). (b) Upper permafrost boundary above suspended cryostructure (RD[2]2). (c) Suspended cryostructure (RD[2]1). (d) Upper permafrost boundary above organic-rich cryostructure (RD[3]1). (e) Upper permafrost boundary above organic-rich cryostructure (RD[3]2). (f) Suspended cryostructure (RD[3]2).



attributable to the topographic difference between the rut and the centre mound. Similar to RD[2] cores, two ice-rich zones with suspended cryostructure are present in the RD[3] cores at 130 to 145 cm and 210 to 220 cm, but sites on road three seem to have less degradation, or a faster recovery, given the shallower active layer.

DISCUSSION

The important element that we draw attention to in these cores is the presence of the suspended cryostructure, and its significance with respect to site history. As the suspended cryostructure is often associated with an ice-rich upper permafrost boundary, it likely marks the former top of the permafrost table following a past disturbance and recovery of the active layer.

All cores sampled near the road sites show two zones of prominent suspended cryostructure, while the forested site has only one zone. Since all of the sites have the same sedimentological setting, and are subject to the same climatic conditions, we can hypothesize that the principal factor influencing the occurrence and depth of these ice-rich layers would be the timing and nature of surface disturbances at each site. Site W1 underwent one known

episode of recent perturbation with deforestation in the early 20th century associated with gold rush era development, whereas the road sites include at least two episodes, the first being the deforestation and the second in response to road clearing. Consequently, the unique ice-rich zone observed at 2 m in W1 likely reflects recovery from the early 20th century degradation. Similarly, in the road sites, the shallowest ice-rich zone was from 130 to 145 cm and reflects the recovery from the road clearing in the late 1960s to early 1970s. The deepest ice-rich zone occurring from 210 to 220 cm, is broadly similar to the W1 site, and likely reflects recovery from early 20th century deforestation.

These ice-rich layers likely reflect past episodes of permafrost degradation and recovery. These levels mainly occur when the freezing front is stationary or progresses slowly and ice segregation processes can generate a thick ice layer. These conditions of weak thermal gradient typically occur following a period of degradation, when the thawing front stagnates. Thereafter, the freezing process starts to progress upward from the permafrost table, or aggradation of the permafrost table begins.

CONCLUSION

In the last century, several perturbations of permafrost occurred at the Dominion Creek study site in response to changing surface conditions associated with early 20th century deforestation, road clearing, and more recently, a forest fire. A consistent set of observations seems to be associated with each of these disturbances. The perturbations are marked initially by a thickening of the active layer over several decades followed by the development of a suspended cryostructure as the permafrost table stabilizes, and ultimately by re-aggradation of the permafrost table as vegetation recovers from the disturbance. The timing of these changes between degradation and recovery is still not well established, but almost certainly depends on the magnitude of the disturbance, and critically, the re-establishment of vegetation cover and its insulating properties.

Vegetation cover influences ground thermal regime; for example, through changes in summer insulation (which shields permafrost from exposure to the sun), or potentially capturing additional winter snow fall (which prevents cold-temperature penetration of the ground during winter) (Linnel, 1973; Burn, 1998). The preliminary results in this study suggest variation of vegetation cover will have a stronger and more immediate impact than temperature alone. Future warming may lead to degradation of the permafrost table as ground temperatures warm and active layers increase; however, these changes will be moderated by the overlying surface cover. Results of this study suggest that some of the related permafrost dynamics can be captured through the record of past disturbances.

CT scanning is a suitable and useful method to study permafrost dynamics through detailed cryostratigraphy. This technique may be more broadly applied in Yukon as a means to document and characterize recent changes in near-surface permafrost, and to provide tangible information about the future evolution of permafrost terrain under predicted warmer climate.

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We thank the Sailer family who have been mining in the study area for many decades and provided us with detailed descriptions of the history of their ground, which provided us with much of the sampling strategy that we used in this study. We particularly appreciate the help of Alberto Reyes and Chris Atkins for field assistance, and Shauna Cameron (Alberta Research Council) for operation of the CT scanner. The manuscript benefited from the constructive comments of Michel Allard (Laval University). Funding for this research was provided by a contract from the Yukon Geological Survey, in addition to the Fonds Québécois de la Recherche sur la Nature et les Technologies Fond, the Natural Sciences and Engineering Research Council of Canada, and Alberta Ingenuity New Faculty Award.

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Recent deglaciation of the upper Wheaton River watershed, Yukon

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ABSTRACT

We document rapid loss of glacier ice in the Wheaton River watershed which contains the northeastern-most glaciers within the Coast Mountains. Our research involves the study of the Wheaton glacier, the largest of the glaciers in the Wheaton River watershed. Since the Little Ice Age, the Wheaton glacier has lost 50% of its area and 58 to 63% of its volume. Thinning and retreat have accelerated in the past 40 years and the glacier is now so thin and short that it may disappear during this century. This loss was quantified through the analysis of sequential aerial photography and bivariate scaling analysis. Observations in the climate record from 1907 to 2005 have shown an increase in mean atmospheric temperature, as well as an increase in average winter snowfall. Despite increasing winter snowfall, changes in temperature continue to be the main cause of the persistent negative mass balance of the Wheaton glacier. If air temperatures continue to rise and glaciers disappear from the Wheaton River watershed, discharges and timing of peak flow events of the Wheaton River will be affected.

RÉSUMÉ

Nous présentons des données sur le recul rapide de la glace de glacier dans le bassin hydrologique de la rivière Wheaton, qui contient le glacier de la chaîne Côtière situé le plus au nord-est. Notre recherche comprend l'étude du glacier Wheaton, le plus grand glacier dans le bassin de la rivière Wheaton. Depuis le Petit Âge glaciaire, le glacier Wheaton a perdu 50 % de sa superficie et entre 58 et 63 % de son volume. Son amincissement et son recul ont accéléré au cours des 40 dernières années, et le glacier est maintenant si mince et petit qu'il pourrait disparaître au cours des 20 prochaines années. Nous avons quantifié la perte de glacier par le biais de l'analyse de photographies aériennes séquentielles et d'une analyse d'échelle à deux variables. Les données climatiques de 1907 à 2005 ont montré une augmentation de la température atmosphérique moyenne ainsi qu'une augmentation de la chute de neige moyenne en hiver. Malgré l'augmentation de la chute de neige en hiver, les changements de température continuent d'être la principale cause du bilan de masse continuellement négatif du glacier Wheaton. Si la température de l'air continue d'augmenter et si les glaciers disparaissent du bassin de la rivière Wheaton, le débit et le moment des débits de pointe dans la rivière Wheaton varieront.

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INTRODUCTION

The Arctic and sub-Arctic will likely experience greater climate warming in the future than other parts of the world (IPCC, 2007). Over the past several decades, temperatures in these areas have increased at twice the rate of the rest of the planet. One of the manifestations of this warming in Yukon is thinning and retreat of many glaciers (ACIA, 2005; Lemmen *et al.*, 2008). Glacier retreat is intimately linked to changes in geomorphology, hydrology and biotic environments.

The Wheaton River watershed in southern Yukon, supports several small glaciers, which are the northeastern-most glaciers within the Coast Mountains. Glaciers in the Wheaton River watershed are located at the fringe of the region capable of supporting ice, making them highly responsive to climate change. This study thus provides a unique perspective on the impacts of changing climate in southern Yukon. We conducted a study of the largest of the glaciers in the Wheaton River watershed, hereafter referred to informally as Wheaton glacier.

OBJECTIVES

This project involves a study of the impact of contemporary deglaciation on the upper Wheaton River valley. The research addresses the following questions:

- How has Wheaton glacier changed over the past century?
- What is the relationship between the historic activity of Wheaton glacier and regional climate?

STUDY AREA

The Wheaton River watershed is in the transition zone between the Coast Mountains and the Yukon Plateau (Bond, 2003). It is located within the Yukon-Stikine Highlands ecoregion, the Boundary Ranges physiographic region, and the Coast morphologic belt (Smith *et al.*, 2004). This part of Yukon is an upland plateau dissected by relatively narrow and deep river valleys (Bond, 2003). The Wheaton River watershed has an area of 875 km² and drains to Lake Bennett near Carcross (Fig. 1; Ramage *et al.*, 2006).

Wheaton glacier (Fig. 2) is located in a high cirque in the headwaters of the Wheaton River watershed. A rock ridge and medial moraine divides the glacier into two lobes. The east lobe has a length of 3 km and is the source of the trunk stream that flows 4 km to a debris-flow fan in

the Wheaton River valley. The west lobe has a length of 3 km and terminates in a small proglacial lake, which then drains into the trunk stream. The glacier is bordered by the highest peaks in the watershed that rise up to 2460 m in elevation. The bedrock beneath and around Wheaton glacier is highly fractured and jointed granite, granodiorite and diorite. Scree covers the lower slopes adjacent to the glacier. The glacier forefield is largely un-vegetated, covered by recessional moraine ridges, ground moraine and erratics, and is bordered by an extensive Little Ice Age terminal moraine. The site of a former proglacial, moraine-dammed lake, just inside the terminal moraine, is marked by a shoreline and a flat lake bed. Rock glaciers are common on the east side of the valley downstream from the Little Ice Age terminal moraine.

GLACIAL HISTORY

The Cordilleran Ice Sheet covered the entire Wheaton River watershed, with the possible exception of the highest peaks, during the Late Wisconsinan McConnell Glaciation (Bond, 2003). During deglaciation, the Cassiar lobe of the Cordilleran Ice Sheet advanced into a zone vacated by the Coast Mountain lobe flowing from the west. A series of proglacial lakes developed throughout southern Yukon at this time. The Wheaton River valley hosted a lake that initially drained via an outlet at the headwaters of Wheaton River, and later through Cowley Creek northward into the Yukon River valley (Bond, 2003).

Wheaton glacier either disappeared or shrank to near its present size during the early Holocene, when climate was warmer than today (Denton and Stuiver, 1966). It reformed or advanced during Neoglaciation and reached its maximum Holocene extent during the Little Ice Age.

METHODS

GLACIAL AREA LOSS AND DOWNWASTING

The Canadian Government acquired sequential aerial photographs of Wheaton glacier in 1948, 1964, 1987 and 1995. These photos were scanned using a photogrammetric scanner at the National Air Photo Library in Ottawa. The digital images were imported into a GIS using ArcView software and were geo-referenced using ground-control points collected during the 2007 field season with both differential and hand-held GPS units. The aerial extent of the glacier in 1948, 1964, 1987 and 1995 was determined in ArcView GIS. The Little Ice Age extent of the glacier was measured based on moraine

and trimline geomorphic features. The 2004, 2006 and 2007 glacier extents are based on our field mapping in the 2007 field season and on previous field surveys by the Yukon Geological Survey and Monica Bruckner, a graduate student at Montana State University. Glacier downwasting was determined by differencing ground control points collected with a differential GPS. Points were collected from the top of a rock ridge separating the two lobes of Wheaton glacier that was first exposed in 1964.

BIVARIATE SCALING ANALYSIS AND VOLUME ESTIMATES

A scaling analysis based on mass and momentum conservation equations shows that glacier volumes can be related by a power law to more easily observed glacier surface areas (Bahr *et al.*, 1997):

$$V \propto S^Y \quad (\text{Equation 1})$$

where V is glacier volume, S is glacier surface area, and Y is an exponent relating volume and surface area.

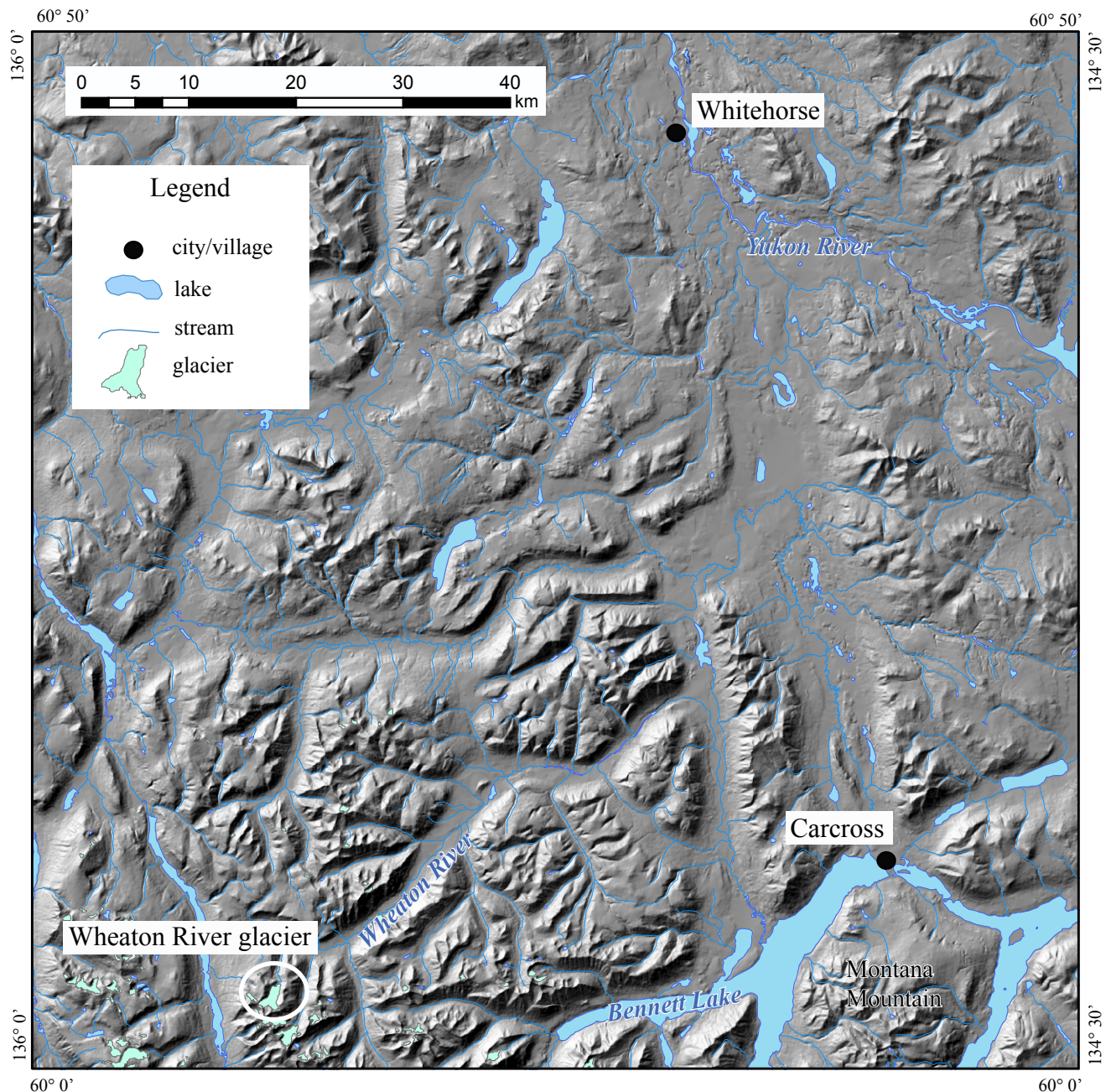
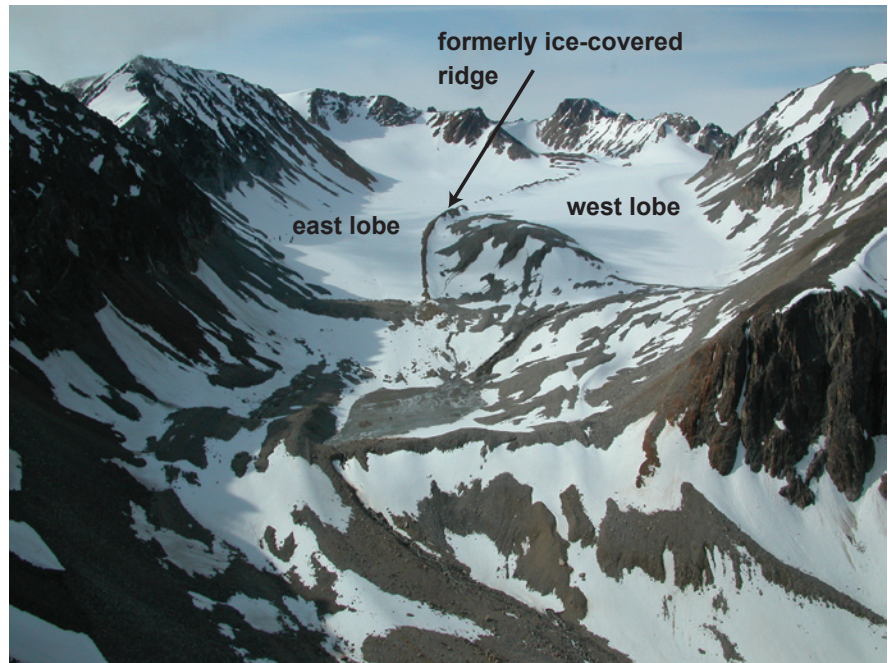


Figure 1. Location of the Wheaton glacier study site.

Figure 2. Wheaton glacier; photograph taken in 2007. Note rock ridge that was covered in ice as recently as the early 1960s.



Bahr *et al.* (1997) estimated Υ to be 1.36 from a dataset comprising 144 glaciers worldwide. Other authors, however, have suggested values in the range of 1.25 (Paterson, 1972) and 1.4 (Macheret *et al.*, 1988). Volume estimates for this study were calculated using three values of Υ (1.25, 1.36, and 1.4) to capture the potential range of values.

GEOMORPHOLOGY

Trimlines, moraines and other geomorphic features in the glacier forefield and cirque were mapped and captured in the GIS. Features were identified and mapped through aerial photographic interpretation and field checking in the summer of 2007.

LICHENOMETRY

Thalli of lichen (*Rhizocarpon geographicum*) on moraines and other features throughout the glacier forefield (Fig. 3) were measured to estimate the time of glacier retreat over the past century. At each site, the maximum diameters of 100 randomly chosen thalli were measured to the nearest millimetre to obtain a sample of the lichen population that included the largest specimens. Measurements for each sample were plotted as histograms for ease of comparison. The value used to estimate the age of each surface is the average of the five largest lichen-thalli diameters (Fig. 4). An average of the five largest thalli was used in order to lessen the influence of anomalous outliers that may have existed within the site lichen population.

A lichen growth curve for subalpine environments in southern Yukon was constructed to estimate the ages of landforms of interest in the Wheaton River watershed. Lichens on surfaces of known age were measured in the same manner as at Wheaton glacier. The surfaces included the Carcross and Tagish First Nations cemetery and several sites on Montana Mountain, including turn-of-the-century stone buildings and national survey points. Each point on the growth curve represents the average of the five largest lichen diameters at a site.

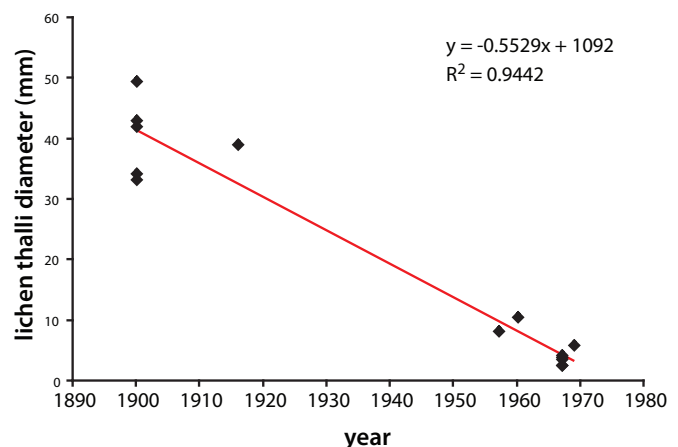


Figure 4. Lichen growth curve based on data collected from sites at Montana Mountain and Carcross.

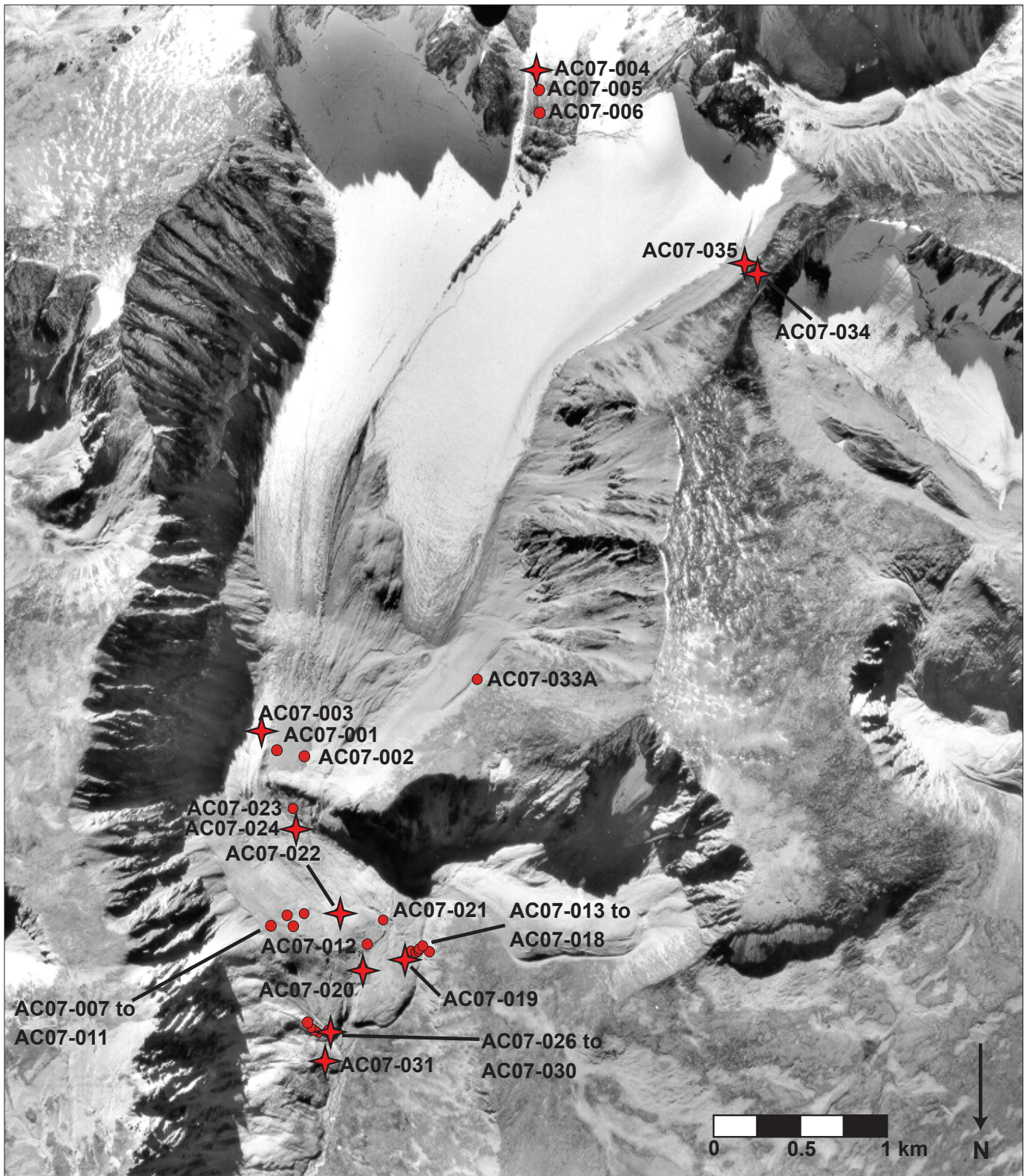


Figure 3. Locations of lichen sample sites. See Figure 5 for histograms showing distribution of lichen size at starred sites.

CLIMATE ANALYSIS

Temperature and precipitation data for Whitehorse and Carcross, the two closest weather stations to the study area, were obtained from the National Climate Data and Information Archive. Data exist for the period from 1907 to present. Yearly and seasonal temperature and precipitation averages were calculated and plotted to identify dominant trends. Comparison was also made to records of Pacific decadal oscillation (PDO), obtained from the University of Washington, and El Niño-Southern Oscillation (ENSO), obtained from National Oceanic and Atmospheric Administration's (NOAA) National Weather Service Climate Prediction Centre.

Table 1. Surface area of Wheaton glacier through time and associated area losses since the Little Ice Age (LIA) and the first aerial photography in 1948.

Date	Area (km ²)	Area loss (since LIA)	Area loss (since 1948)
Little Ice Age (LIA)	3.55		
1948	3.42	1.05 km ² /18.5%	
1964	2.72	0.83 km ² /23.4%	0.70 km ² /20.5%
1987	2.21	1.33 km ² /37.6%	1.20 km ² /35.2%
1995	1.81	1.74 km ² /49.0%	1.61 km ² /47.1%
2004	1.78	1.76 km ² /49.7%	1.63 km ² /47.8%
2006	1.77	1.77 km ² /50.0%	1.65 km ² /48.2%
2007	1.76	1.79 km ² /50.4%	1.66 km ² /48.6%

RESULTS

GLACIER ICE LOSS

Table 1 and Figure 5 summarize the change in the area of Wheaton glacier through time and Table 2 presents glacier volume changes calculated using the bivariate scaling procedure summarized above.

The area of Wheaton glacier in 2007 was 1.80 km² (50.4%) less than at the time of the Little Ice Age maximum in the nineteenth century. Since the first aerial photographs were taken in 1948, 1.66 km² or 48.6% of the glacier's area has been lost.

Estimated volume loss of glacier ice between the Little Ice Age and 2007 is 2.8 to 3.7 km³, or 58 to 63% of the glacier mass. Since 1948, volume losses on the glacier have ranged from 2.6 to 3.4 km³, or 56 to 61%.

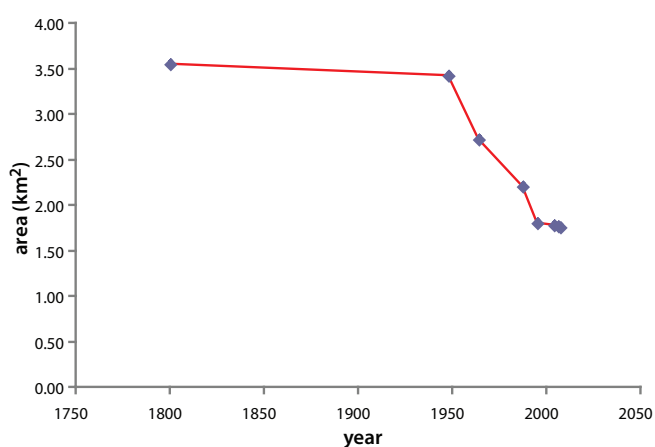


Figure 5. The area of the Wheaton glacier throughout time.

Table 2. Volumes of Wheaton glacier through time, estimated using bivariate scaling analysis for three values of Υ (1.25, 1.36, and 1.4) and associated volume losses since the Little Ice Age (LIA) and the first aerial photography in 1948.

	$\Upsilon = 1.25$			$\Upsilon = 1.36$			$\Upsilon = 1.4$		
	Volume (km ³)	Volume loss since: LIA 1948		Volume (km ³)	Volume loss since: LIA 1948		Volume (km ³)	Volume loss since: LIA 1948	
LIA	4.9			5.6			5.9		
1948	4.6	0.2 km ³ /4.5%		5.3	0.3 km ³ /4.9%		5.6	0.3 km ³ /5.0%	
1964	3.5	1.4 km ³ /28.3%	1.2 km ³ /25.0%	3.9	1.7 km ³ /30.4%	1.4 km ³ /26.8%	4.1	1.8 km ³ /31.1%	1.5 km ³ /27.5%
1987	2.7	2.2 km ³ /44.5%	1.9 km ³ /42.0%	2.9	2.6 km ³ /47.3%	2.4 km ³ /44.6%	3.0	2.8 km ³ /48.3%	2.5 km ³ /45.6%
1995	2.1	2.8 km ³ /60.0%	2.6 km ³ /55.0%	2.2	3.4 km ³ /60.0%	3.1 km ³ /58.0%	2.3	3.6 km ³ /61.1%	3.3 km ³ /59.1%
2004	2.1	2.8 km ³ /57.6%	2.6 km ³ /55.6%	2.2	3.4 km ³ /60.7%	3.1 km ³ /58.7%	2.2	3.6 km ³ /61.8%	3.3 km ³ /59.7%
2006	2.0	2.8 km ³ /58.0%	2.6 km ³ /56.0%	2.2	3.4 km ³ /61.1%	3.1 km ³ /59.1%	2.2	3.7 km ³ /62.1%	3.4 km ³ /60.1%
2007	2.0	2.8 km ³ /58.4%	2.6 km ³ /56.4%	2.2	3.4 km ³ /61.5%	3.2 km ³ /59.5%	2.2	3.7 km ³ /62.5%	3.4 km ³ /60.6%

The top of the rock ridge separating the east and west lobes of the glacier was first exposed in 1964. The glacier downwasted 120 m in this area between 1964 and 2007 (from 1873 to 1753 m asl).

GEOMORPHOLOGY AND CHRONOLOGY

The Little Ice Age terminal moraine is a distinct ridge bordering the glacier forefield. A conspicuous trimline above the current glacier surface is continuous with the terminal moraine and delineates the glacier margin at the Little Ice Age maximum (Fig. 6).

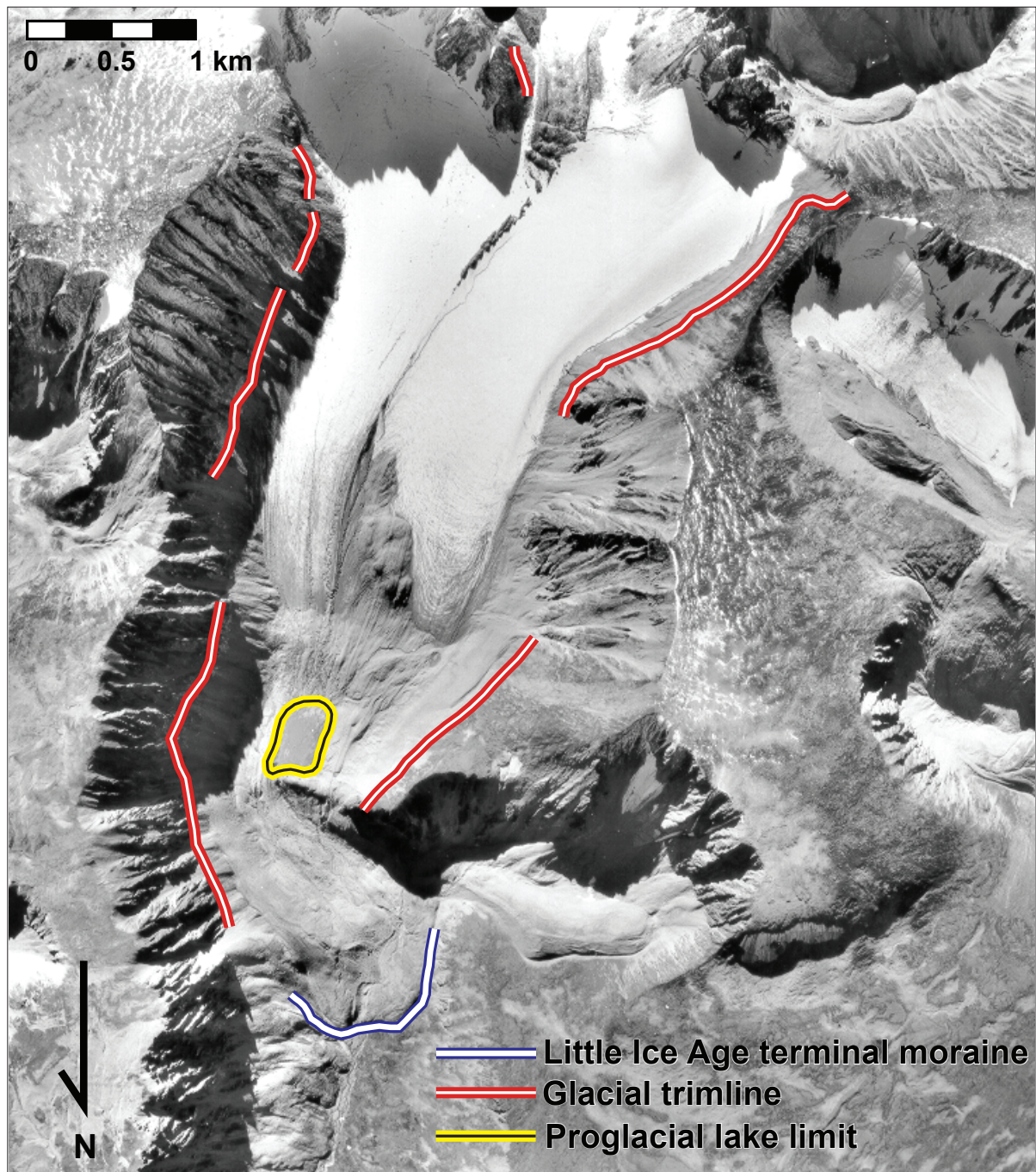


Figure 6. Locations of Little Ice Age trimline, moraines in the glacier forefield, and a former proglacial lake visible on 1995 aerial photographs.

Figure 7 presents lichen data from the glacier forefield, and Figure 4 shows the lichen growth curve used to estimate the ages of surfaces in the Wheaton glacier forefield. Table 3 summarizes the age of each lichen site predicted from the lichen growth curve, and Figure 8

shows locations of the glacier terminus at several different times since the Little Ice Age. The lichen ages suggest a steady rate of retreat between the Little Ice Age and 1940s, a period during which no photographs are available.

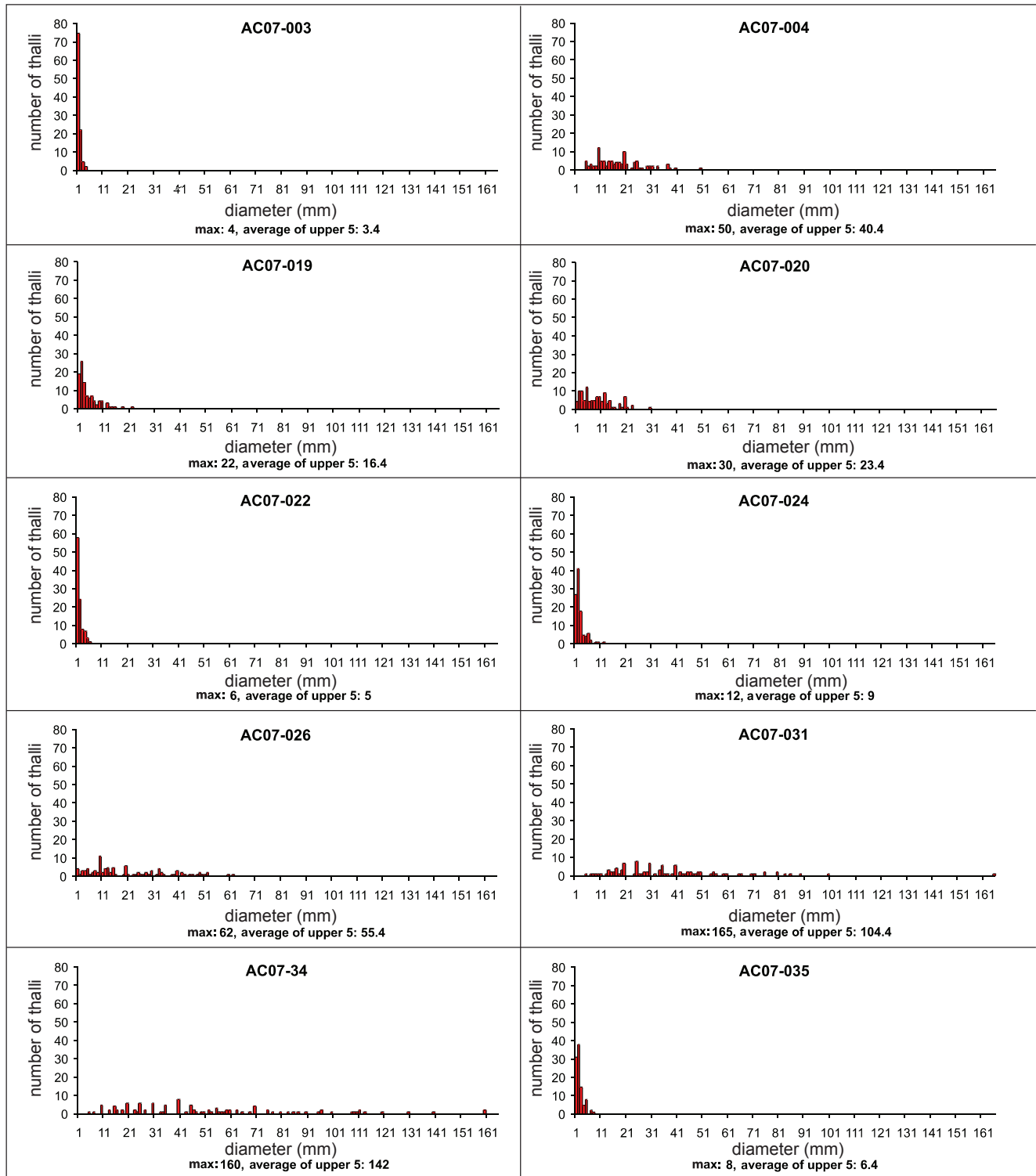


Figure 7. Histograms of the maximum diameter of lichen thalli in the Wheaton glacier forefield and surrounding area.

Table 3. For each site, average long-axis diameter of the five largest lichen thalli and ages predicted using the lichen growth curve.

Lichen site number	Average diameter of five maximum lichen thalli (mm)	Estimated age from lichen growth curve	Lichen site number	Average diameter of five maximum lichen thalli (mm)	Estimated age from lichen growth curve	Lichen site number	Average diameter of five maximum lichen thalli (mm)	Estimated age from lichen growth curve
AC07-001	4	1968	AC07-012	25	1930	AC07-023	13	1952
AC07-002	4	1967	AC07-013	33	1915	AC07-024	9	1959
AC07-003	3	1969	AC07-014	21	1936	AC07-026	55	1875
AC07-004	40	1902	AC07-015	13	1952	AC07-027	97	1799
AC07-005	17	1944	AC07-016	19	1941	AC07-028	93	1808
AC07-006	49	1886	AC07-017	17	1944	AC07-029	68	1853
AC07-007	11	1954	AC07-018	18	1942	AC07-030	54	1877
AC07-008	10	1957	AC07-019	16	1945	AC07-031	104	1786
AC07-009	8	1960	AC07-020	23	1933	AC07-033A	11	1954
AC07-010	27	1925	AC07-021	8	1960	AC07-034	142	1718
AC07-011	126	1748	AC07-022	5	1966	AC07-035	6	1963

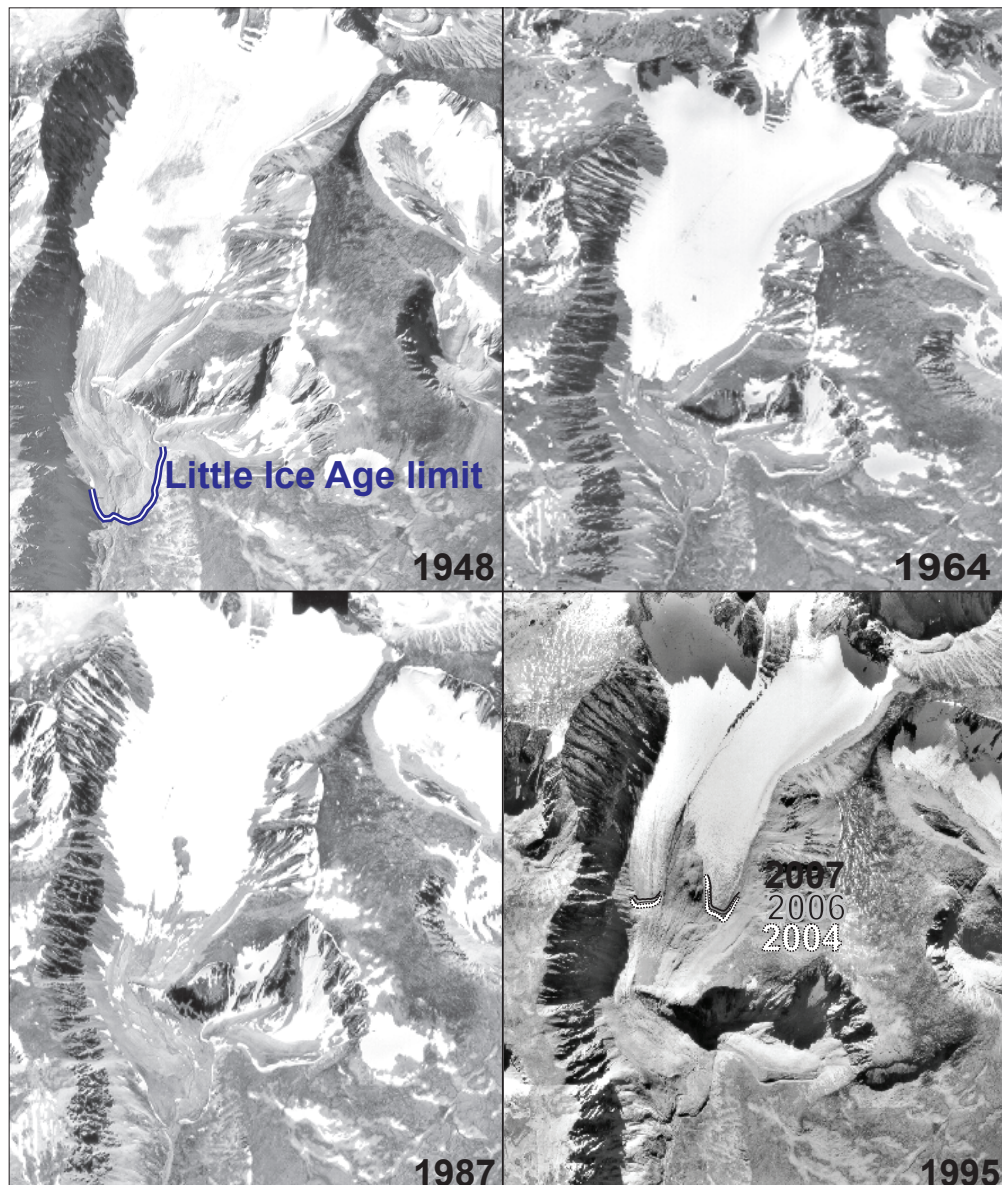


Figure 8. Glacier margins at the peak of the Little Ice Age and in 1948, 1964, 1987, 1995, 2004, 2006 and 2007.

CLIMATE

Annual average temperature at Whitehorse and Carcross increased for the period 1907 to 2005 (Fig. 9). Annual average precipitation increased in Carcross but has been relatively constant at Whitehorse for the period 1907 to 2005 (Fig. 10).

At both stations, average winter (November to February) temperature increased; average spring (March to May) and summer (June to August) temperatures also increased; and average fall (September to October) temperature decreased (Fig. 11). Average summer and fall precipitation increased over the period of record; winter precipitation increased at Carcross, but decreased at Whitehorse (Fig. 12). Spring precipitation has not changed significantly at Carcross and has decreased at Whitehorse.

ENSO events have been associated with warming and increased precipitation in some areas of northwest North America (Cayan *et al.*, 1998). Figure 13 shows the relationship between ENSO events and the temperature and precipitation records for Carcross and Whitehorse.

Negative PDO events appear to amplify warm ENSO events, further increasing warming and precipitation in northwest North America (Mantua *et al.*, 1997). Figure 14 illustrates a negative correlation between PDO and temperature and precipitation at Carcross and Whitehorse suggesting that ENSO and PDO do not have a major effect on climate of southern Yukon, and therefore, on the mass balance of Wheaton glacier.

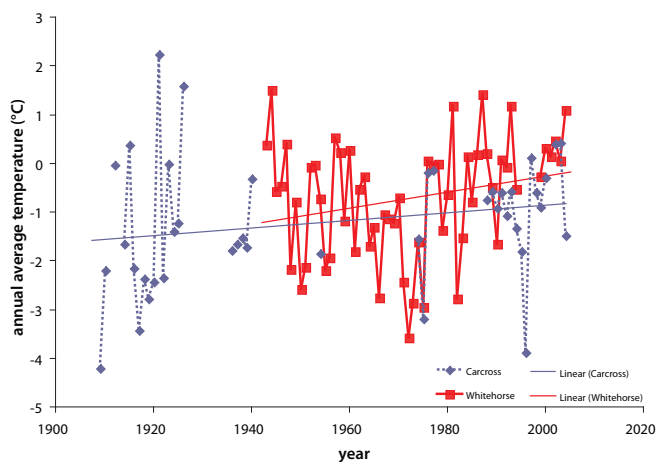


Figure 9. Annual average temperature at Whitehorse and Carcross for the period 1907 to 2005.

DISCUSSION

Wheaton glacier has lost 50% of its area and 58 to 63% of its mass since the maximum of the Little Ice Age in the nineteenth century. Most of the loss since the Little Ice Age (92%) has occurred since the 1940s suggesting that thinning and retreat have accelerated post-1948. In the past 60 years, Wheaton glacier has undergone a steady rate of retreat until the 1990s when its rate of retreat decreased slightly. The glacier is now so thin and short that it may disappear during this century.

The majority of the lichen ages determined using the constructed lichen growth curve appear to agree with the aerial photographs of the area. One notable exception is sites AC07-007, AC07-008 and AC07-009. The lichen populations measured at these three sites suggest ages of 1954, 1957 and 1960, respectively. These ages appear to be anomalous. Sites AC07-001, AC07-002 and AC07-003 all record ages within the 1960s and coincide closely with the ice margin captured in the 1964 aerial photograph. Other sites nearby the three anomalous sites record significantly older ages. The three anomalous sites lie within the boundaries of a rock fall track that is suspected of triggering a debris flow that affected the valley below; we will explore this in a subsequent paper.

The climate record shows that mean temperature in southern Yukon has increased since 1907. Average winter snowfall in Carcross has increased over this period and although winter precipitation has decreased at Whitehorse, annual average precipitation has increased. The lower elevation, drier climate and greater distance of Whitehorse from Wheaton glacier, make that weather

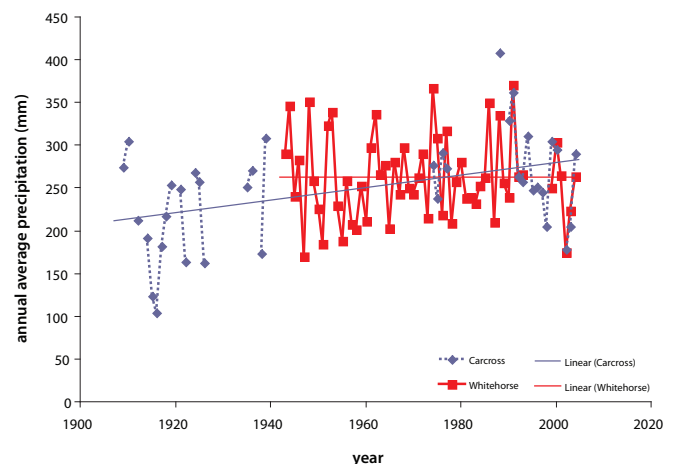


Figure 10. Annual average precipitation at Whitehorse and Carcross for the period 1907 to 2005.

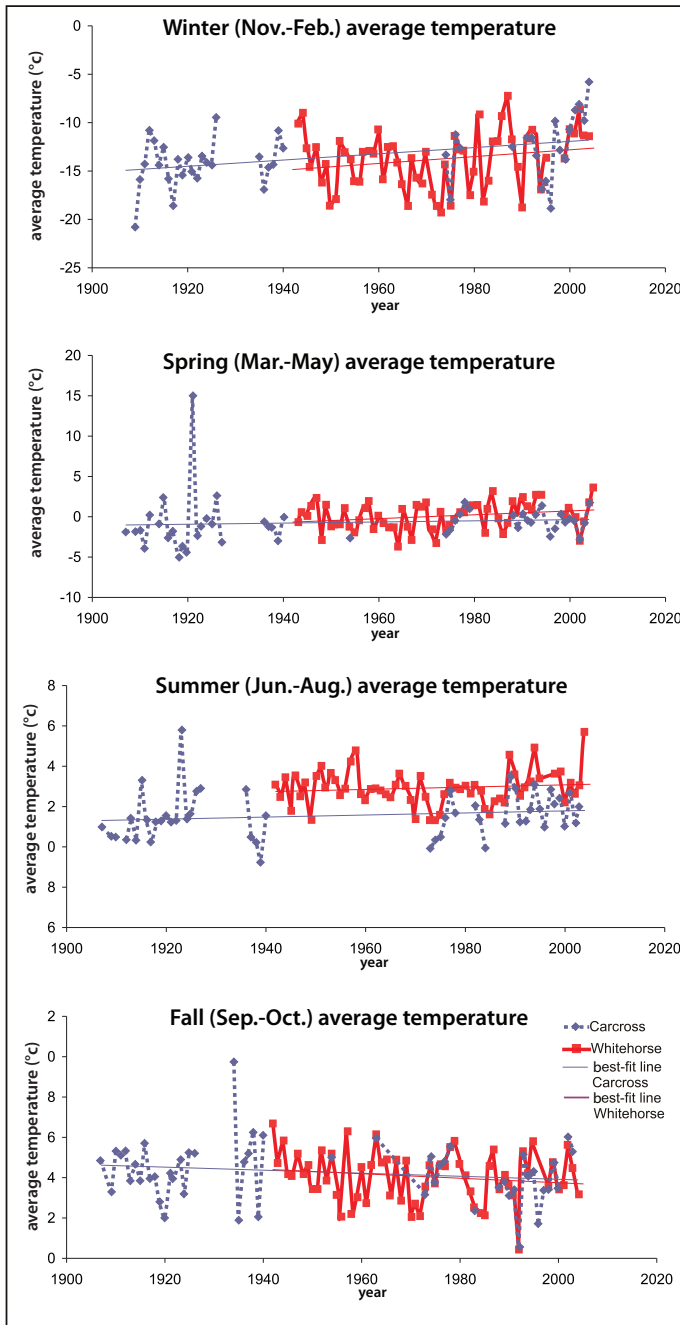


Figure 11. Average seasonal temperatures at Whitehorse and Carcross for the period 1907 to 2005.

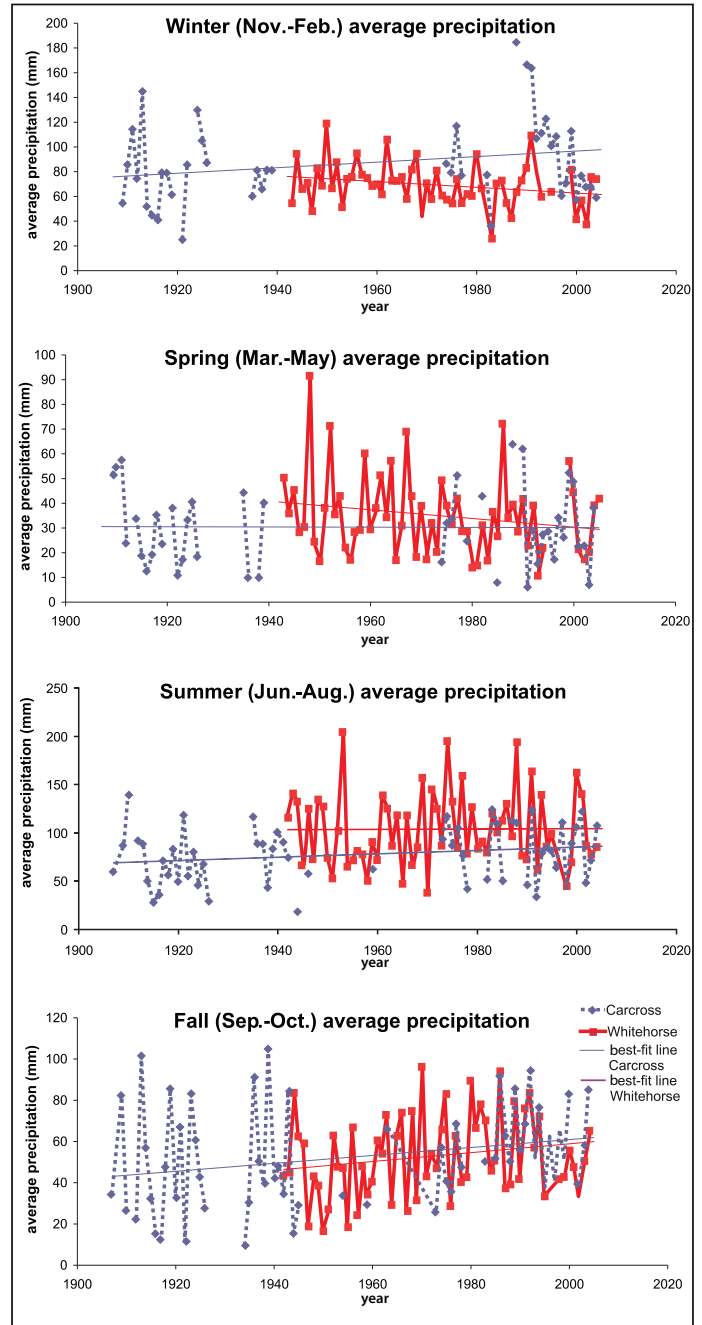


Figure 12. Average seasonal precipitation at Whitehorse and Carcross for the period 1907 to 2005.

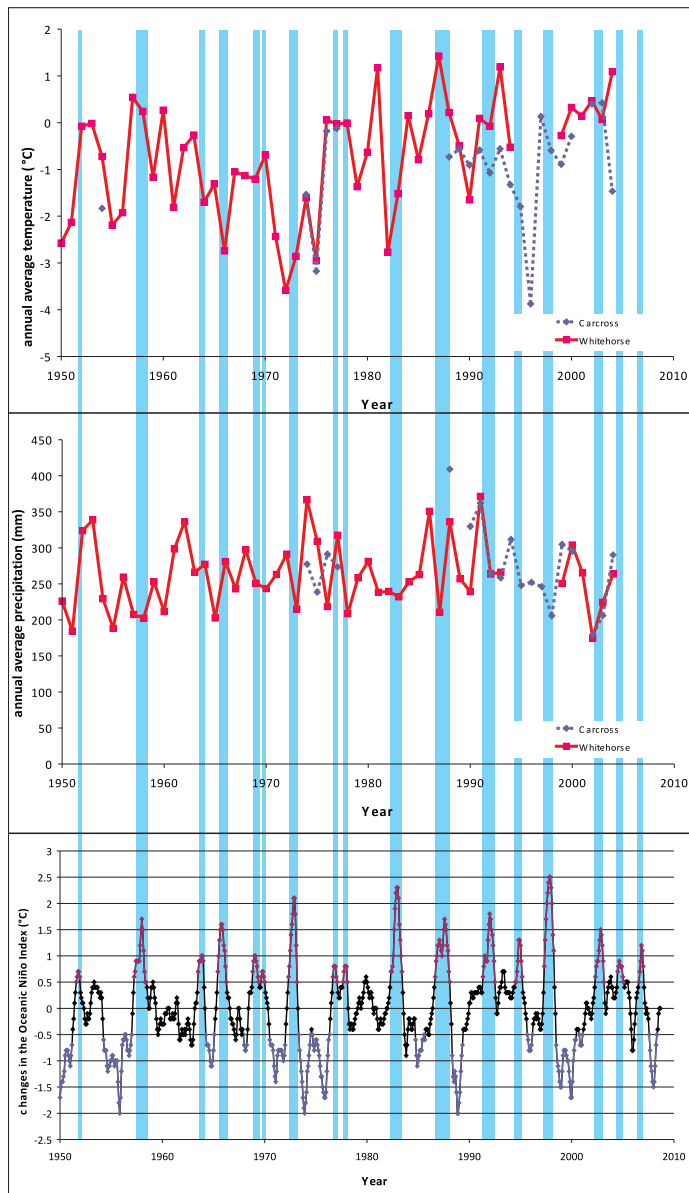


Figure 13. ENSO record for the period 1950 to 2008 compared to precipitation and temperature at Whitehorse and Carcross. Shaded bars are warm ENSO events.

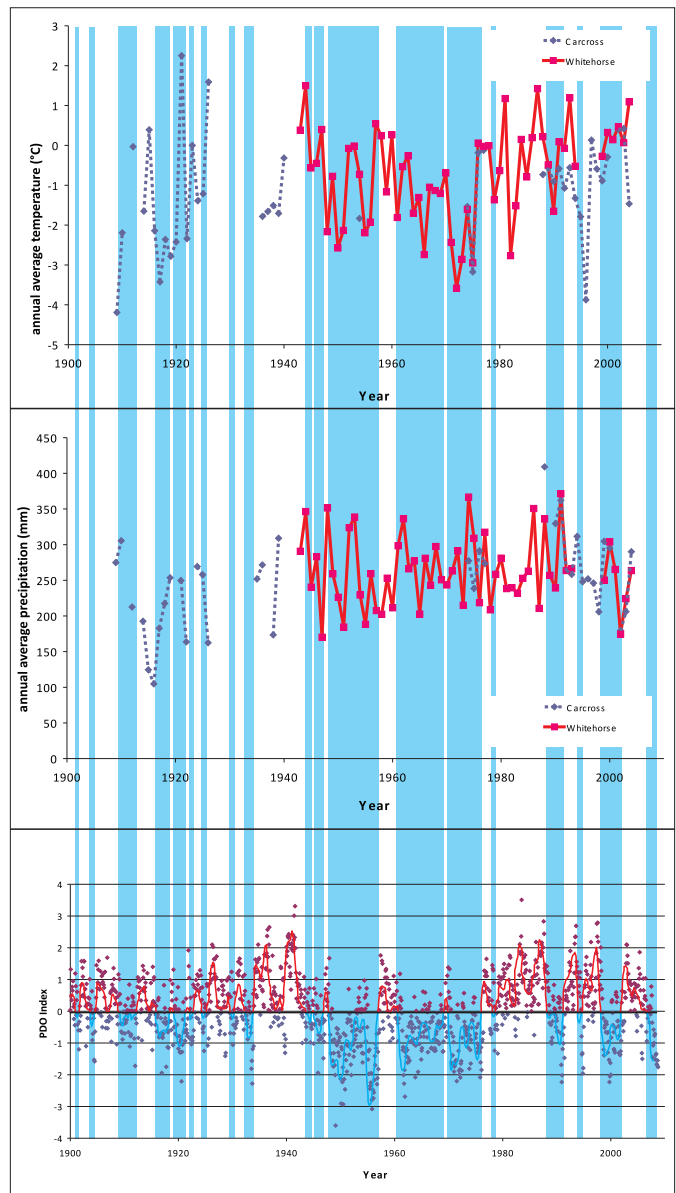


Figure 14. PDO record for the period 1900 to 2008 compared to precipitation and temperature at Whitehorse and Carcross. Shaded bars are negative PDO events.

station less representative than the Carcross station with regards to conditions at Wheaton glacier. On a larger scale, increases in precipitation and temperature during the historic period are consistent with trends throughout most of Yukon territory (Furgal and Prowse, 2008).

Although PDO and ENSO have a significant impact on climate in many areas of northwest North America, they do not appear to significantly affect the climate of the Wheaton River watershed. The increase in temperature during the twentieth and early twenty-first centuries is the main cause of the persistent negative mass balance of Wheaton glacier. Neither PDO phase changes nor increased winter snowfall have affected the activity of the glacier.

CONCLUSION

Wheaton glacier has significantly thinned and retreated over the past century. Since the Little Ice Age in the 1800s, the glacier has lost 50% of its area and 58 to 63% of its mass. Most of this loss has occurred since the first aerial photographs of the glacier were taken in 1948. Climate data from Whitehorse and Carcross show that temperature in southern Yukon has increased since 1907; winter snowfall has increased at Carcross, but not at Whitehorse. Warming appears to be the main cause of the persistent negative mass balance of Wheaton glacier. If temperatures continue to rise, the glacier will disappear, probably in this century.

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Soil genesis in relation to glacial history in central Yukon

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ABSTRACT

Reconnaissance studies of soils on low-elevation McConnell (~30-12 ka), Reid (~150-80 ka) and pre-Reid (~2.6-0.2 Ma) glacial deposits were conducted in the 1970s and 1980s. We initiated a study in the summer of 2008 to assess whether the distinct morphological and clay mineral characteristics of these soil groups are also present at upland sites in south-central Yukon, approximately 25 km southwest of Carmacks. Soils at the pre-Reid sites are developed on weathered bedrock. Solum thickness at these sites exceeds the depth of the excavated pits (85-110 cm), and the solum has been strongly cryoturbated. Soils at the Reid and McConnell sites are developed on till with solum thicknesses of 50-75 cm and <50 cm respectively. These younger soils do not exhibit significant cryoturbation at depth. No significant differences in solum colour are apparent among the soil groups, and no clay skins were observed. Results of chemical and micromorphological analyses will be reported in 2009.

RÉSUMÉ

Des études de reconnaissance des sols sur des dépôts glaciaires de McConnell (~30-12 Ka), de Reid (~150-80 Ka) et antérieurs à la Glaciation de Reid (~2,6-0,2 Ma) à faible altitude ont été menées dans les années 1970 et 1980. À l'été 2008, nous avons lancé une étude visant à évaluer si les caractéristiques morphologiques et les minéraux argileux particuliers de ces groupes de sols sont également présents dans les hautes terres du centre sud du Yukon, environ 25 km au sud ouest de Carmacks. Les sols aux sites antérieurs à la Glaciation de Reid reposent sur un substratum rocheux altéré. L'épaisseur du solum à ces sites dépasse la profondeur des puits excavés (de 85 à 110 cm), et le solum a été fortement remanié par géliturbation. Les sols aux sites de Reid et de McConnell reposent sur un till, et l'épaisseur du solum y est de 50 à 75 cm et de plus de 50 cm, respectivement. Ces sols plus jeunes ne montrent aucun signe important de géliturbation en profondeur. Aucune différence significative n'est apparente dans la couleur du solum parmi les groupes de sols, et aucune pellicule argileuse n'a été observée. Les résultats des analyses chimiques et micromorphologiques seront présentés dans un rapport en 2009.

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INTRODUCTION

Soil genesis studies in central Yukon initially focussed on glacial deposits and have only recently begun to address soils formed on weathered bedrock in unglaciated regions of the territory. Foscolos *et al.* (1977), Tarnocai *et al.* (1985), Smith *et al.* (1986) and Tarnocai and Smith (1989) conducted the first studies of soil development on Quaternary deposits, shown in Figure 1 as the area of previous research. They characterized soils on glacial deposits of McConnell (~30-12 ka), Reid (~150-80 ka), and pre-Reid (~2.6-0.2 Ma) age, based largely on the model of Yukon glaciation proposed by Bostock (1966). The soils comprise a chronosequence, a series of related soils that differ primarily as a result of differences in time of formation. Stronger morphological development and distinctive clay mineralogy characterize soils on deposits of older glaciations. The only study of soils in central Yukon in the past 20 years showed that this model does not fully apply to soils on Yukon River terraces

downstream from Ft. Selkirk, south of the areas studied in the 1970s and 1980s (Huscroft *et al.*, 2006).

The study area was selected to capture a range of surface ages and includes soils developed on weathered bedrock. Studies of soil genesis and mineral weathering in unglaciated regions of the central Yukon are limited and thus data for comparing soils formed primarily from *in situ* weathered bedrock to soils previously identified on glaciated surfaces in the chronosequence is limited (Bond and Sanborn, 2006). Due to the paucity of data, it is not yet possible to relate soils formed in complex parent materials, including weathered bedrock, to the soil chronosequence developed from the study of glacial deposits. The examination in this study of upland soil derived from weathered bedrock may be relevant to the study of soils on unglaciated surfaces beyond the pre-Reid limit.

Recent research has better constrained the ages of the McConnell and pre-Reid glaciations. The McConnell

Glaciation is late Wisconsinan (~30-11 ka) in age, and the oldest pre-Reid advance occurred at the end of the Pliocene (~2.6 Ma) (Froese *et al.*, 2000). The age of the penultimate glaciation, however, has not yet been resolved. In the past, researchers have assigned it variously to marine oxygen isotope stages 4 (~58-75 ka), 6 (~127-195 ka), or 8 (~244-297 ka) (Bradley, 1999; Westgate *et al.*, 2001; Huscroft *et al.*, 2004; Ward *et al.*, 2007). Recent surface exposure ages of 51-54 ka on penultimate drift thought to be a Reid-age deposit greater than marine oxygen isotope stage 4 indicates unresolved complexity in the glacial chronology (Ward *et al.*, 2007).

This study examines soil development on surfaces of a variety of ages in order to assess the contribution of weathering to soil properties and pedogenic pathways at upland sites in central Yukon. The study area is south of the region of previous studies, thus the research provides new data on surface weathering and contributes to establishing the chronology of ice sheet glaciation with more certainty. Results of the study can be applied to surficial geology mapping where the ages of deposits are uncertain. This report provides preliminary results of the 2008 fieldwork component of the project. Synthesis and analytical results will be reported in 2009.

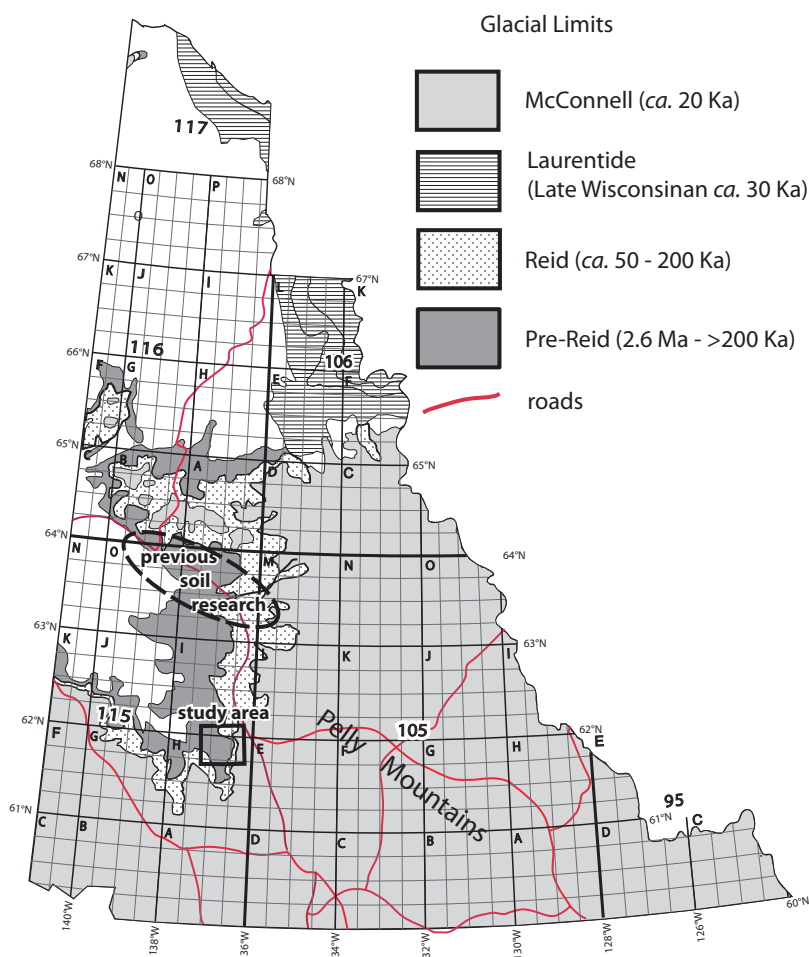


Figure 1. Glacial limits in Yukon and location of the study area (after Duk-Rodkin, 1999).

STUDY AREA

The study area is approximately 25 km southwest of Carmacks in central Yukon. Study sites are located on the Yukon Plateau in the southeast corner of the Carmacks (NTS 115I) map sheet and the northeast corner of the Aishihik Lake (NTS 115H) map sheet. Figure 1 shows the location of the study sites with respect to glacial limits and the area of previous study.

GEOLOGY

The study area overlies Early Jurassic Long Lake Suite porphyritic plutonic rocks that have intruded conglomerate. The Long Lake Suite comprises massive to weakly foliated, fine to coarse-grained, biotite, biotite-muscovite and biotite-hornblende quartz monzonite to granite (Gordey and Makepeace, 2001).

Bostock (1966) inferred that the area was glaciated during four advances of the Cordilleran Ice Sheet – from oldest to youngest, the Nansen, Klaza, Reid, and McConnell glaciations. The McConnell glacial limit is clearly delineated within the study area by conspicuous moraines, meltwater channels and ice-marginal features. Moraines and meltwater features of the Reid glaciation are above and beyond the McConnell limit and are much more subdued in character (Fig. 2; Hughes, 1990). Most rolling upland surfaces inside the Reid and McConnell limits are blanketed by till. In contrast, upland sites beyond the Reid limit are mantled by colluvium or weathered bedrock, with no till. In the Carmacks map area, evidence of glaciations beyond the Reid limit includes till, glaciofluvial landforms, glacial erosional landforms and drainage anomalies (Hughes, 1990; Jackson, 2000). Tors are common within these areas (Fig. 3), and cryoplanation



Figure 2. Meltwater channel formed during the Reid glaciation.

terraces occur in the Aishihik Lake map sheet west of the study area (Hughes, 1990). The age of upland pre-Reid surfaces is unknown.

ECOREGION

The study sites are within the Boreal Cordillera ecoregion. The west margin of this ecoregion is delineated by the maximum extent of glaciation (Smith *et al.*, 2004). The region is within the zone of discontinuous permafrost and is characterized by a continental climate with low precipitation (250-300 mm/year) and cool temperatures (mean annual temperature -4°C) (Smith *et al.*, 2004). Study sites range in elevation from <1100 m asl (McConnell-age sites) to >1250 m asl (pre-Reid). Open boreal forest at lower elevations within the study area comprises *Picea mariana* and a ground cover of shrubs (*Ledum groenlandicum*, *Vaccinium vitis-idaea* and *Betula glandulosa*), lichens (dominated by *Cladina rangiferina*, *Cladina mitis* and *Cladonia spp.*) and mosses. Subalpine sites have patches of krummholtz *Picea mariana* and a dominant ground cover of lichens and shrubs. Alpine sites lack spruce and have areas of bare ground.

SITE SELECTION

Figure 4 shows the locations of the 14 sites that were described in detail and sampled in this study. Sites are located in stable landscape positions where glacial sediments are most likely to be preserved and the most mature soils would be present. Criteria for site selection included an upland landscape position (>1000 m asl), gentle slopes ($0-5^{\circ}$), west to southwest aspect, good drainage, weathered bedrock or till parent material, and either no permafrost or a thick active layer.



Figure 3. Tor located beyond the Reid limit, adjacent to sample site Y08-10.

FIELD OBSERVATIONS

PARENT MATERIALS

All soils are developed on complex parent materials. Silty White River tephra, which is approximately 1150 years BP (Clague *et al.*, 1995), is the uppermost parent material at all sites. It is discontinuous in some profiles and ranges up

to a thickness of 25 cm. The colour of the tephra differs from light grey (10YR 7/1) to brown (10YR 4/3) in the Munsell Soil Colour Chart as a result of increasing alteration from the original parent material. The tephra is commonly cryoturbated.

Silty material typically directly underlies the tephra on surfaces of all ages, either as a distinct layer up to 10 cm

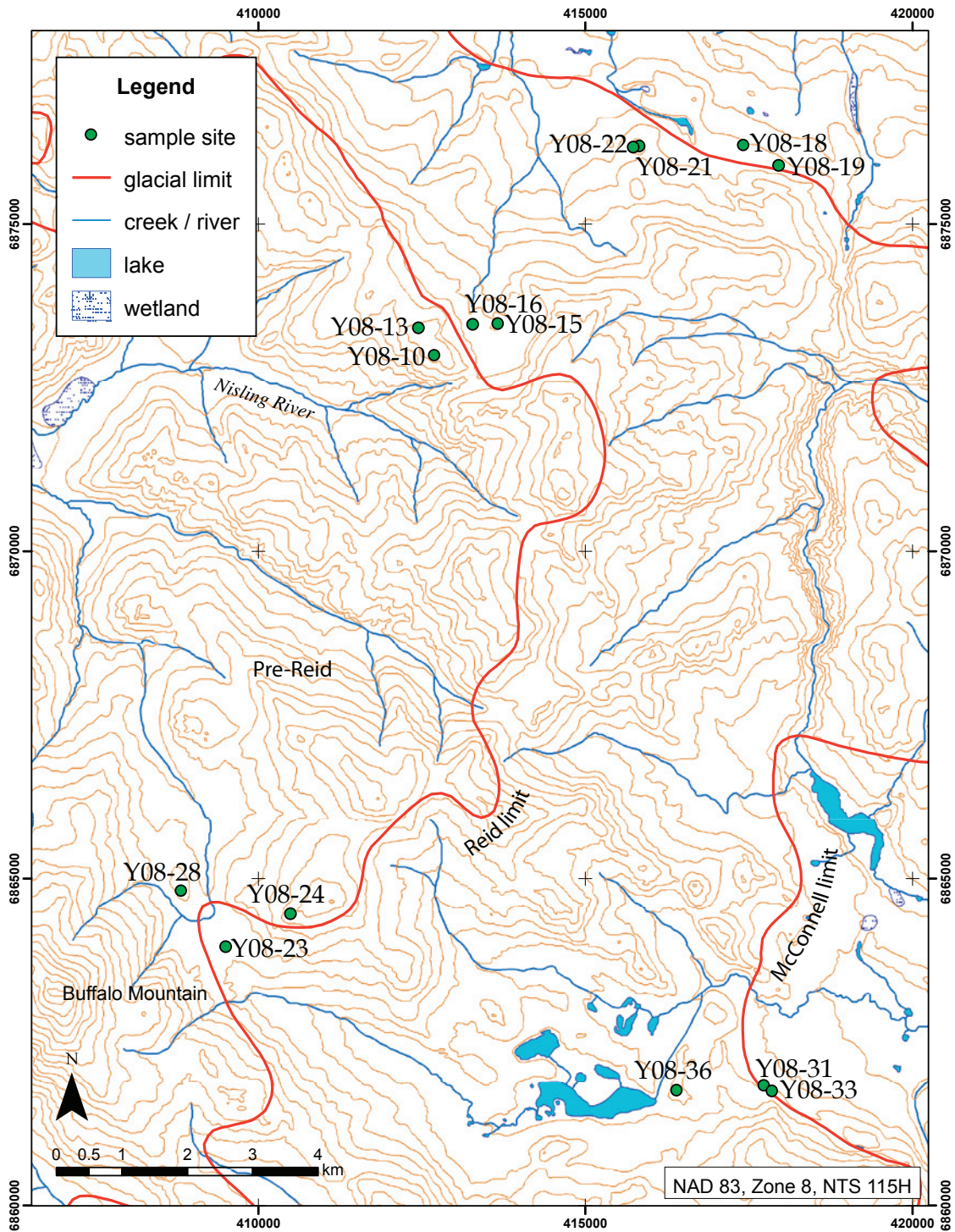


Figure 4. Location of sample sites with respect to glacial limits.

thick, or mixed with the underlying coarse material. This material is likely eolian in origin (loess). Significant downward translocation of silt within the soil profile is indicated by the presence of silt caps on coarse fragments in lower horizons. The silt caps were found in soils of all ages and are up to 2 cm thick (Fig. 5).

The main parent material at Reid and McConnell sites is till. The matrix of Reid till is generally sandier than that of the McConnell till. The main parent material at pre-Reid sites are weathered bedrock, formed primarily by *in situ* disintegration of intrusive bedrock (grus), and colluvium from frost action and slow downslope creep. No glacial deposits were observed at the pre-Reid sites.

GENERAL OBSERVATIONS

Soils on surfaces of all three ages are Brunisols, with the exception of a single Cryosolic soil. Brunisols are soils with insufficient development to be classified as either Luvisols or Podzols (Soil Classification Working Group, 1998). No evidence of mottling was observed in any of the soil pits. Mottles are irregular patches or spots that differ in colour from the dominant horizon colour and result from oxidation-reduction reactions. The presence of mottles would indicate seasonal fluctuations in the water table.

Soil structure is poorly developed throughout the study area, except locally in finer materials. No clay skins were observed at the sites, although, as mentioned previously, silt caps are common. The lower surfaces of some rock fragments in McConnell and Reid soils have dark staining, probably from organic acids. The B-horizons of soils of all ages differ little in colour; nearly all have a Munsell hue of 10YR.

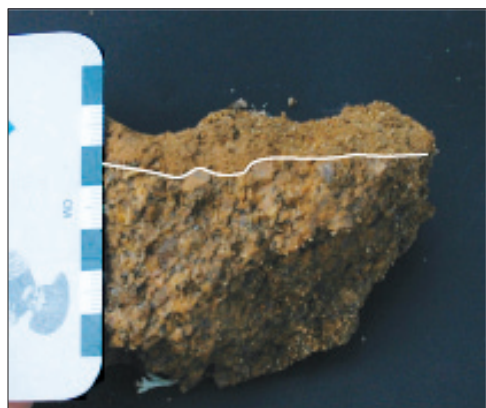


Figure 5. Silt cap on weathered bedrock at pre-Reid site Y08-13.

PRELIMINARY CHRONOSEQUENCE OBSERVATIONS

In a true soil chronosequence, all soil-forming factors except time (parent material, climate, topography, and biota) do not vary significantly. The chronosequence concept is not completely valid in this study because pre-Reid surfaces are not underlain by glacial sediment. Pre-Reid sites thus must be excluded from the chronosequence concept, but the study still provides insight into the character of high-elevation soils developed on weathered bedrock adjacent to previously glaciated areas. Due to differences in till matrix, Reid and McConnell sites do not constitute a true chronosequence, however, they can still be compared for studying time-related differences in soil formation.

McConnell soils

Soils at the four McConnell sites (Y08-18, Y08-19, Y08-31, Y08-33) are developed on thick till with a generally loamy matrix (loam is a mixture of sand, silt and clay). Figure 6 shows a McConnell moraine in a black spruce forest; the arrow indicates the approximate location of the soil pit shown in Figure 7. Table 1 provides descriptions of

Table 1. Soil horizon notation. Description of soil horizon types as observed in field sites (Soil Classification Working Group, 1998).

Organic horizons
F - moderately decomposed organic matter
m - abundant fungi present
i - incorporation of mineral component into organic layer
Mineral horizons
A - uppermost horizon(s) (not always present)
h - enriched in organic matter
e - bleached in appearance
B - middle horizon(s)
m - moderate degree of modification of parent material
BC - transitional horizon between B and C
C - original mineral parent material with only slight modification of chemical and/or physical properties
Additional modifiers applied to A, B or C horizons
b - buried
y - cryoturbated (disrupted by freeze/thaw activity)
j - indicates weak expression of the property that precedes it
II, III, IV - Roman numeral prefix identifies materials differing significantly in geological origin or texture
1, 2, 3 - Numeric suffix identifies horizon subdivision

abbreviations used for soil horizons. Table 2 provides an abbreviated summary of the soil profile description. Soils are classified as Orthic Dystric Brunisols or Eluviated Dystric Brunisols. They have a solum thickness (combined depth of the A and B horizons) of <50 cm and have



Figure 6. McConnell landscape (site Y08-33). Arrow indicates location of soil pit.

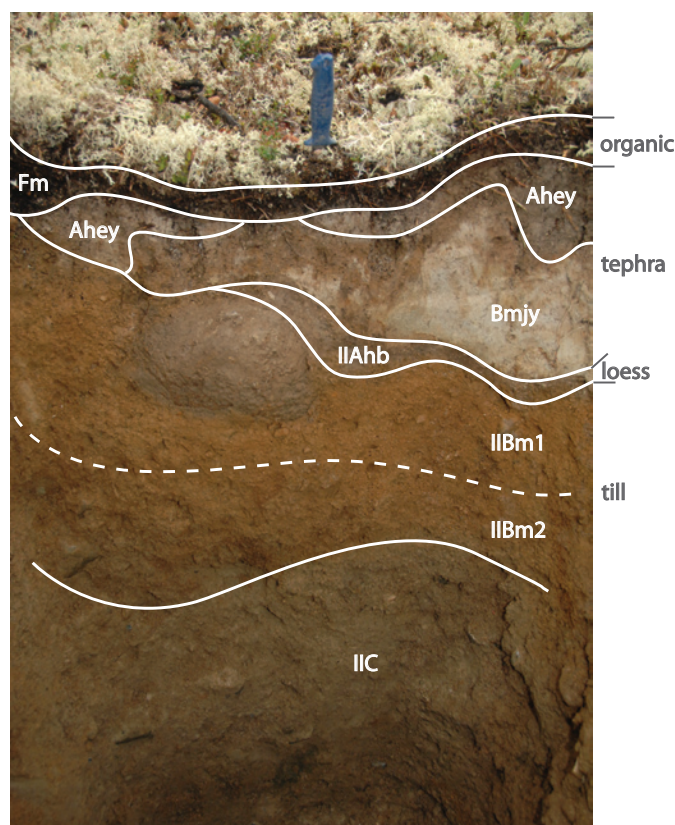


Figure 7. Eluviated Dystric Brunisol formed in McConnell till at site Y08-33. The horizon parent material is labelled to the right of the photograph. Knife handle is 11 cm long.

moderate colouration in the till B horizon ranging from brown (10YR 5/3) to olive brown (2.5Y 4/3). The till parent material ranges from brown (10YR 5/3) to dark greyish brown (2.5Y 4/2).

The upper solum has a pH (CaCl₂) of <5.5¹; pH is slightly higher in the lower solum and parent material (>5.5) in three of the four sites. Secondary carbonate was observed on the underside of clasts at site Y08-19 and

¹Soil pH measurements used soil:water ratios of 1:1 for mineral and 1:2 for organic horizons and a soil:0.01 M CaCl₂ ratio of 1:2 for both mineral and organic horizons (Carter and Gregorich, 2008). The Canadian System of Soil Classification (1998) uses pH values determined in CaCl₂ for soil classification purposes because the ionic strength of this solution more closely resembles that found in natural soil solutions. The pH measurements in CaCl₂ normally provide slightly lower values by ~0.5-1.0 units than those determined in water.

Table 2. Abbreviated description of soil at McConnell site Y08-33 (Fig. 7).

Horizon	Depth (cm)	Abbreviated description	Coarse fragments (%) *
Fm	+4-0	organic horizon 2-5 cm thick; colour 10YR 2/1; pH (H ₂ O) 4.87 and pH (CaCl ₂) 4.15	n/a
Ahey	0-3	tephra; 0-14 cm thick; colour 10YR 7/1 and 10YR 5/3; pH (H ₂ O) 4.87 and pH (CaCl ₂) 3.92	0/0/0
Bmjy	3-19	tephra; 4-23 cm thick; colour 10YR 7/2 and 10YR 5/3; pH (H ₂ O) 5.21 and pH (CaCl ₂) 4.18	0/0/0
IIAhb	19-22	till with loess incorporated; 0-3 cm thick; colour 10YR 3/3; pH (H ₂ O) 5.29 and pH (CaCl ₂) 4.30	5/0/0
IIBm1	22-34	till; combined IIBm1 and IIBm2 horizons have total thickness of 24-37 cm; horizon separation based on minor colour difference (10YR 4/6 and 10YR 3/6); pH (H ₂ O) 5.55/5.79 and pH (CaCl ₂) 4.46/4.67	15/15/10
IIBm2	34-48		
IIC	48- ≥107	till; colour 2.5Y 5/3; pH (H ₂ O) 6.49 and pH (CaCl ₂) 5.40; silt caps present with vesicular structure developing in some; volcanic boulders present; sandy silty matrix	20/30/10

*Coarse fragments (% by volume, estimated visually) refers to pebble (2-64 mm)/cobble (64-256 mm)/boulder (>256 mm).



Figure 8. Reid landscape (site Y08-15). Top arrow indicates Reid meltwater channel and lower arrow indicates location of soil pit.

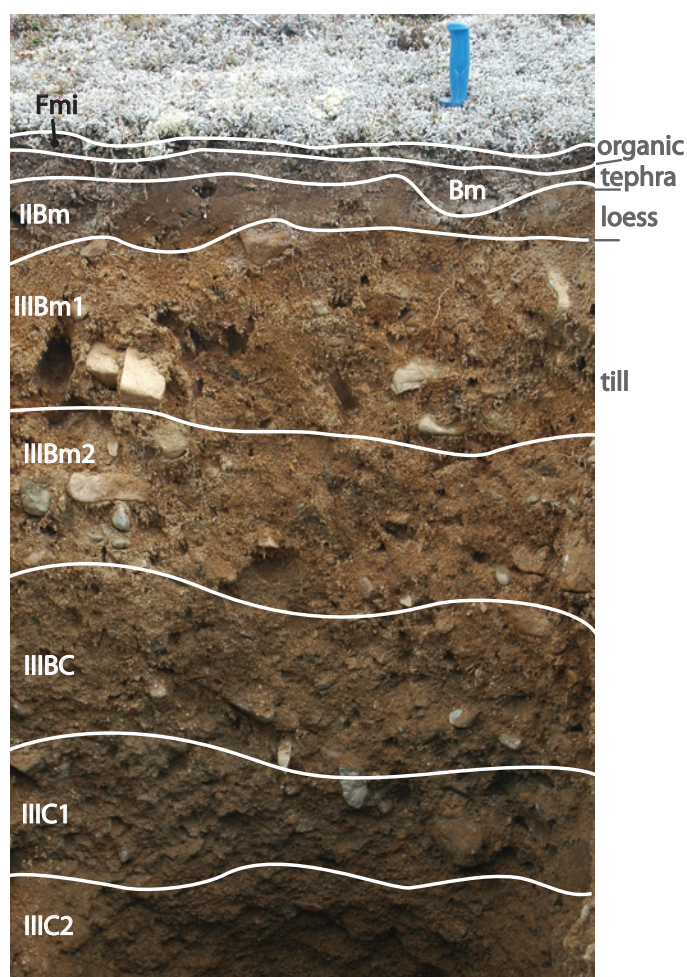


Figure 9. Orthic Dystric Brunisol formed in Reid till at site Y08-15. The horizon parent material is labelled to the right of the photograph. Knife handle is 11 cm long.

within the matrix at site Y08-31. Cryoturbation features were noted in the tephra layer at only one McConnell site (Y08-33; Fig. 7). However, we purposely avoided areas where permafrost is present, thus this finding is not surprising. *In situ* disintegration of granitic rock fragments was noted at one site and is likely a result of both chemical and physical weathering.

Reid soils

Soils at six Reid sites (Y08-15, Y08-16, Y08-21, Y08-22, Y08-23, Y08-36) are developed on thick till or thin till over bedrock. Areas of thick Reid till are restricted to moraines (Fig. 8). Reid till in this area generally has a sandy matrix, although amounts of silt and clay in the parent material are variable.

Table 3. Abbreviated description of soil at Reid site Y08-15 (Fig. 9).

Horizon	Depth (cm)	Abbreviated description	Coarse fragments (%) *
Fmi	+2-0	organic horizon 2-4 cm thick; colour 10YR 2/2; pH (H ₂ O) 4.58 and pH (CaCl ₂) 3.63	n/a
Bm	0-4	tephra-dominated; 3-6 cm thick; colour 10YR 4/3 and 10YR 7/2; pH (H ₂ O) 4.59 and pH (CaCl ₂) 3.60	0/0/0
IIIBm	4-10	loess-dominated; 4-11 cm thick; colour 10YR 3/4; pH (H ₂ O) 5.36 and pH (CaCl ₂) 4.40	3/0/0
IIIIBm1	10-36	till; 17-27 cm thick; colour 7.5YR 4/6; pH (H ₂ O) 5.66 and pH (CaCl ₂) 4.56	50/10/0
IIIIBm2	36-60	till; 16-25 cm thick; colour 10YR 4/6; pH (H ₂ O) 5.84 and pH (CaCl ₂) 4.52	60/15/0
IIIIBC	60-90	till; 20-37 cm thick; colour 10YR 5/4; pH (H ₂ O) 5.75 and pH (CaCl ₂) 4.55; occasional silt caps	60/20/0
IIIIC1	90-119	till; 18-31 cm thick; colour 10YR 4/4; pH (H ₂ O) 6.03 and pH (CaCl ₂) 4.85; occasional silt caps	55/15/0
IIIIC2	119- ≥160	till; colour 10YR 4/3; pH (H ₂ O) 6.25 and pH (CaCl ₂) 5.02; sandy matrix.	50/0/0

*Coarse fragments (% by volume, estimated visually) refers to pebble (2-64 mm)/cobble (64-256 mm)/boulder (>256 mm).

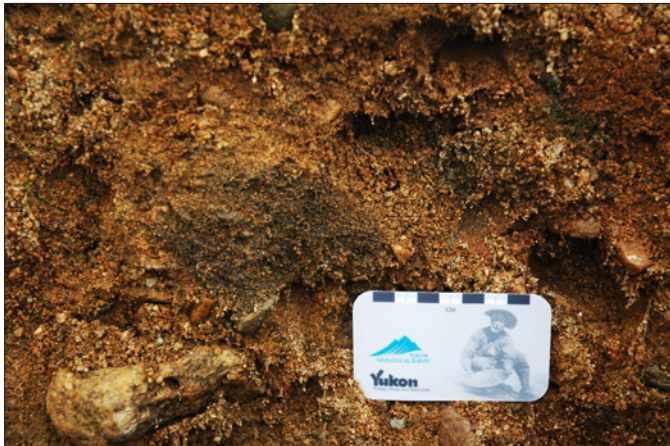


Figure 10. Weathered granitic clast at Reid site Y08-15.

Soils are classified as either Orthic Dystric Brunisols or Eluviated Dystric Brunisols (Fig. 9; Table 3). All soils are acidic, with pH (CaCl₂) in the solum <5.5. The colour of the till component of the B horizon ranges from brown and strong brown (7.5YR 4/6 and 7.5YR 4/4) to olive brown (2.5Y 4/4), but is dominantly dark yellowish brown (10YR). The unweathered till ranges in colour from brown (10YR 5/3) to olive brown (2.5Y 4/4). *In situ* disintegration of granitic coarse fragments is common (Fig. 10). Cryoturbation at the six Reid sites is limited to the near-surface tephra.

Solum depths for Reid soils range from 50 to 75 cm, except at site Y08-36, where the solum thickness is only 36 cm. This site has been mapped as hummocky Reid moraine (Hughes, 1990), but it is located less than 1 km from the McConnell glacial limit. The solum thickness indicates that this profile is less developed than soils at

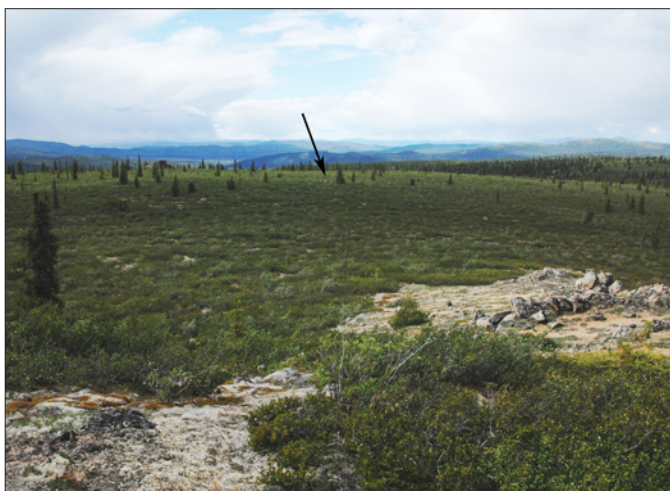


Figure 11. Pre-Reid landscape (Y08-13). Arrow indicates location of soil pit.

the other Reid sites and is similar to the solum thickness of McConnell soils. It is possible that the limit of the McConnell glaciation is farther west than the present mapped limit, or that the hummocky moraine at the study site was deposited during a glacial advance separate from the McConnell and classic Reid advances. Field data are insufficient to establish whether either scenario is plausible, and laboratory analysis is required to elucidate the history of this site.

Pre-Reid soils

Soils at four pre-Reid sites (Y08-10, Y08-13, Y08-24, Y08-28) are developed on bedrock. They are dominated by angular coarse fragments, and the matrix is sandy except where finer sediment has accumulated in silt caps. The soils are Brunisolic Dystric Cryosols, Eluviated Dystric Brunisols and Orthic Dystric Brunisols. Figure 11 shows the landscape and vegetation associated with the Eluviated Dystric Brunisol shown in Figure 12, and an

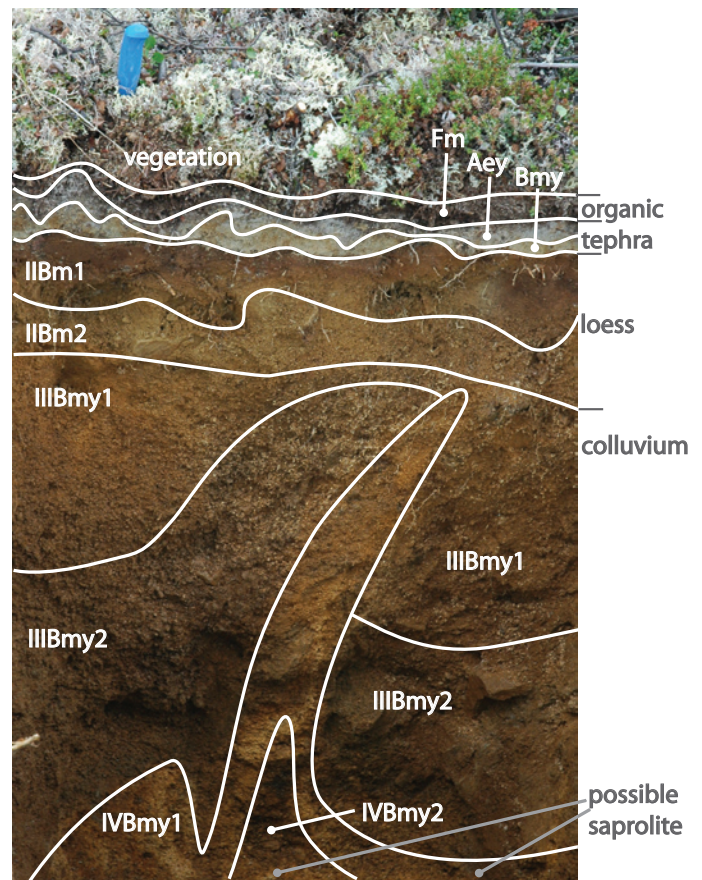


Figure 12. Eluviated Dystric Brunisol formed in weathered bedrock at pre-Reid site Y08-13. The horizon parent material is labelled to the right of the photograph. Knife handle is 11 cm long.

abbreviated profile description is given in Table 4. Unlike Reid and McConnell soils, all pre-Reid soils are strongly cryoturbated throughout the entire solum thickness. Cryosols are characterized as having permafrost within 1 m of the surface, or within 2 m of the surface if the solum is strongly cryoturbated (Soil Classification Working Group, 1998). Evidence for permafrost within 2 m of the surface was confirmed at only one site (Y08-10). We were unable to excavate pits at the pre-Reid sites to more than 1.1 m depth, thus some soils designated as Brunisolic soils may actually be Cryosols. The pre-Reid sites have the thickest sola and extend deeper than the bottoms of the excavated pits (85-110 cm). B horizon colours range from

reddish yellow (5YR 6/8) to olive brown (2.5Y 4/4), but are dominantly yellowish brown (10YR), with only single examples of each of the extreme hues. All soils are acidic with pH (CaCl₂) in the solum <5.5.

DISCUSSION

McConnell and Reid soils are Brunisols formed on till, and pre-Reid soils are Brunisols and Cryosols developed on weathered bedrock. As expected, solum depth increased with surface age. However, other criteria identified in past studies as useful for differentiating soils developed on glacial deposits of different age, such as presence or absence of clay skins, colour of the B horizon, and presence or absence of weathered clasts, were found to not be reliable field indicators of soil age in this study. The reason may be that the sites are sufficiently geomorphically active that episodic or continuous removal of soil materials occurs before these morphological features can develop.

The interaction of confounding site factors, such as soil texture and elevation, may also lead to less dramatic morphological development than would be expected between sites based on age differences alone. The decreasing rate of weathering associated with more severe climates at higher elevation may be sufficient to reduce the morphological expression of soil development. The maximum relief between sites is approximately 350 m. The production of clay may be limited at these high elevation sites. Additional analysis of clay mineralogy will determine whether clays are present within the profiles.

Disintegrated coarse fragments of granite were observed in soils developed on till. Although overall they appear to be more common at Reid sites, their presence or absence cannot be used to confidently differentiate between McConnell and Reid-age surfaces because they were present in both.

Only pre-Reid soils are strongly cryoturbated throughout the full solum depth. This cryoturbation is likely due, in part, to a longer soil history with greater exposure to freeze-thaw activity than McConnell and Reid sites. However, because sites were preferentially selected to avoid permafrost, the lack of cryoturbation in the sola of these younger soils does not indicate its absence in other parts of the landscape. Small changes in aspect, thickness of organic matter layer, and other soil features lead to an irregular distribution of permafrost. Although no periglacial features were observed in till horizons,

Table 4. Abbreviated description of soil at pre-Reid site Y08-13 (Fig. 12).

Horizon	Depth (cm)	Abbreviated description	Coarse fragments (%) [*]
Fm	+6-0	organic horizon; 4-10 cm thick; colour 10YR 2/2; pH (H ₂ O) 4.64 and pH (CaCl ₂) 3.77	n/a
Aey	0-3	tephra; 2-4 cm thick; colour 10YR 6/3; pH (H ₂ O) 4.58 and pH (CaCl ₂) 3.64	0/0/0
Bmy	3-8	tephra; 2-6 cm thick; colour 10YR 6/3 and 10YR 5/6; pH (H ₂ O) 4.99 and pH (CaCl ₂) 4.14	0/0/0
IIBm1	8-13	loess; 5-9 cm thick; colour 10YR 4/4; pH (H ₂ O) 5.47 and pH (CaCl ₂) 4.37	5/0/0
IIBm2	13-20	loess; 6-10 cm thick; colour 10YR 3/6; pH (H ₂ O) 5.74 and pH (CaCl ₂) 4.79	5/0/0
IIIBmy1	20-66	colluvium; discontinuous; colour 10YR 4/6; pH (H ₂ O) 5.90 and pH (CaCl ₂) 4.74	65/15/0
IIIBmy2	20-90	colluvium; discontinuous; colour 10YR 4/6; pH (H ₂ O) 5.90 and pH (CaCl ₂) 4.73	65/25/0
IVBmy1	23- ≥110	possible saprolite; discontinuous; colour 10YR 5/8 and 7.5YR 5/8; pH (H ₂ O) 5.90 and pH (CaCl ₂) 4.65	75/5/0
IVBmy2	83- ≥110	possible saprolite; discontinuous; colour 10YR 6/8 and 7.5YR 6/8; pH (H ₂ O) 6.13 and pH (CaCl ₂) 5.08	75/5/0

^{*}Coarse fragments (% by volume, estimated visually) refers to pebble (2-64 mm)/cobble (64-256 mm)/boulder (>256 mm).

cryoturbation was noted in horizons containing tephra at some Reid and McConnell sites. Different material types will be affected by freeze-thaw processes in different ways. For example, the silty texture of the tephra has a greater water-holding capacity than the coarser textured till and will thus be more susceptible to cryoturbation.

McConnell till appears to be less acidic than Reid till. Because of the small number of our sites, it is unclear if this difference is a result of the duration and/or intensity of weathering, or lithological differences.

FURTHER WORK

This study is the field component of an MSc research project. The laboratory component of the project will be completed in 2009. Chemical and mineralogical characteristics of the soils will be quantified to elucidate differences in pedological pathways that are not obvious from field evidence. These additional characteristics include particle size distribution, clay mineralogy, and soil micromorphology. The micromorphology of the soils will be determined from intact soil samples collected in the field. Samples will be analyzed for extractable iron and aluminum to characterize weathering products, and major and trace element concentrations will be measured to calculate weathering indices.

CONCLUSION

Field work suggests that solum depth is the best criterion for differentiating upland soils developed on McConnell (<50 cm) and Reid (50-75 cm) surfaces in the study area. Other criteria identified in past studies as useful for differentiating soils developed on glacial deposits of different age, such as B horizon colour, clay skins, weathered clasts and periglacial features, were not reliable indices in this study. Preliminary results suggest that observable field characteristics may be insufficient to characterize Reid and McConnell upland surfaces with certainty. Laboratory analyses may be required to identify chemical or mineralogical signatures that distinguish soils of different ages at glaciated upland sites in central Yukon. While the excellent preservation of McConnell and Reid landforms makes this area suitable for comparing upland soils developed on middle and late Pleistocene glacial deposits, we found it difficult to find parent materials of similar texture, and the differences in texture that we document may affect soil development.

Pre-Reid soils were developed on weathered bedrock; although composed of different parent materials, the pre-Reid and younger soils have similar colouration. Estimates of solum thickness at pre-Reid sites were limited by the excavated depth of the pits (<100 cm). Unlike at McConnell and Reid sites, periglacial features are common throughout the solum thickness. Because our sampling protocol preferentially selected unfrozen sites, the lack of periglacial features in younger soils is likely not representative of the entire landscape. Although the oldest pre-Reid glaciation is well dated to 2.6 Ma, the age of the pre-Reid surfaces in our study area is unknown.

ACKNOWLEDGEMENTS

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Preliminary results of detrital zircon geochronology, Wernecke Supergroup, Yukon

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ABSTRACT

The Paleoproterozoic Wernecke Supergroup is a >13 km-thick metasedimentary succession exposed in the Wernecke, Ogilvie and Richardson mountains of central and northern Yukon. A program of field and laboratory investigations was initiated in 2007 in order to constrain the provenance, age and environment of deposition of the Wernecke Supergroup, as well as to better constrain the age of subsequent Proterozoic deformation (Racklan orogeny). Clastic and carbonate samples were collected from the Wernecke Supergroup for analysis of detrital and metamorphic minerals, as well as whole rocks, using a range of isotopic methods. Preliminary results from U-Pb analysis of detrital zircons from quartz sandstone beds, using ion probe mass spectrometry, are provided in this report. Patterns of the detrital zircon ages are broadly comparable to other Paleo- to Mesoproterozoic basins in Canada, suggesting a common Laurentian source. The maximum age of the Supergroup of 1.61 ± 0.03 Ga is provided by the age of the youngest detrital grain, which is ~ 0.1 Ga younger than expected.

RÉSUMÉ

Le Supergroupe de Wernecke du Protérozoïque précoce est une succession métasédimentaire de plus de 13 km d'épaisseur exposée dans les monts Wernecke, Ogilvie et Richardson du centre et du nord du Yukon. Un programme d'étude sur le terrain et en laboratoire a été lancé en 2007 afin de déterminer l'origine, l'âge et le milieu de dépôt du Supergroupe de Wernecke et de préciser l'âge de la déformation protérozoïque subséquente (orogénèse de Racklan). Des échantillons de roches détritiques et carbonatées ont été prélevés dans le Supergroupe de Wernecke aux fins d'analyse des minéraux détritiques et métamorphiques, ainsi que d'analyse de la roche entière, à l'aide d'une gamme de méthodes isotopiques. Les résultats préliminaires de l'analyse U-Pb des zircons détritiques de lits de grès quartzeux, à l'aide de la spectrométrie de masse et d'une sonde ionique, sont présentés dans ce rapport. La distribution des âges des zircons détritiques est dans l'ensemble comparable à celle dans d'autres bassins du Protérozoïque précoce à moyen au Canada, ce qui suggère une origine laurentienne commune. L'âge maximum du Supergroupe de $1,61 \pm 0,03$ Ga est obtenu d'après l'âge du grain détritique le plus jeune, qui est $\sim 0,1$ Ga plus jeune que prévu.

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INTRODUCTION

The Wernecke Supergroup is a Paleoproterozoic metasedimentary succession exposed in the Wernecke, Ogilvie and Richardson mountains, Yukon (Fig. 1). A detailed stratigraphic description of the Wernecke Supergroup and its subdivision into three groups (Fairchild Lake Group, Quartet Group and Gillespie Lake Group) were provided by Delaney (1981, 1985).

The Wernecke Supergroup was weakly deformed and variably metamorphosed during the Racklan orogeny (Thorkelson, 2000; Brideau *et al.*, 2002; Laughton *et al.*, 2005) and then locally invaded by hydrothermal fluids to form numerous breccia zones (Bell and Delaney, 1977; Thorkelson *et al.*, 2001). Despite these events, the Wernecke Supergroup has retained much of its original sedimentary character and composition. The provenance, age of deposition and basinal architecture of the succession, however, remain largely unknown.

To add to the understanding of the geologic evolution of the Wernecke Supergroup, we have undertaken a program of petrological and mineralogical investigations. This paper provides a summary of the fieldwork and the preliminary results of U-Pb analysis of detrital zircons from quartz sandstones. The findings are used to constrain the age of sedimentation and initiate a discussion on the possible sources of the sediments. Forthcoming geochemical and isotopic data will be coupled with the detrital zircon ages to further constrain the location of source terranes, aid in comparison with other Proterozoic basins in North America and abroad, and facilitate critical re-examination of paleocontinental reconstructions.

The study area is located 110 km northeast of the village of Mayo and extends throughout much of NTS map areas 106C/13, 106D/16, and 106E/1 (Fig. 1). The area is remote and mountainous, and access was obtained by helicopter and fixed-wing aircraft.

THE WERNECKE SUPERGROUP

The Wernecke Supergroup is exposed in the Wernecke and Ogilvie mountains, Yukon, and belongs to Sequence A as established by Young *et al.* (1979). It comprises 13 to 14 km of weakly to moderately metamorphosed (upper to lower greenschist grade) siliciclastic and carbonate rocks (Fig. 2). The succession consists of three conformable groups: the Fairchild Lake Group (oldest), the Quartet Group (middle) and Gillespie

Lake Group (Delaney, 1981; 1985). Each group consists of stratigraphic units which may be regarded as informally defined formations.

The Fairchild Lake Group is at least 4 km thick and is composed mainly of siltstone, sandstone and minor carbonate. In most locations, the rocks still preserve their original sedimentary textures and mineralogy. Locally, the finer grained rocks have been metamorphosed into slate, phyllite and schist. The Fairchild Lake Group has been subdivided into five formations that, in ascending order, are F-1, F-2, F-3, F-4, F-TR (Delaney, 1981; Fig. 2). Formation F-TR includes beds of carbonate and slate, including a white-weathering dolostone marker bed.

The Quartet Group is a 4 km-thick succession consisting of pyritic black shale and slate (formation Q-1) and an overlying succession of siltstone and minor fine-grained sandstone (Q-2; Delaney, 1981; Fig. 2).

The Gillespie Lake Group is the uppermost group and consists of an approximately 4 km-thick succession of dolomitized carbonate and subordinate clastic rocks. Stromatolites, algal mats and oolites are locally abundant and suggest a platformal environment. The Gillespie Lake Group was subdivided into seven formations: G-TR, G-2, G-3, G-4, G-5, G-6, and G-7 (Delaney, 1981; Fig. 2). Formation G-TR, which gradationally overlies the Quartet Group, has a striking orange- and grey-banded appearance on mountainsides and consists largely of trough cross-bedded sandstone and orange-weathering dolostone.

Thorkelson (2000) mapped the Wernecke Supergroup in the study area, but used only two divisions within the Fairchild Lake Group, with the upper part corresponding mainly to formation F-TR of Delaney (1981). Thorkelson (*ibid*) mapped the Quartet Group as one unit and the Gillespie Lake Group as two units, with the basal Gillespie Lake Group corresponding mainly to Delaney's formation G-TR.

FIELDWORK 2007

In July, 2007, three weeks of fieldwork were undertaken by F. Furlanetto to collect a representative suite of samples from throughout the Wernecke Supergroup for petrologic, mineralogical, geochemical and isotopic analysis. Fifty-seven samples were taken from clastic and carbonate rocks and were combined with other samples collected during previous and subsequent field work by D. Thorkelson. The stratigraphic position of each sample

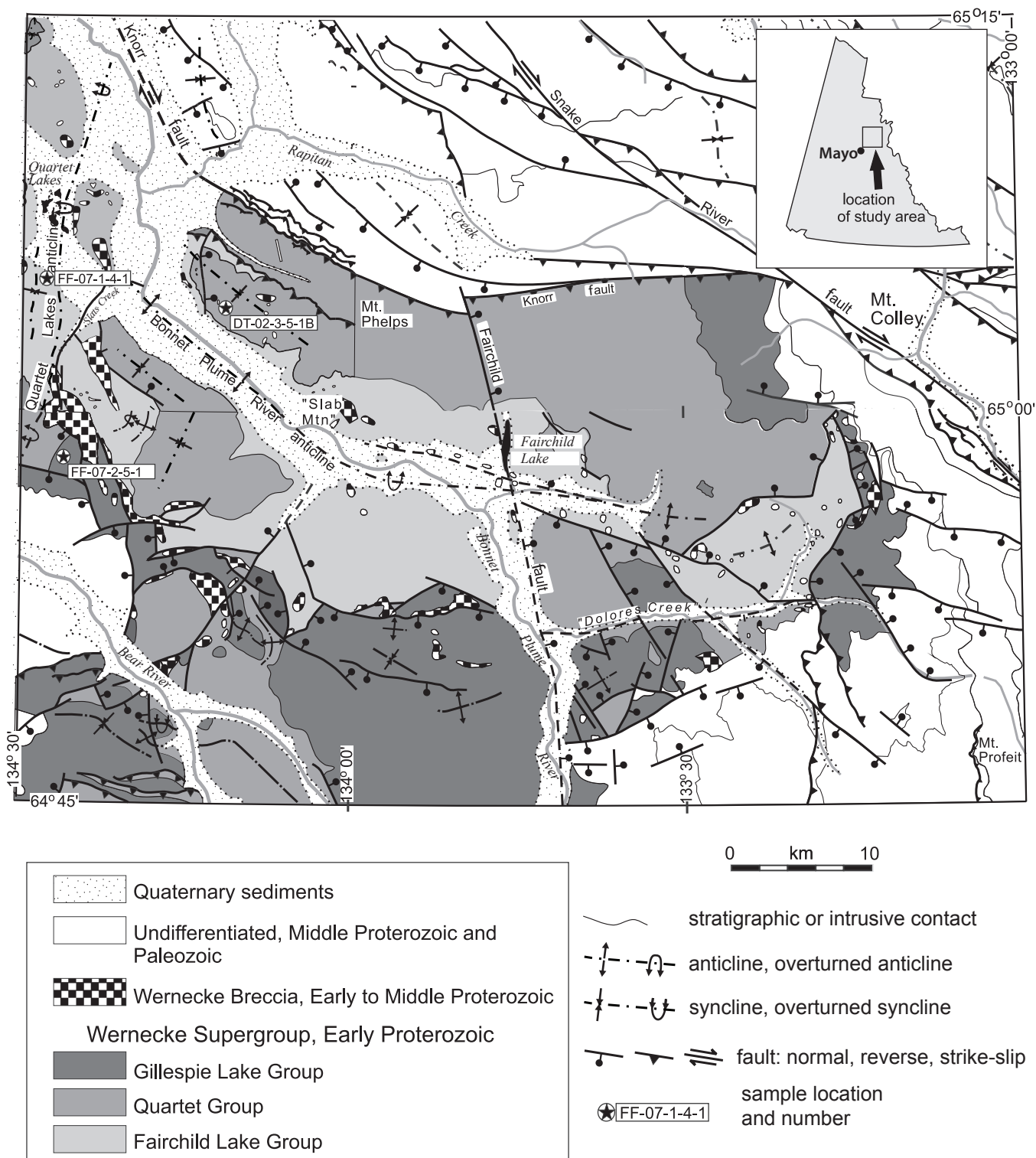
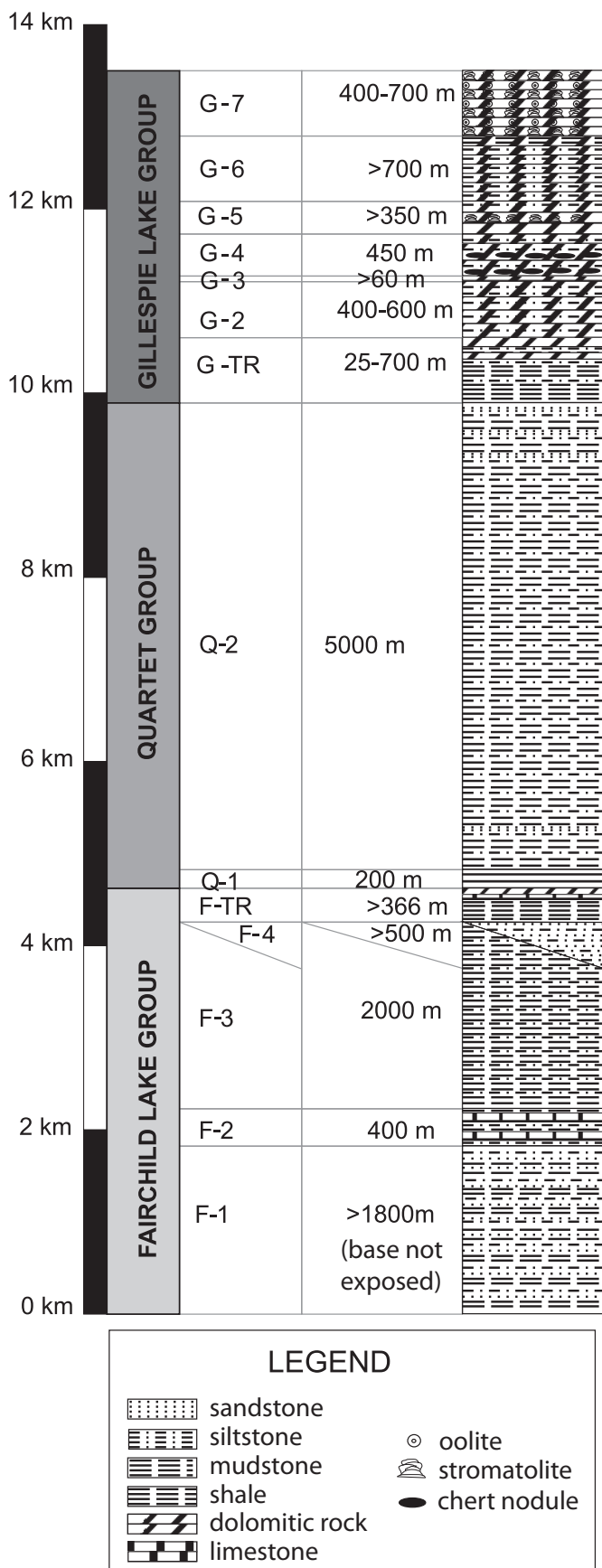


Figure 1. Simplified geological map of the study area, modified from Thorkelson et al. (2005) showing location of analysed detrital zircon samples. Samples FF-07-4-1-1 and DT-06-3-5-1B are located outside the study area, in NTS 106D/9 and 106L/6 map areas, respectively.



(using error bars to indicate uncertainty) is shown in Figure 3.

In Figure 3, the samples are organized by the four main rock types collected: quartz sandstone, carbonate, shale/phyllite and garnetiferous schist. The sandstone was collected for U-Pb analysis of detrital zircons; the carbonate for C, O and Sr isotopes; the shale/phyllite for Nd isotopes; and the garnetiferous schist for Lu-Hf dating of garnet. The goal of these analytical methods is to establish the provenance and maximum age of the sediments, and in the case of Lu-Hf dating, the age of deformation, which is considered to be Racklan orogeny (Brideau *et al.*, 2002; Laughton *et al.*, 2005; Thorkelson *et al.*, 2005). Results from U-Pb dating of detrital zircons are the first analytical results from this study and are summarized in a subsequent section of this paper. A preliminary study of Nd isotopic composition of whole rock samples was published in Thorkelson *et al.* (2005) and is the only previous isotopic work on the provenance of the Wernecke Supergroup.

Samples collected from the Fairchild Lake Group include fine-grained sandstone, shale and slate, chloritoid ± garnet-bearing schist and phyllite, and carbonate. The fine-grained sandstone is present as massive beds within siltstone and mudstone in the lower to middle Fairchild Lake Group. These are mostly grey to light grey and locally greenish grey-weathered coarse siltstone to very fine sandstone (grey on fresh surfaces), with cross and parallel laminations. The shale and slate are dark grey on the weathered and fresh surfaces. The chlorite-muscovite-chloritoid/garnet-bearing schists and phyllites are light grey-green, light blue, locally rusty, weathered, kink-folded and finely crenulated. Other garnet-bearing rocks sampled for garnet dating are light green to light grey and light brown-weathered siltstones (grey on fresh surfaces), with garnets up to 4 mm in diameter within chlorite-rich domains. The carbonate samples have been collected in two levels in the lower and middle Fairchild Lake Group and are brownish grey, rusty-weathered with even parallel laminations (light grey to white on fresh surfaces). The sample collected from the 'white marker' in formation F-TR is a light grey to white-weathered dolomitic siltstone and is grey on the fresh surfaces.

Figure 2. Simplified stratigraphic column of the Wernecke Supergroup with main lithologies and thicknesses, modified from Delaney (1981).

Gillespie Lake Group. These are massive brown to orange, yellow and grey-weathered dolomitic siltstone to very fine grained sandstone (grey on fresh surfaces), and are locally laminated. The carbonate and shale samples collected are fairly homogeneously distributed throughout the entire Gillespie Lake Group. The carbonate samples weather light brown, orange-grey and orange-yellow, and are grey on fresh surfaces. They include algal mats and locally contain diagenetic chert beds and nodules. Stromatolites and oolites are found in the middle to upper part of the succession. Some rocks show parallel laminations and others display storm textures and contain intraclasts.

Four samples, which include two carbonates and two shales of the Gillespie Lake Group, were collected from exposures south of Bear River and do not belong to any of the formations identified by Delaney (1981). These units were described by Thorkelson (2000) as mudstone, shale and dolomitic siltstone and interpreted as facies equivalents of the lower part of the Gillespie Lake Group described by Delaney (1981). The samples are shown in Figure 3 as possible equivalents of Delaney's (1981) formation G-2.

One carbonate and one shale sample were collected from strata which apparently sit above G-7, the highest formation of the Gillespie Lake Group defined by Delaney (1981) (Fig. 3). The lower of the two samples comes from a 250 m-thick succession of shale and the upper sample comes from an overlying succession of orange-weathering dolostone (see Fig. 11 of Thorkelson, 2000).

SANDSTONE PETROGRAPHY

Petrographic analysis of the Wernecke Supergroup samples was carried out using transmitted and reflected-light microscopy, as well as a scanning electron microscope (SEM). Most samples are classified as quartz arenite with modest amounts of other minerals including accessory zircon as described below. White mica is present in some samples and appears to reflect metamorphism of detrital clay and feldspar. The quartz grains typically display undulose extinction, sub-grain rotations and local grain-boundary migrations (Fig. 4), consistent with deformation and metamorphism (possibly associated with the Racklan orogeny). SEM observations indicate the presence of xenotime overgrowths (up to 6 microns thick, Fig. 5) on the surface of many zircon grains.

FAIRCHILD LAKE GROUP

In the Fairchild Lake Group quartz sandstone, quartz is the predominant mineral. Minor constituents are fine lamellae of white mica, mainly in the form of chlorite and sericite. Accessory minerals are iron oxides, rutile, and zircon, the latter being 20 microns in average length. Garnet (partially chloritized) is present in sample DT-06-3-5-1B, but it is unclear whether these grains are detrital or metamorphic in origin.

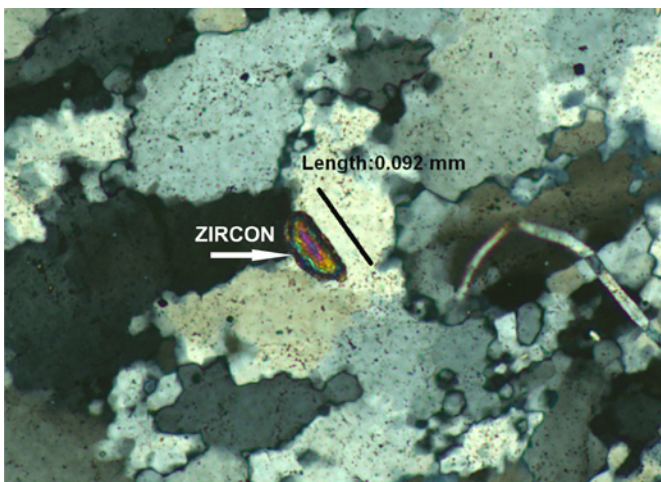


Figure 4. Photomicrograph of DT-02-3-5-1B quartz sandstone, showing a zircon grain bounded by quartz grains that show evidence for grain-boundary migration. Length of scale bar is 0.092 mm.

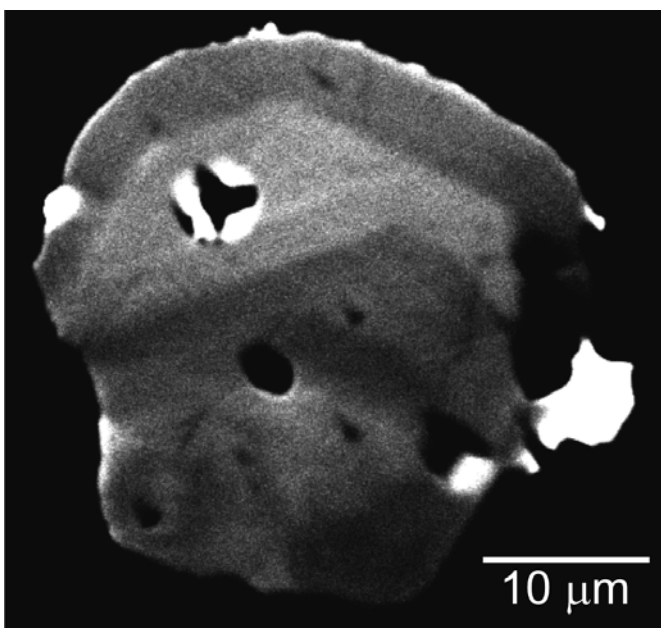


Figure 5. Backscattered scanning electron microscopic image of zoned zircon with xenotime overgrowth from sample FF-07-4-1-1.

QUARTET GROUP

The sandstone samples collected in the lower Quartet Group is mainly composed of quartz and white mica, with iron oxides, zircon, and other high relief accessory minerals. The sample from the upper Quartet Group is composed of quartz and carbonate in equal proportions, rare mica, iron oxides, and zircon as accessory minerals.

GILLESPIE LAKE GROUP

The sandstone samples collected in the lower Gillespie Lake Group are mainly composed of quartz and carbonate in equal proportions, minor white mica, iron oxides, and rare zircon as accessory minerals.

DETRITAL ZIRCON STUDY

U-Pb geochronology of detrital zircon from quartz-rich sandstones of the Wernecke Supergroup was conducted to identify the provenance of sediments that fed the Wernecke Basin during the Paleoproterozoic. The study is also designed to establish the maximum age of the sedimentation, which is poorly constrained at present. The results will, in turn, be used for correlating the Wernecke Supergroup with potentially coeval successions in North America and elsewhere in the world in order to refine paleocontinental reconstructions that involved Laurentia at that time.

In this study, we analysed 5 of 12 samples collected in the field, which were selected according to their stratigraphic position, geographic location and zircon abundance observed in thin section. The geographic locations of three of the five samples analysed are shown in Figure 1, and the stratigraphic positions of all five samples is shown in Figure 3. Two samples belong to the Fairchild Lake Group: FF-07-1-4-1 is from the middle Fairchild Lake Group in the Wernecke Mountains and DT-06-3-5-1B (not plotted on Figure 1) is from the Richardson Mountains. Sample DT-02-3-5-1B belongs to the lower Quartet Group; sample FF-07-4-1-1 (not plotted on Figure 1) is from the upper Quartet Group, close to the transition with the Gillespie Lake Group; and, sample FF-07-2-5-1 belongs to the basal Gillespie Lake Group. No samples from the middle and upper Gillespie Lake Group were collected due to the absence of sandstones in that part of the succession.

After the preliminary petrographic observations described above, the samples were processed using standard techniques of crushing, grinding and heavy mineral

separation using a Wilfley table at Simon Fraser University. Frantz magnetic separation and heavy liquid processing were conducted on sample FF-07-2-5-1. Selection of grains according to size, colour and morphology was avoided in order to maintain the integrity of the sample and prevent biasing of age populations.

The zircon grain shapes range from elongate to nearly spherical and from well rounded to nearly euhedral-prismatic crystals. Some grains, however, have irregular shapes probably because they were damaged during sample processing. The grains range from pink to brown, to brownish green, and rarely, colourless. Grain size is quite small, ranging from 40 to 140 microns, with an average of ~60 microns (Fig. 6).

The grains were mounted in a 2 cm-diameter epoxy puck, which was polished to reveal grain centres and then coated with high purity gold. Prior to the analysis, the zircon grains were examined and photographed with a reflected light microscope and with a scanning electron microscope operating in backscatter mode (BSE).

PRELIMINARY RESULTS

The detrital zircon grains were analysed with the Sensitive High Resolution Ion Microprobe (SHRIMP II) at the J.C. Roddick Ion Microprobe Laboratory of the Geological Survey of Canada in Ottawa. Analytical procedures were based on those described by Stern (1997), and the assessment of errors and reduction of data were based on Stern and Amelin (2003). The zircon standard used for the analysis is z6266 Sri Lanka megacryst (weighted mean $^{206}\text{Pb}/^{238}\text{U}$ age of 559 ± 0.2 Ma). The reduced data were filtered, eliminating those grains characterized by discordances greater than 5%, high common lead, excess

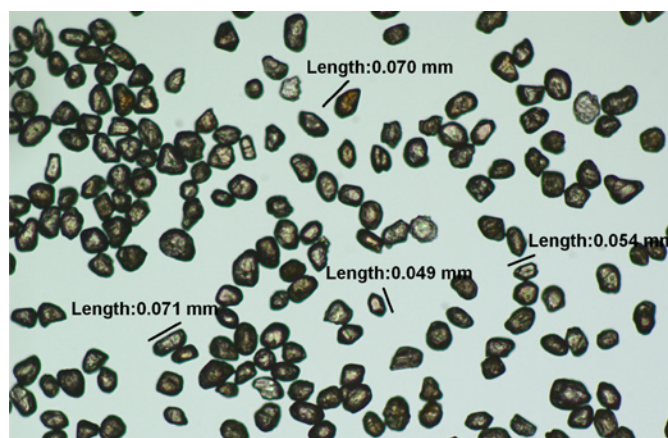


Figure 6. Photomicrograph of separated detrital zircon grains from sample FF-07-2-5-1.

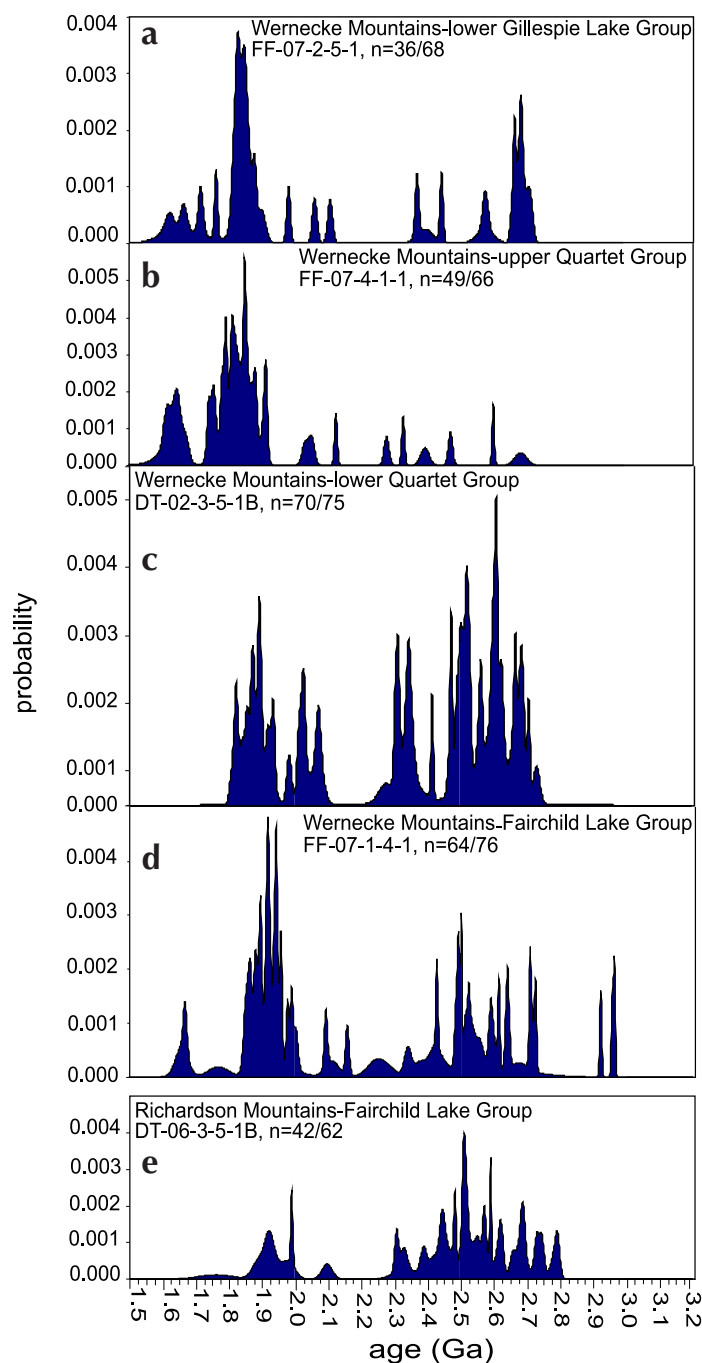


Figure 7. Probability density distribution diagrams of detrital zircon ages from five samples of the Wernecke Supergroup, arranged according to stratigraphic order. Analyses over 5% discordant were not included. The quotient “n” indicates the number of 95-105% concordant grains over the total number of grains analysed. The graphs were produced using AgeDisplay (Sircombe, 2004).

uranium, and large errors on the U-Pb ages. The ages are displayed here in probability density distribution diagrams using AgeDisplay (Sircombe 2004; Fig. 7). Multiple analyses were performed on the youngest zircons in order to reproduce the result, improve the precision and assess possible isotopic disturbance within the grains. The ages of those grains are displayed on U-Pb concordia diagrams using ISOPLOT (Ludwig, 2003; Fig. 8). Tables of isotopic data and histograms of zircon populations will be provided in a future paper.

A total of 352 grains were analysed and several age populations with peaks ranging from late Paleoproterozoic to Archean are evident (Fig. 7a-e). Sample FF-07-1-4-1 (Fig. 7d; Fairchild Lake Group) displays age distributions ranging from 1850 to 2000 Ma, 2500 to 2700 Ma and 2900 to 3000 Ma, which are the oldest detrital zircon grains from the Wernecke Supergroup. Minor peaks are present at ca. 2100, 2200, 2300 and 2400 Ma. The youngest peak is at ca. 1660 Ma. Sample DT-06-3-5-1B (Fig. 7e; Fairchild Lake Group, Richardson Mountains) shows similar age populations with clustering from 1900 to 2000 Ma and 2300 to 2800 Ma, and a minor peak at ca. 2100 Ma. Sample DT-02-3-5-1B (Fig. 7c; lower Quartet Group) has three main populations, with ages ranging from 1800 to 1950 Ma, 2300 to 2400 Ma and 2500 to 2750 Ma. Sample FF-07-4-1-1 (Fig. 7b; upper Quartet Group) has a cluster of nine grains, 95 to 105% concordant, from 1600 to 1700 Ma. This sample contains by far the highest number of younger grains compared to the other samples analysed. Replicate analyses of the three youngest grains are within error of each other at 1610 ± 30 Ma, 1621 ± 27 Ma and 1642 ± 66 Ma (Figs. 8b,c,d), and suggest a post-1650 Ma depositional age of the upper Quartet Group. The most prominent grouping in this sample (FF-07-4-1-1) is from 1750 to 1900 Ma, with minor and variable number of grains from 2000 to 2700 Ma. Sample FF-07-2-5-1 (Fig. 7a; lower Gillespie Lake Group) is similar to FF-07-4-1-1 except for a smaller 1600 to 1700 Ma population. A grouping between 1800 to 1900 Ma is the highest, with a minor population from 2000 to 2700 Ma.

GEOLOGICAL SIGNIFICANCE

This new set of data allows us to make some preliminary comparisons between the Wernecke Supergroup and other post-1700 Ma basins in Laurentia. Two possible correlatives with the Wernecke Supergroup are the Athabasca Group and the Muskwa assemblage, given the similar detrital zircon age distributions and also because

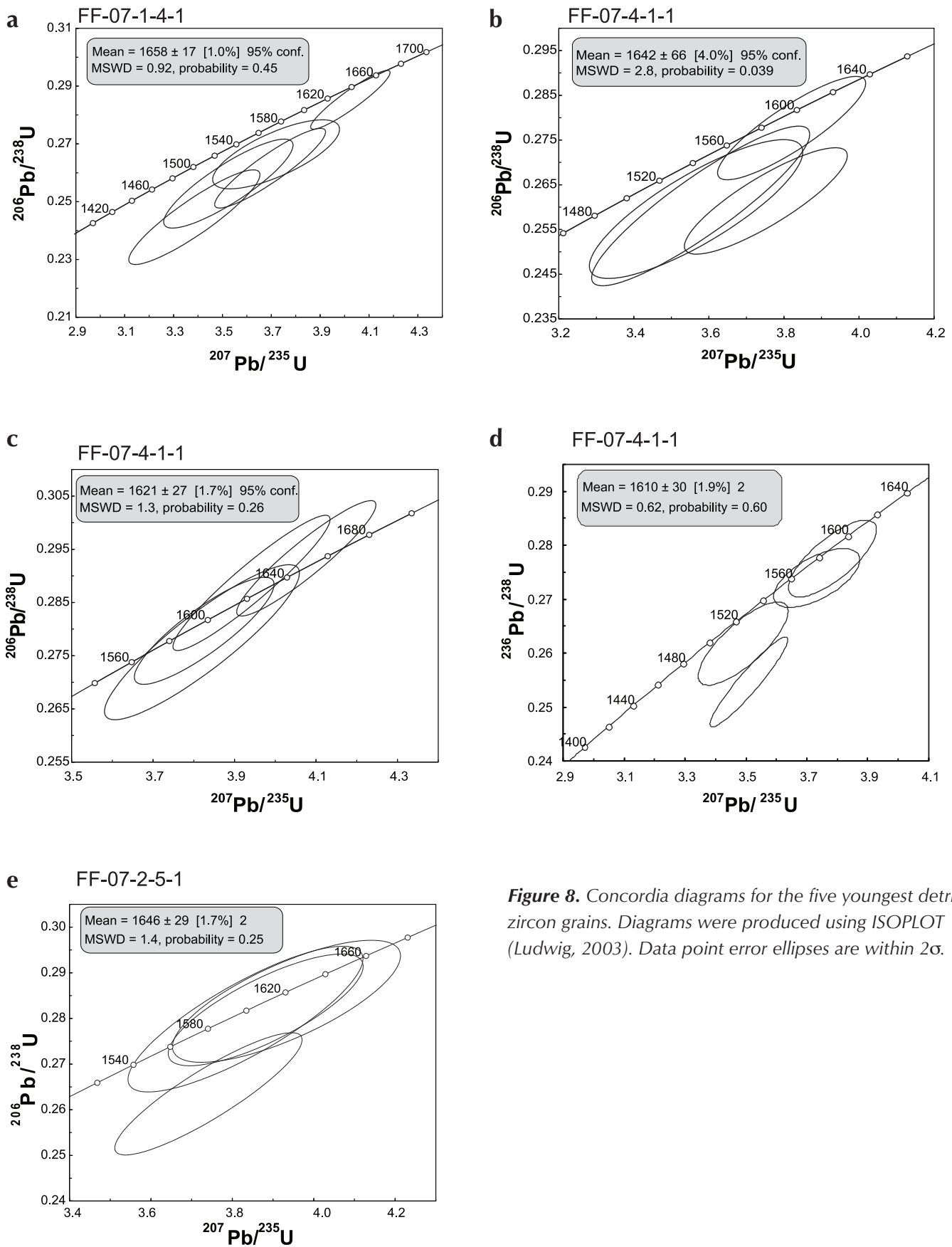


Figure 8. Concordia diagrams for the five youngest detrital zircon grains. Diagrams were produced using ISOPLOT (Ludwig, 2003). Data point error ellipses are within 2σ .

all three successions contain detrital zircon grains with ages between 1660 and 1700 Ma. One notable difference between the Wernecke Supergroup and the Athabasca and Muskwa successions is that only the Wernecke succession contains grains younger than 1660 Ma. In three of the five samples from the Wernecke Supergroup, five grains yielded ages between 1610 ± 30 Ma and 1658 ± 17 Ma. The youngest of these ages suggests that the Wernecke Supergroup may be up to 100 Ma younger than previously thought (>1710 Ma; Thorkelson *et al.*, 2001).

Possible sources for the <1700 Ma grains in the Wernecke Supergroup include the Labradorian orogen of eastern Canada (Nunn *et al.*, 1985), or the Yavapai-Mazatzal orogen of the southern United States (Whitmeyer and Karlstrom, 2007). A more local source could be the Narakay Volcanic Complex in the upper Hornby Bay Group of the Northwest Territories, which has been dated at 1663 ± 8 Ma (Bowring and Ross, 1985). It is also possible that some of the grains were derived from another craton having a history of late Paleoproterozoic igneous activity, such as Australia (Solomon and Groves, 1994).

CONCLUSIONS

Zircon was extracted from samples collected from all three groups of the Wernecke Supergroup, spanning approximately 10 km of stratigraphic thickness. U-Pb isotope analysis by ion probe on 352 grains from 5 samples has produced two main results. First, the patterns of age distributions are similar to those of the Athabasca and Muskwa basins, with notable abundances at 1700 and 1900 Ma, and groupings of ages from 2200 to 2800 Ma, with few grains with ages >3000 Ma (Rainbird *et al.*, 2006). Second, three of the five samples show peaks in the 1600 to 1700 Ma range, with the weighted mean ages of the five youngest grains ranging from 1610 ± 30 to 1658 ± 17 Ma. Zircons with ages this young have not been recorded in samples from the Muskwa and are only found in the upper part of the Athabasca basin (Wolverine Point Formation, Rainbird *et al.*, 2006).

The detrital zircon results suggest that the Wernecke basin developed slightly after the Muskwa and could be synchronous with the upper Athabasca basin, but that all three were filled by detritus from similar sources, probably located on Laurentia (Ancestral North America). The youngest set of zircons from the Wernecke Supergroup (1610 to 1660 Ma) may also have been derived from

Laurentia, from relatively nearby sources such as the Narakay volcanics of the Northwest Territories or more distal sources such as the Yavapai-Mazatzal orogen in the southern United States or the Labradorian orogen of eastern Canada. Alternatively, these grains may have been derived from another continent with a late Paleoproterozoic history of magmatism, such as Australia.

Previously, the age of the Wernecke basin was considered to be >1710 Ma, based on an interpretation that the 1710 Ma Bonnet Plume River intrusions crosscut the Wernecke Supergroup (Thorkelson *et al.*, 2001). Our new data suggest that the Wernecke Supergroup, which must be younger than its youngest detrital zircon grain (1610 ± 30 Ma), is younger than previously thought, and calls into question the interpretation of emplacement of the Bonnet Plume River intrusions into the Wernecke Supergroup.

ACKNOWLEDGEMENTS

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High-grade hydrothermal copper-gold mineralization in foliated granitoids at the Minto mine, central Yukon

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ABSTRACT

Speculation regarding the genetic history of the Minto copper-gold deposit in the Carmacks map area (NTS 1151) has existed since its discovery. Minto copper sulphides are hosted in sheet-like expanses of biotite-rich, variably deformed granitoids surrounded by massive granodiorite. Attempts to explain Minto's unusual mineralization style have ranged from digested red-bed copper, to aborted and deformed porphyry, and recently to an Iron Oxide Copper Gold (IOCG) type system. Although these commonly used genetic frameworks can explain many aspects of Minto-style mineralization, questions regarding chemistry, paragenesis, and structural controls on mineralization still remain. This paper is part of an M.Sc. thesis project that will focus on characterizing mineral textures, mineral chemistry, mineral paragenesis and micro and macro structural analyses to improve our understanding of the Minto copper-gold mineralized system and to enhance regional exploration potential in the district. This paper summarizes some preliminary observations at the Minto deposit and outlines future research.

RÉSUMÉ

L'origine du gisement de cuivre-or de Minto, dans la région cartographique de Carmacks, a été le sujet de spéculations depuis sa découverte. À Minto, les sulphures de cuivre sont contenus dans des couches de granitoïdes riches en biotite et à déformation variable entourés de granodiorite massive. Ce style peu commun de la minéralisation fût au préalable expliqué par de nombreux modèles, incluant: 1) du cuivre sédimentaire digéré par l'intrusif; 2) un système de porphyre interrompu et déformé; ou 3) un système de type cuivre-or-oxide de fer (IOCG). Bien que ces divers modèles expliquent plusieurs des caractéristiques de la minéralisation à Minto, plusieurs questions demeurent à propos des contrôles chimiques, paragénétiques, et structuraux sur la minéralisation. Cet article fait parti d'un projet de maîtrise concentré sur les textures, la chimie, et la paragénèse des phases minérales, et sur l'analyse micro- et macro-structurale du système minéralisé en cuivre-or de Minto. Cette étude a pour bût d'améliorer notre connaissance du gisement de Minto et d'accroître le potentiel pour l'exploration du district. Cet article présente des observations préliminaires sur ce gisement et établi la direction de cette étude.

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INTRODUCTION

The Minto mine (Yukon MINFILE 1151 021; Deklerk, 2008) consists of a series of high-grade Cu-Au deposits with a measured and indicated resource at 0.5% Cu cutoff of ~19.3 Mt averaging 1.42% Cu, 0.51 g/t Au and 5.38 g/t Ag, plus an additional inferred resource of ~15.1 Mt averaging 0.89% Cu, 0.25 g/t Au and 2.6 g/t Ag at the same cutoff (Sherwood Copper Corp., News Release #08-30, August 5, 2008). The deposit is hosted in the Granite Mountain batholith, approximately 240 km north of Whitehorse and 35 km southwest of Pelly Crossing in central Yukon (Figs. 1 and 2). The main Minto deposit was discovered in 1973 and was the subject of intermittent exploration in the 1970s, 1980s and 1990s. Mine development was initiated in the mid- to late 1990s by Minto Explorations Ltd. but was suspended in 1998 due to low metal prices. Sherwood Copper Corporation (now Capstone Mining Corporation) acquired 100% interest in the Minto project in 2005 and quickly resumed mine development. The Minto mine entered commercial production in October 2007.

Studies on the genesis of the Minto deposit were conducted at various stages in its exploration history. Sinclair (1977) interpreted the Minto deposit as a redbed copper deposit that was assimilated by the younger (Early Jurassic) Granite Mountain batholith. Pearson and Clark (1979) suggested that Minto resulted from metamorphism of a pre-existing hydrothermally derived copper-gold deposit hosted in rafts of Paleozoic Pelly Gneiss (now part of the Simpson Range plutonic suite; Colpron, 2006). More recently, Tafti (2005) concluded that the Minto deposit was an aborted or stalled porphyry system, although an Iron Oxide Copper Gold (IOCG) style of mineralization has not been ruled out (Tafti, 2005; Quin and Mercer, 2008).

The goal of this study is to refine our understanding of the genesis and subsequent evolution of economic mineralization at Minto in light of the vast amount of geoscience data collected since 2005 through geological drill core logs, geochemical analyses, geophysical surveys, and ongoing open-pit extraction of the ore body. Specific objectives are:

(i) to determine the possible influence of pre-, syn- and post-mineralization structural controls on ore and grade distribution, including the development of a geometric and kinematic model for the structural development of the deposit;

(ii) to characterize the style and spatio-temporal distribution of alteration and mineralization at the Minto deposit, particularly mineral textures, mineral chemistry, mineral paragenesis and their relationships to structures; and

(iii) to develop an improved genetic model for the Minto deposit and clarify its relationship to other Cu-Au ore systems.

Initial fieldwork for an MSc study of the Minto deposits was conducted between June and August, 2008. The primary objectives for this first field season were to become familiar with the deposit features (lithologies, structure, sequence and variety of alteration) and to begin detailed logging of a series of drill core in order to define a down-dip transect of the deposits. Logging was performed on holes in Areas 2 and 118 (Fig. 3a). These detailed logs will provide the basis for interpreting the large database of existing drill logs, core photography and geochemical analyses maintained by Capstone Mining Corporation; these interpretations will determine property-scale

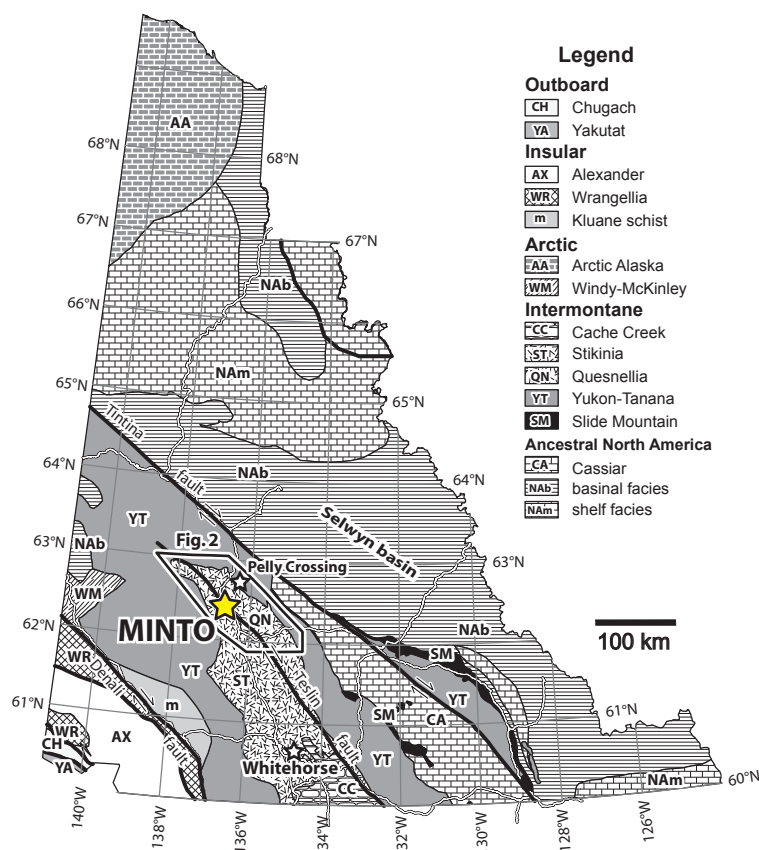


Figure 1. Terrane map of Yukon illustrating the location of the Minto mine. Parallelogram outlines location of Figure 2.

trends in mineralization, alteration and structure. The results of this study will assist in designing exploration strategies to facilitate discovery of additional Cu-Au deposits in the district. This project is a partnership between Capstone Mining Corporation, the Yukon Geological Survey, and the Mineral Deposit Research Unit (MDRU) at the University of British Columbia.

PROPERTY GEOLOGY AND DEPOSIT CHARACTERISTICS

The Minto mine is located in the centre of Carmacks map area (NTS 1151) within the Carmacks copper belt of west-central Yukon. This mineralized belt is a 180 km by 60 km-wide belt of similar intrusion-hosted Cu-Au mineralization trending approximately north-northwest. This district also includes the Williams Creek (now Carmacks Copper) deposit (Yukon MINFILE 1151 008) and

the STU prospect (Yukon MINFILE 1151 011) to the southeast of Minto (Fig. 2). Regional 1:250 000-scale mapping of the area was first conducted by Bostock (1936) and subsequently updated by Tempelman-Kluit (1984). The Minto deposit is hosted in intermediate to felsic intrusive and meta-intrusive rocks of the Early Jurassic Granite Mountain batholith, specifically the Minto pluton, which intrudes the boundary between Stikinia and Yukon-Tanana terranes (Figs. 1 and 2; Tempelman-Kluit, 1984; Gordey and Makepeace, 1999; Colpron, 2006). The Minto pluton intrudes Upper Triassic augite-phyric basalts of Stikinia (or Quesnellia) to the east and north, and Early Mississippian meta-plutonic rocks of Yukon-Tanana terrane (Simpson Range plutonic suite) to the west (Fig. 2). Its eastern contact with Triassic rocks is locally faulted. To the south, the Minto pluton is in fault contact with basalt of the Upper Cretaceous Carmacks Group; further south, the Carmacks Group unconformably

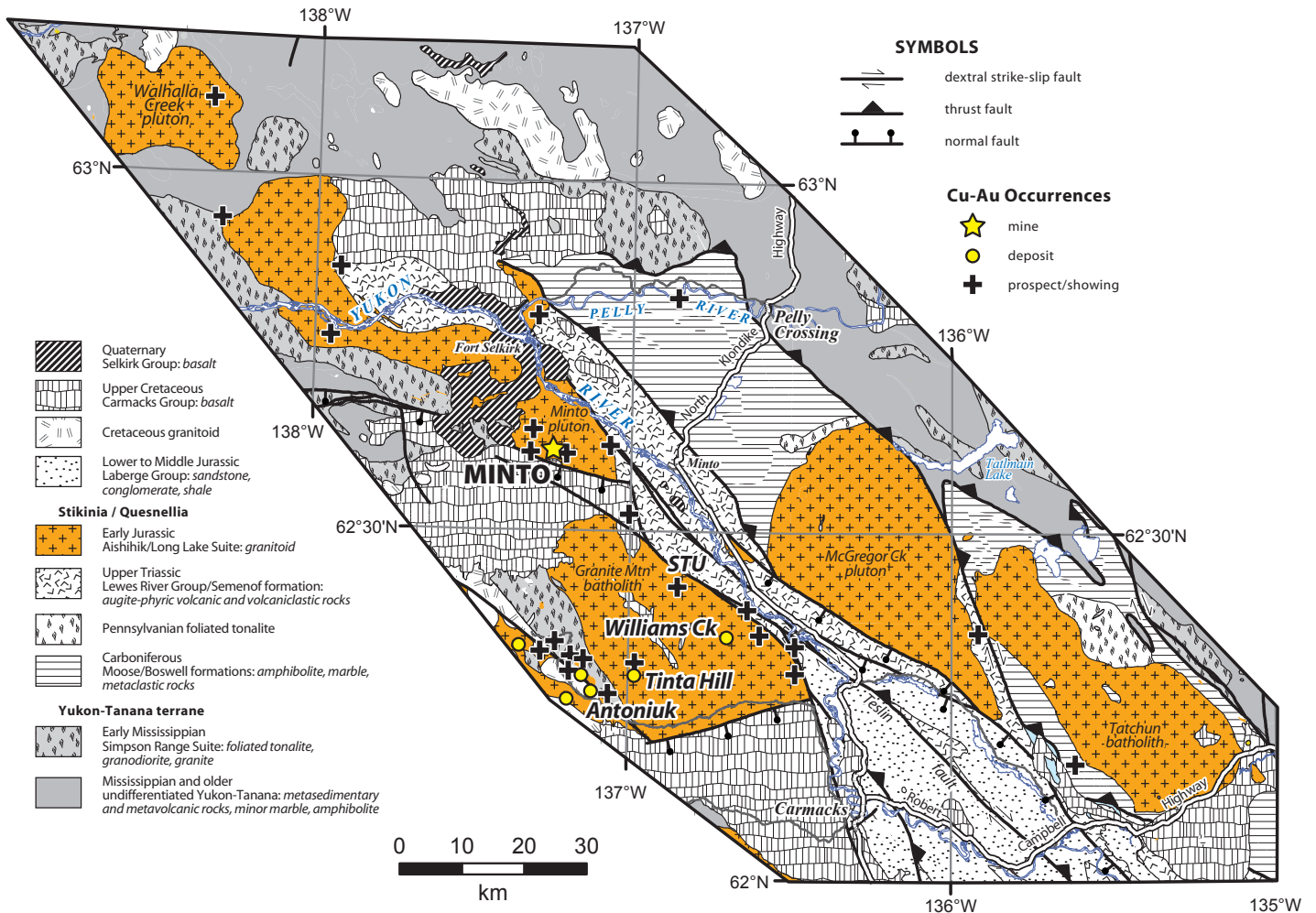
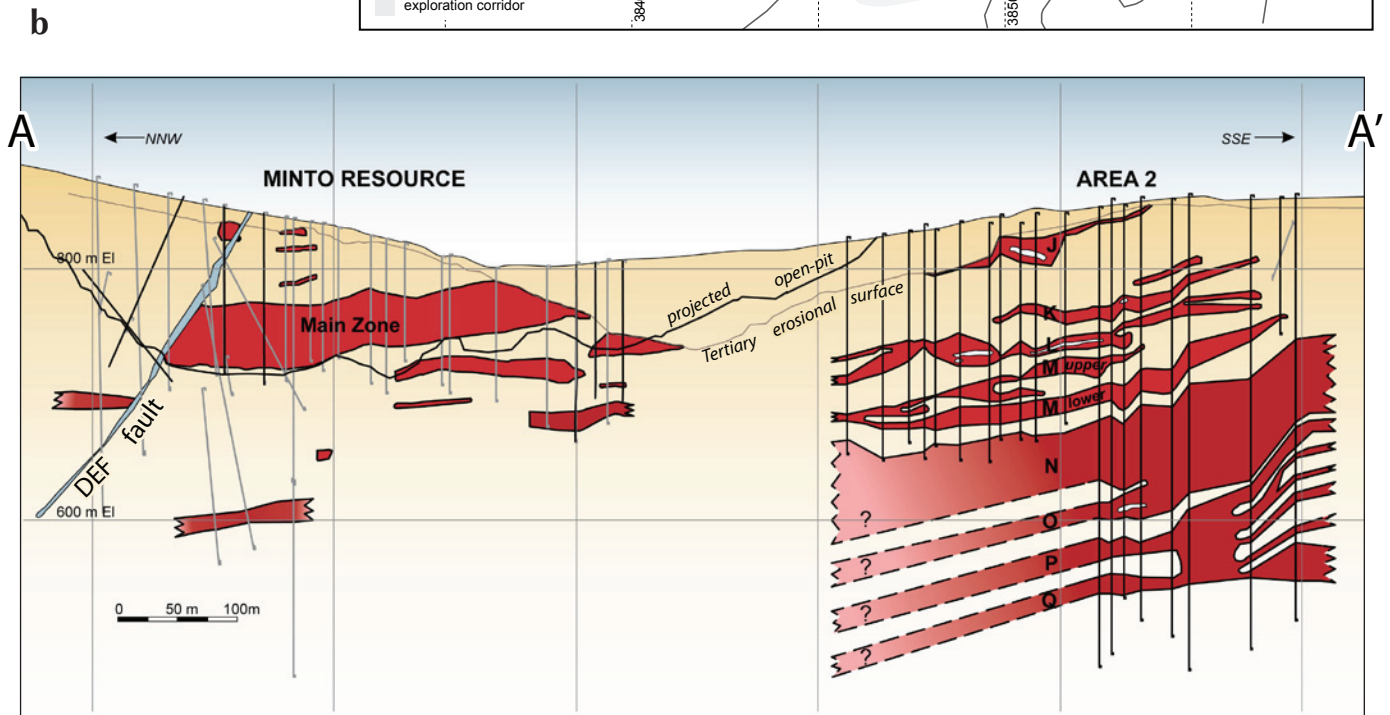
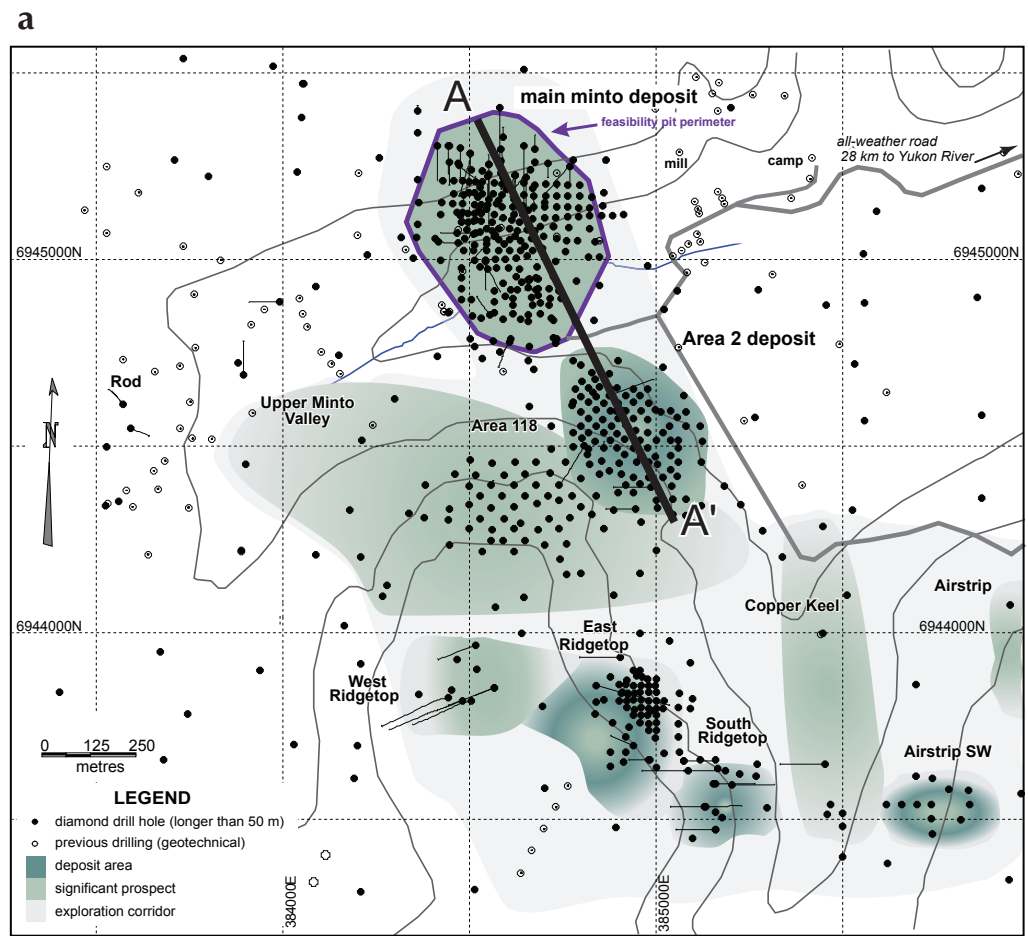


Figure 2. Regional geology of the Carmacks copper belt in west-central Yukon (modified from Tempelman-Kluit, 1984; Gordey and Makepeace, 1999; Colpron, 2006; and Colpron et al., 2007).

Figure 3. (a) Plan view of the Minto property illustrating the distribution of high-grade deposits and significant prospects (shaded areas). Coordinates NAD83, UTM Zone 8. **(b)** Cross-section A-A' from main Minto deposit to Area 2 depicting the stacked geometry of foliated and mineralized horizons (dark grey). Projected Minto pit outline is also shown. Section oriented 340° and located on Figure 3a.



overlies the southern portion of the Granite Mountain batholith (Fig. 2). North of the Minto property, Pliocene and younger basalt flows of the Selkirk Group cover the Early Jurassic intrusion.

The Minto pluton is dominantly composed of massive granodiorite (Le Bas and Streckeisen, 1991), but also includes sheets of variably deformed intrusive rocks (Fig. 3b). U-Pb zircon geochronology by Tafti (2005) indicates a maximum age of 199 ± 7 Ma for the Minto pluton with younger phases ranging to ~ 185 Ma. Geothermobarometric analyses suggest an emplacement depth of at least 9 km and crystallization temperatures of ca. 711°C for the youngest phase (Tafti, 2005). However, occurrences of magmatic epidote in older phases indicate that part of the Minto pluton crystallized at pressures in excess of 6 kbar (18-20 km depth; Tafti, 2005). In the southern portion of the Minto property, the pluton is unconformably overlain by a Late Cretaceous(?) conglomerate that locally contains mineralized clasts. Primary hypogene mineralization at Minto is hosted by variably foliated granodiorite and diorite, with gneissic rocks containing the highest grades. Supergene mineralization occurs proximal to near-surface extension of the primary mineralization and beneath the Cretaceous conglomerate.

The Minto property comprises several high-grade deposits (e.g., the Minto open-pit mine, Area 2, Area 118 and Ridgetop) plus several other significant prospects (e.g., Copper Keel, Copper Keel South, Airstrip, West Ridgetop and Upper Minto Valley) clustered within an area approximately 4 km^2 and centred on Area 118, located about 400 m south of the current open pit (Fig. 3a). Ongoing exploration drilling has now established continuity between some deposits (e.g., Main, Area 2, Area 118 and Copper Keel). Results from drilling are progressively suggesting that the Minto mineralization represents a single, large copper-gold deposit where the currently outlined deposits and prospects are actually high-grade pockets within a much larger copper-gold system (Fig. 3a). Discontinuities between areas appear to be due to post-mineralization faulting. In addition to the large aerial extent of this system, deep drilling (~ 300 - 350 m) within each of these zones consistently shows that this system comprises up to 13 individual deformed and mineralized horizons, stacked in a sub-horizontal, openly folded geometry (Fig. 3b). Although the mineralization is generally contained within these deformed zones, not all horizons exhibit ore grades; but all horizons yield some degree of copper-gold mineralization, from geochemically

anomalous to very high grade. Individual horizons range from 1 to 2 m thick, to over 60 m thick, and have typical drill intersections of 10 to 25 m for the best mineralized intervals. A lateral continuity of individual horizons of up to 1.5 km was observed in drill holes and justifies the use of this stacked succession of deformation zones as pseudo-stratigraphy (Fig. 3b). This model has proven successful in guiding exploration and has provided additional copper-gold mineralization targets at the Minto property.

MAJOR LITHOLOGICAL UNITS

Three major lithologies are identified on the Minto property and are differentiated by composition and degree of deformation. These rocks range from variably deformed gneisses to massive granitoids (Pearson, 1977; Tafti, 2005). Observations of lithological contacts were made mainly from drill core; preliminary interpretation of contact relationships will be discussed later in this paper.

MEGACRYSTIC K-FELDSPAR GRANODIORITE

Composition of the megacrystic K-feldspar granodiorite unit (Fig. 4a) is predominantly granodiorite, but ranges to quartz diorite and rarely to quartz monzonite or granite. Plagioclase represents 50% of the modal mineralogy, K-feldspar 10-50%, quartz 20-25%, biotite \pm hornblende 10-15% and primary epidote $<1\%$. K-feldspar occurs as euhedral to subhedral phenocrysts, and commonly as megacrysts 1-8 cm long. Orientation of these megacrysts is nearly always random; weak local fabric development is ascribed to magmatic flow. Megacrystic K-feldspar granodiorite is observed within the Minto open-pit, and in places in drill core, it grades into equigranular biotite \pm hornblende monzodiorite (Fig. 4b). Composition and texture of this latter unit is nearly identical to the megacrystic K-feldspar granodiorite, but without potassium feldspar. Locally, glomeroporphyritic quartz (<1 cm) is present in both the megacrystic K-feldspar granodiorite and equigranular biotite-hornblende monzodiorite.

The K-feldspar megacrystic granodiorite varies in texture from massive to foliated within the Minto pluton. Foliated biotite granodiorite and foliated hornblende-biotite granodiorite (Fig. 4c,d,e) contain plagioclase, quartz and potassium feldspar. Average modal composition is 40-45% plagioclase, 15-20% quartz, 10-15% K-feldspar, 10-15% biotite and 0-5% hornblende (substituting for biotite). Biotite, the dominant mafic mineral, defines a

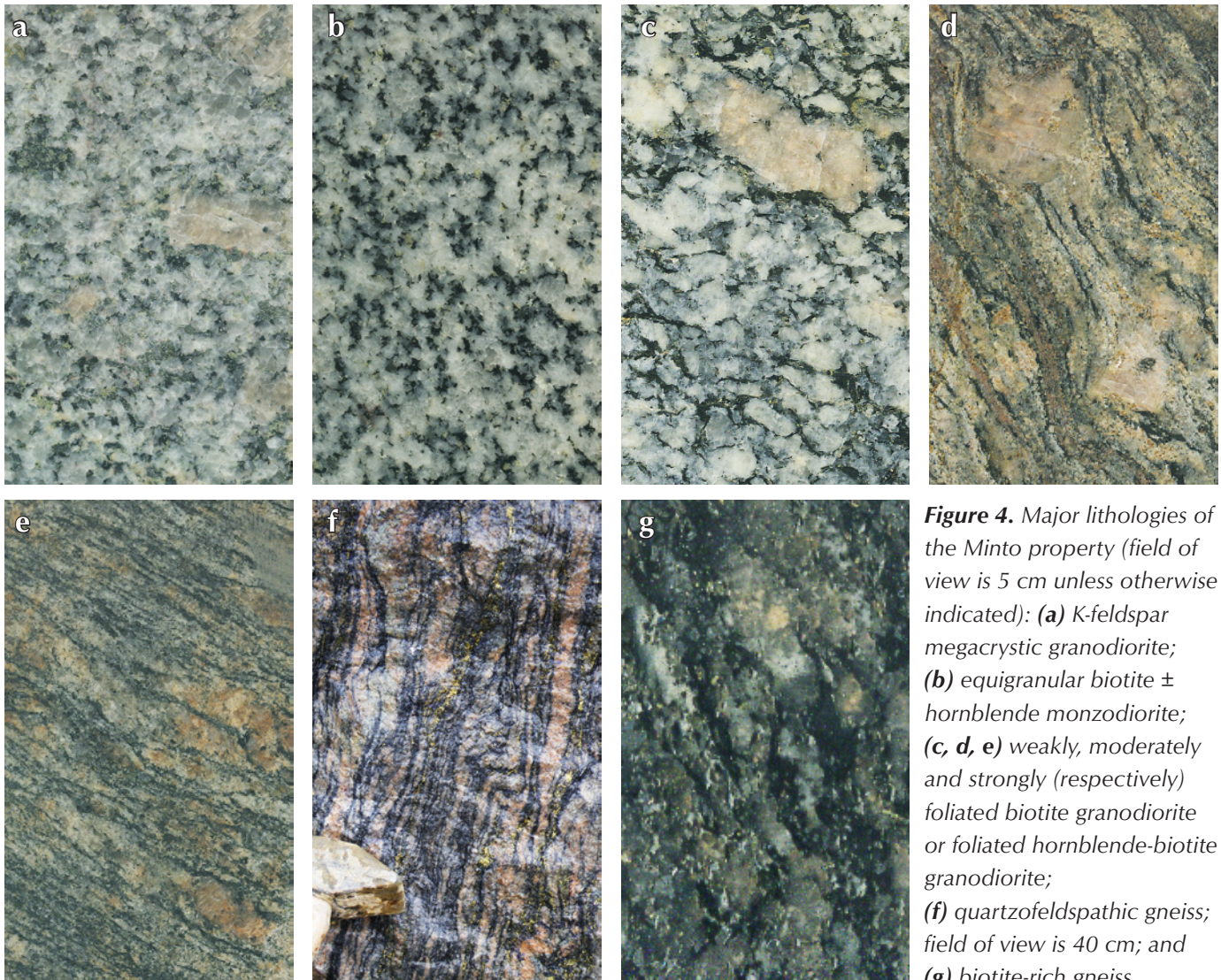


Figure 4. Major lithologies of the Minto property (field of view is 5 cm unless otherwise indicated): (a) K-feldspar megacrystic granodiorite; (b) equigranular biotite \pm hornblende monzodiorite; (c, d, e) weakly, moderately and strongly (respectively) foliated biotite granodiorite or foliated hornblende-biotite granodiorite; (f) quartzofeldspathic gneiss; field of view is 40 cm; and (g) biotite-rich gneiss.

disjunctive and discontinuous foliation with centimetre-scale spacing. K-feldspar megacrysts are rotated, have common tails, and are fractured within these subunits. Red garnet is an uncommon accessory mineral and occurs locally as individual grains or as sub-millimetre-sized grains in 1 to 5 mm crystal aggregates.

FOLDED QUARTZOFELDSPATHIC GNEISS

The folded quartzofeldspathic gneiss (Fig. 4f) consists of well developed, centimetre-thick compositional layers of mainly quartz and potassium feldspar, alternating with bands of biotite and magnetite. This unit contains 25-50% equigranular K-feldspar, 0-30% individual or layered bands of euhedral to subhedral magnetite, 25-30% equigranular quartz, 5-10% biotite and minor plagioclase. The compositional banding is nearly always folded by

centimetre to decimetre-scale disharmonic, gentle to isoclinal folds. Copper-sulphide mineralization in this unit is nearly ubiquitous and may represent up to 15% or more of the rock composition. Locally, magnetite-quartz gneiss contains up to 25% magnetite.

BIOTITE-RICH GNEISS

The biotite-rich gneiss (Fig. 4g) is a major ore-hosting unit and is well exposed in the Minto main pit. Composition is commonly around 40-50% biotite, 30-40% plagioclase, and contains minor quartz and K-feldspar. Locally, this unit is composed of massive biotite.

HYDROTHERMAL ALTERATION AND MINERALIZATION

Preliminary observations of alteration mineralogy and assemblages have been made through examination of drill core and the Minto pit. Assemblages listed here are grouped by their most commonly observed mineral associations.

VEINING

Veins are generally less than 0.5 cm in width and consist of late-stage calcite veining and fracture infill with

associated hematite veining (Fig. 5a); late-stage calcite veining and fracture infill without hematite veining (Fig. 5b); late-stage gypsum veining (Fig. 5c); late-stage hematite veinlets (Fig. 5d); and, epidote veins or stringers that are sharp-walled, without selvages (Fig. 5e).

SILICIFICATION

A silica-rich alteration (Fig. 5f) commonly overprints the quartzofeldspathic gneiss, and in places overprints other lithologies and their alterations. In the silicified quartzofeldspathic gneiss, quartz forms the majority of

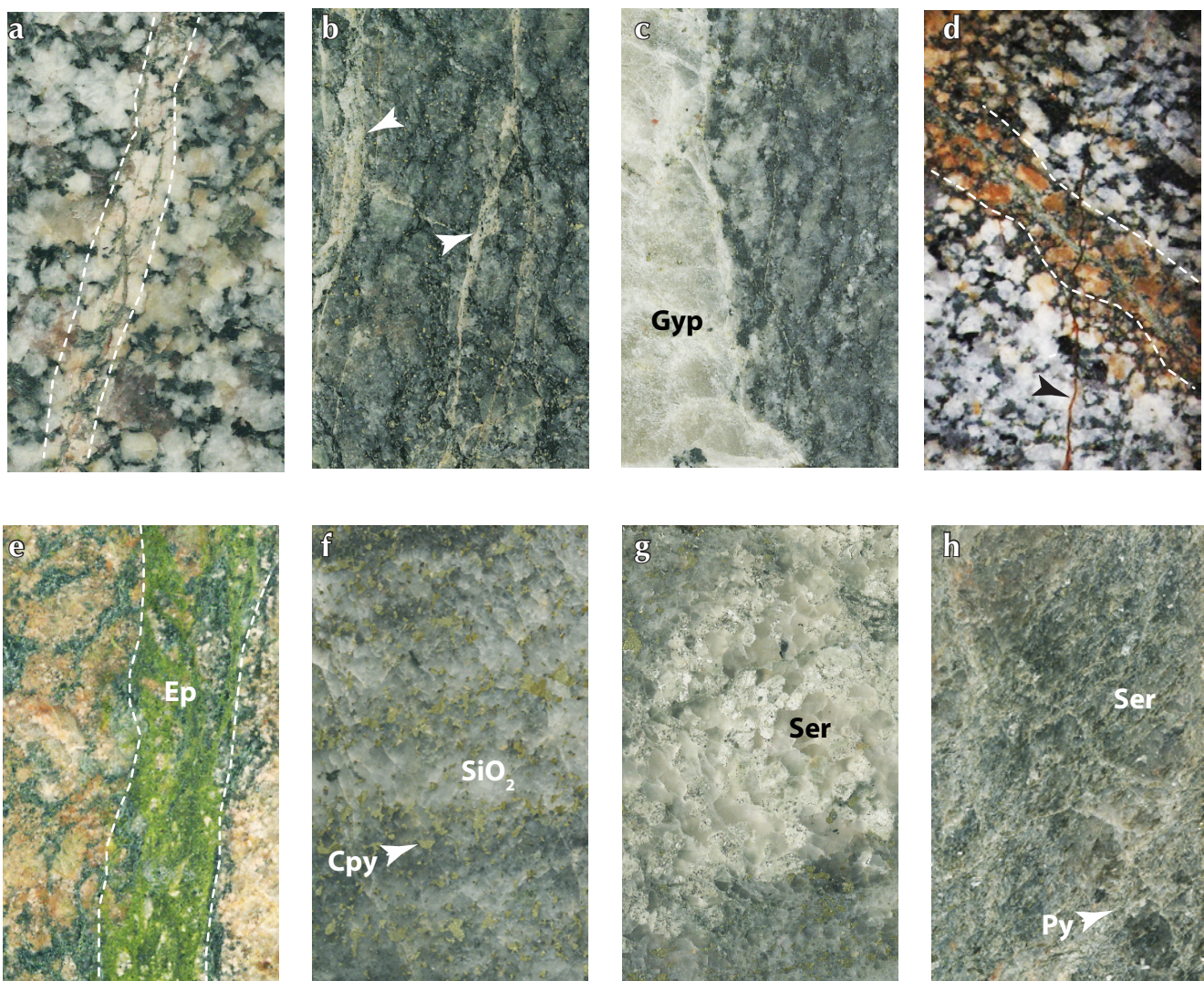


Figure 5. Common alteration assemblages of the Minto area (field of view is 5 cm unless otherwise indicated): (a) late-stage calcite veining (dashed outline) with associated hematite; field of view is 2 cm; (b) late-stage calcite veining (arrows); (c) late-stage gypsum (Gyp) veining; field of view is 2 cm; (d) late-stage hematite veining (arrow and dashed outline); field of view is 3 cm; (e) epidote (Ep) veining (dashed outline); field of view is 2 cm; (f) silicification (SiO_2); note disseminated chalcopyrite [Cpy]; (g) sericite (Ser) pseudomorph of feldspar (saussuritization); (h) pervasive sericite (Ser) with pyrite (Py; arrow). [Figure 5 continues on next page.]

the rock matrix, and relict feldspar, sulphides and magnetite define a faint foliation.

SERICITIZATION

Sericitization is observed in two forms at Minto. Most commonly, it is fine-grained saussuritization of plagioclase (Fig. 5g). Development of pervasive medium-grained white mica is less common (Fig. 5h). This alteration is texturally destructive and is associated with minor anhedral pyrite.

EPIDOTE + CHLORITE ± MAGNETITE

The epidote + chlorite ± magnetite assemblage is characterized by the patchy replacement of biotite, hornblende and rarely K-feldspar by anhedral, patchy epidote (Fig. 5i). This secondary epidote is distinct from primary euhedral magmatic epidote locally observed in the granodiorite (Tafti, 2005). Biotite within the alteration

selvage is often weakly chloritized, and some zones contain alteration-associated magnetite.

HEMATITE + CHLORITE ± K-FELDSPAR

Hematite + chlorite ± K-feldspar alteration is one of the most commonly observed alteration types within the Minto deposit. This alteration is characterized by pink fracture-controlled selvages of hematite dusting (Fig. 5j). This alteration is present in both deformed and undeformed units at Minto. It is rarely controlled by veinlets. Alteration selvages are millimetres to decimetres in scale. Feldspars are commonly replaced by orthoclase, and biotite and hornblende are generally replaced with chlorite.

BIOTITE + MAGNETITE

Development of biotite and magnetite occurs in a range of lithologies and mineral associations, although always

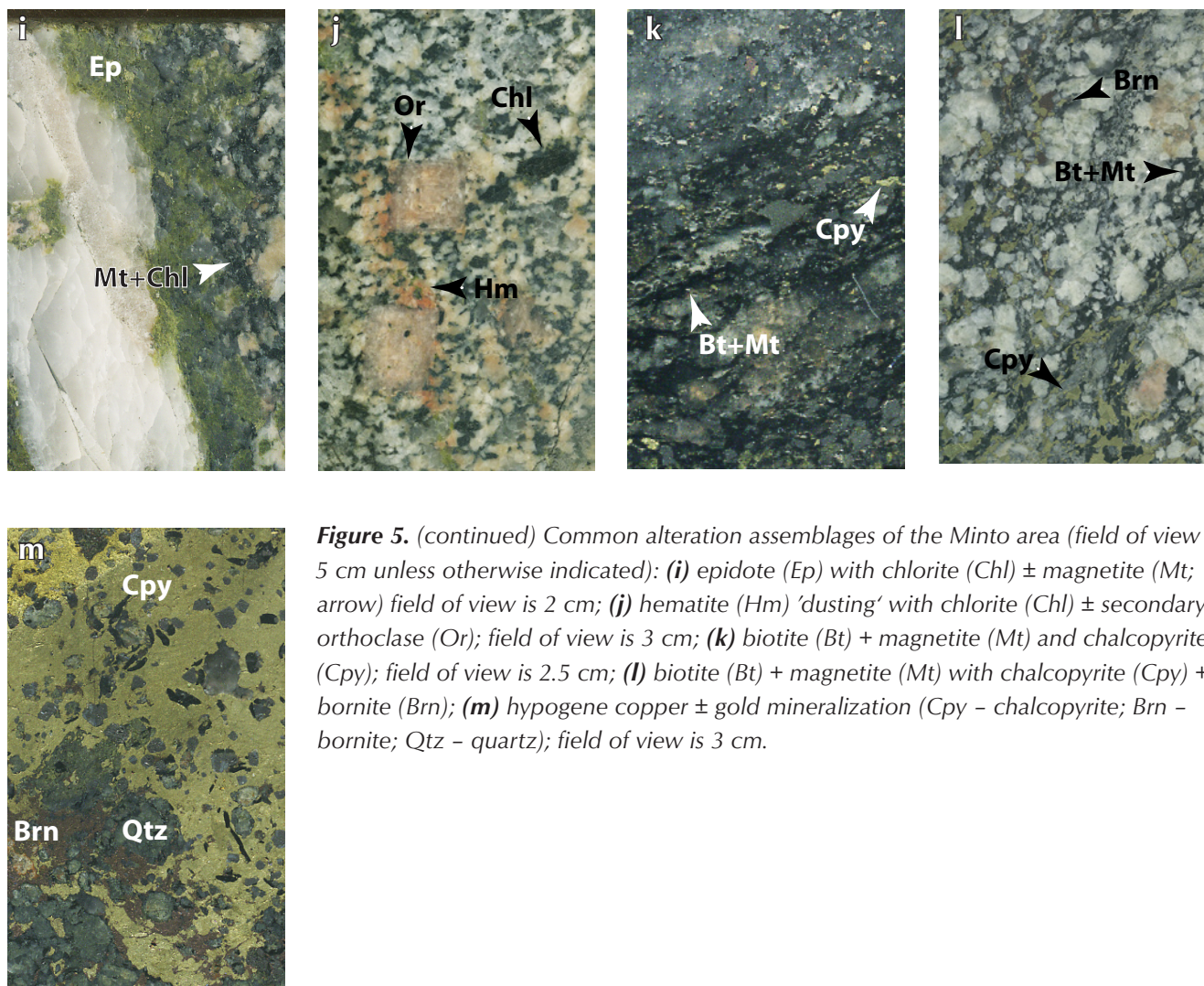


Figure 5. (continued) Common alteration assemblages of the Minto area (field of view is 5 cm unless otherwise indicated): **(i)** epidote (Ep) with chlorite (Chl) ± magnetite (Mt; arrow) field of view is 2 cm; **(j)** hematite (Hm) 'dusting' with chlorite (Chl) ± secondary orthoclase (Or); field of view is 3 cm; **(k)** biotite (Bt) + magnetite (Mt) and chalcopyrite (Cpy); field of view is 2.5 cm; **(l)** biotite (Bt) + magnetite (Mt) with chalcopyrite (Cpy) + bornite (Brn); **(m)** hypogene copper ± gold mineralization (Cpy - chalcopyrite; Brn - bornite; Qtz - quartz); field of view is 3 cm.

within deformed units (Fig. 5k). Generally, this alteration appears to follow foliation, but is also seen as euhedral magnetite and biotite books within massive sulphides, or as massive shreddy biotite with magnetite.

MINERALIZATION

Hypogene mineralization consists of chalcopyrite and bornite and very rare euhedral chalcocite; these minerals may occur in combination or as individual blebs of massive to semi-massive mineralization. Gold and silver occur as microscopic inclusions within bornite. Free native gold is rare. Mineralization is nearly ubiquitously contained within foliated rocks, although there is an isolated case of native copper enclosed in a K-feldspar megacryst within the massive K-feldspar granodiorite. Hypogene copper sulphidation may be part of the biotite + magnetite alteration assemblage, as biotite and magnetite nearly always occur together with chalcopyrite and bornite (Fig. 5l). Massive chalcopyrite and/or bornite occur as stringers in all deposits, but are most common in the Minto main pit (Fig. 5m). These stringers are observed as being both parallel and oblique to foliation, as well as cross-cutting the main foliation in ore horizons.

Supergene alteration at Minto has produced secondary copper minerals such as chalcocite, azurite and malachite. These minerals usually occur along rims or fractures of primary copper minerals, or as whole-grain replacement. Native copper is rarely present as narrow veinlets or isolated blebs. Zones of supergene alteration are commonly close to surface, and are only locally observed at depth due to fault-controlled meteoric water penetration.

CONTACT RELATIONSHIPS BETWEEN LITHOLOGIES

Preliminary examinations of contact relationships at Minto were made during the Summer of 2008. The following observations are not definitive, and detailed work will be completed during the 2009 field season.

Based on macroscopic observations, contact relationships between deformed and massive units in the 2008 study areas are nearly always sharp, suggesting that they are intrusive in nature. However, a strain gradient over <1 cm is locally apparent in drill core, suggesting that some degree of deformation may be localized along the contacts. The foliation within the deformed horizons is nearly always parallel to the contacts with adjacent

massive units, a relationship that is most consistent with structural development of the contacts. However, after close examination of contact relationships in the main pit walls, the foliation was observed to be locally at high-angle to contacts with the massive unit, and may vary in attitude along the length of exposure. Microscopic examination of these contacts will be critical in determining their original nature and will help to determine the significance of deformation with respect to their development.

Preliminary analysis of lithological contact relationships with respect to foliation orientations within deformed horizons along a northwest-trending transect in the Area 2 deposit suggests a geometry of tight to isoclinal folding with a wavelength on the order of about 30 m. Folds within this area appear to trend approximately northwest, parallel to regional structural trends (Tempelman-Kluit, 1984). This suggests that some degree of deformation may predate emplacement of the massive units and that deformed lithologies are older than the massive units, an interpretation supported by isotopic age dates (Tafti, 2005).

DISCUSSION AND FUTURE WORK

The purpose of the current study is to better understand the relationship of mineral chemistry, mineral paragenesis, and foliation development to fluid flow and metal precipitation in the Minto Cu-Au deposit. As discussed above, one fundamental issue at Minto is the relationship between massive and deformed units. What is the nature of lithological contacts: intrusive, flow-related, or tectonic? Do the foliated units have protoliths with similar bulk chemistry as the massive units? Or is their bulk chemistry similar to older units of Stikinia and/or Yukon-Tanana terrane that are intruded by the Granite Mountain batholith? What mechanisms have led to foliation development, and how are they related to regional tectonism?

Petrography, geochemistry, and micro and macro-structural examination will be used to establish the mineral paragenesis, structural and chemical evolution, and the fluid flow history at Minto. Relative timing between intrusion, deformation, and metasomatism and mineralization will be determined by field and laboratory observation of geologic relationships. Determination of post-intrusion (*i.e.*, metasomatic and metamorphic) mineral associations based on field observation and geochemical analysis will help to determine the alteration

paragenesis at Minto. Radiometric dating of molybdenite and other sulphide minerals by the $^{187}\text{Re}/^{187}\text{Os}$ method will aid in constraining discrete mineralizing events within this paragenetic sequence. Subsequent comparison of grade, alteration, and mineral chemistry with a range of known hydrothermal Cu-Au deposits will allow for a better understanding of the Minto deposit relative to other Cu-Au systems on Earth.

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New results on the stratigraphy and placer gold potential of Indian River, Dawson, central Yukon

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ABSTRACT

Most of the historic placer gold recovered from the Indian River has been from the modern river gravel; however, a significant amount of placer gold has been mined from older deposits, including low-level, intermediate-level and high-level gravel terraces.

Significant placer gold reserves exist in Indian River drainage in various forms. Prospective targets include 1) modern (Holocene) alluvial channels, alluvial fans and tributary gulches; 2) modern (Holocene) low-level buried and/or abandoned alluvial terraces; 3) early to late Pleistocene intermediate-level buried abandoned terraces and alluvial fans; 4) early Pleistocene (pre-Reid) glaciofluvial gravel sequences; 5) Pliocene high-level alluvial terraces (White Channel Gravel); and 6) technogenic (tailings) deposits.

Fine-grained placer gold existing in size ranges not recovered efficiently by conventional sluicing operations has been found in alluvial and glaciofluvial gravel and tailings deposits. These deposits may represent an important resource and any future mining operations must address the metallurgical implications to maximize recovery.

RÉSUMÉ

La plus grande partie de l'or placérien extrait à ce jour de la rivière Indian provient du gravier contemporain de la rivière. Cependant, une quantité importante d'or placérien a également été extraite de dépôts plus anciens, y compris les terrasses de gravier de niveau inférieur, intermédiaire et supérieur.

D'importantes réserves d'or placérien existent sous diverses formes dans le bassin hydrologique de la rivière Indian. Les cibles de prospection comprennent 1) les chenaux alluviaux et les ravins affluents contemporains (Holocène); 2) les terrasses alluviales abandonnées et enfouies de niveau inférieur contemporaines (Holocène); 3) les terrasses abandonnées et enfouies de niveau intermédiaire et les cônes alluviaux de vallées latérales du Pléistocène précoce à tardif; 4) les séquences de gravier fluvioglaciaire du Pléistocène précoce (antérieur à la Glaciation de Reid); 5) les terrasses alluviales de niveau supérieur du Pliocène (gravier de White Channel); 6) les dépôts résultant du développement technologique.

De l'or placérien à grain fin qui n'est pas récupérée efficacement par les méthodes de concentration conventionnelles se retrouve dans des unités de gravier fluvioglaciaire ainsi que dans des dépôts résultant du développement technologique (résidus) dans le cadre d'activités minières antérieures. Ces dépôts pourraient contenir d'importantes ressources et devront être considérés lors de futures opérations minières afin d'en améliorer la récupération.

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INTRODUCTION

In 2003, a resurgence in placer exploration and mining activity by several mining companies in the Indian River area resulted in the creation of new exposures which became available to be studied and sampled.

Subsequently, a joint Canada/Russia project was initiated in 2006 in order to develop a better understanding of the evolution of placer gold deposits and gold potential of the Indian River drainage. The study was divided into several components consisting of the stratigraphic framework (led by William LeBarge of the Yukon Geological Survey, [YGS]); the nature and recovery of fine and thin gold particles (led by Dr. Vladimir Naumov of Perm State University, Russia); and a geochemical comparison between placer gold particles and local sources of bedrock gold (led by Dr. Rob Chapman, University of Leeds and Dr. Jim Mortensen, University of British Columbia). This paper presents some results from the first two components, while the third component will be presented in a later publication which will integrate the results of all three aspects of the study.

PREVIOUS WORK

High-level terraces along the Indian River were studied by Morison (1998) and more recently by Nelson and Jackson (2003). Lowey (1985) studied the conglomerates at McKinnon Creek (a left-limit tributary to Indian River) and grouped placer deposits along Indian River into several classes (Lowey, 1999). Lowey (2004) later described parts of the Indian River drainage and included this stratigraphy as part of a larger study of the Klondike Placer District. In 1999, Duk-Rodkin re-mapped the glacial limits which were initially defined by Bostock (1942, 1966) and Hughes *et al.* (1969). Glacial limits were later re-interpreted by Jackson *et al.* (2001). Froese *et al.* (2001) described the setting of placer deposits of Dominion Creek, a right-limit tributary of Indian River. Placer activity of the Dawson area was compiled by Lipovsky *et al.* (2001). The surficial geology of the Klondike and Indian River areas was mapped by Jackson (2005) and Froese and Jackson (2005a,b,c) as part of the Ancient Pacific NATMAP project.

PROJECT OBJECTIVES

The project was designed to yield two types of information: 1) to describe the mineralogy of gold in context with the stratigraphic framework; and, 2) to describe the physical characteristics of the sampled gold grains from the study area. To date, there have been no detailed mineralogical studies of placer gold from the

Indian River drainage and little work has been completed on the overall stratigraphic framework, specifically the stratigraphy of intermediate and low-level terraces. This project aims to better understand the relationship between the bedrock sources of gold and the placer gold in order to create a broader stratigraphic framework which can be used for exploration for new deposits of bedrock and placer gold, both within Indian River drainage and in adjacent areas of central Yukon. The combined studies of gold characteristics and stratigraphy may make it possible to re-trace the evolution of gold grains from their present location in modern river alluvium, back through the intermediate hosts of Tertiary gravel and Cretaceous conglomerate, and finally, to their original lode sources. The physical characterization of the gold grains recovered from sampling permits evaluation of the efficiency of past and current processing techniques used in placer mining. This information will be especially useful for miners wanting to redesign their processing methods in order to maximize gold recovery.

PLACER GOLD PRODUCTION

The Indian River Placer District, which is on the southern boundary of the Klondike Placer District, includes highly productive creeks such as Quartz and Dominion creeks and their respective tributaries, as well as less productive, but significant tributaries such as Ninemile, Ophir, Ruby, McKinnon, Montana, Eureka, Wounded Moose and Australia creeks (Fig. 1). Government royalty records (Yukon Mining Recorder, 2008) indicate the total cumulative recorded placer gold production to the end of 2008 to be 1 509 186 crude ounces (46 940 966 g) for the Indian River and its tributaries; approximately 71% of that came from Dominion, Sulphur and Gold Run creeks. No recorded mining took place on the main Indian River prior to 1983, and most placer gold production took place in the late 1980s, peaking at 30 482 crude ounces (948 097 g) in 1988. Only 3736 crude ounces (116 203 g) were recorded as royalties in 2008.

METHODOLOGY

FIELD METHODS

Between 2005 and 2007, over 50 sites were visited; these included active mine sites and natural exposures (Fig. 1). Sedimentary structures and stratigraphy were described, and more than 90 samples were collected from gravel units, organic-rich silt, wood (for ¹⁴C dating) and tephtras

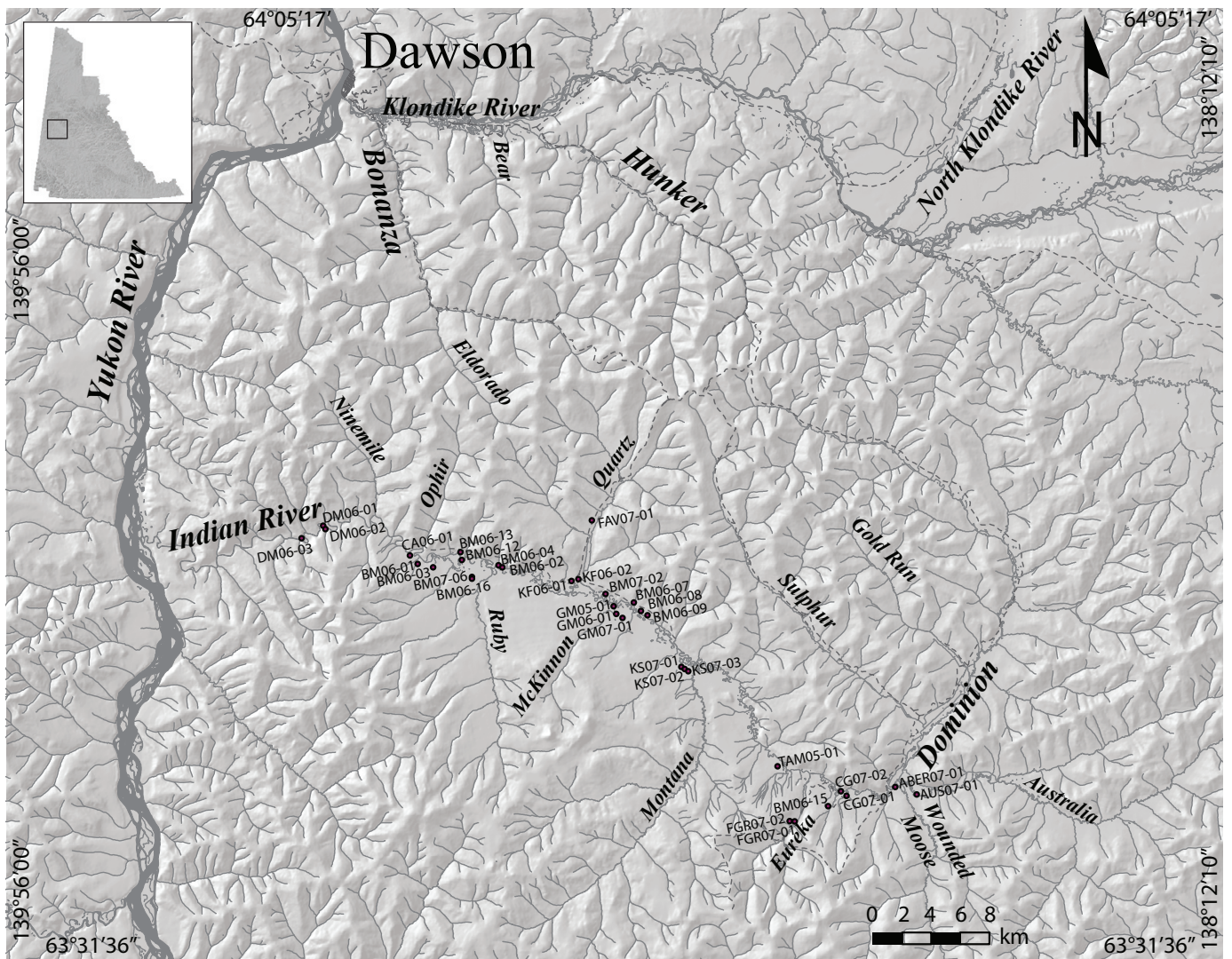


Figure 1. Location map including site locations studied from 2005 to 2007.

(for tephra chronology). Gravel units were sampled in vertical transects and were approximately 20 L in volume. These samples were processed according to the methods described by Lunev (1967) and Lunev and Osovetskiy (1987). Initially, samples were wet-screened in the field to size fractions of +4 mm and +1 mm. Size fractions of +4 mm were kept for lithological analyses and +1 mm size fractions were examined later in the lab to determine the presence of coarse gold. The -1 mm size fraction was mixed into a slurry and processed through a spiral concentrator ('Screw Sluice', Fig. 2). At the bottom of the spiral concentrator, material was separated into two fractions, with the heavier material on the inside of the spiral. Both mineral fractions were retained for laboratory analyses.



Figure 2. Dr. Vladimir Naumov operating a 'Screw Sluice' test plant on the banks of Indian River.

LABORATORY METHODS

At the Institute of Natural Sciences in Perm University, Russia, gold and heavy minerals were separated out of the collected samples using heavy liquids. Gold was separated from the heavy minerals and individual grains were counted. The gold grains were further separated into the following size fractions: +1.0 mm, -1.0 to 0.5 mm, -0.5 to +0.25 mm, -0.25 to +0.1 mm and -0.1 mm; the total mass of each of these size fractions was recorded. Gold grains were photographed using a scanning electron microscope (SEM) and were described in detail, along with the composition of each of the heavy mineral fractions.

Beta Analytic Inc., Miami, Florida, analyzed the wood and silt samples using standard AMS radiocarbon dating, and selected tephra were geochemically analyzed by Dr. John Westgate at the University of Toronto.

RESULTS

GENERAL STRATIGRAPHIC SETTING

Three major levels of terraces are known in the Indian River drainage. High-level terraces occur throughout the length of the valley and likely correlate to the Pliocene White Channel Gravel (WCG) which is found on Bonanza and Hunker creeks (Fig. 1; Nelson and Jackson, 2003). These high terraces are capped by a thin layer of glaciofluvial outwash and sand which was deposited during the first pre-Reid glaciation (Nelson and Jackson, 2003; Jackson, 2005; Froese and Jackson, 2005a,b,c). Intermediate-level terraces are exposed mainly upstream of the mouth of Quartz Creek, whereas low-level terraces occur on several closely spaced levels, primarily downstream of the mouth of Ruby Creek (Fig. 1). Modern river gravel is within, and immediately adjacent to, the active channel of the Indian River.

PRELIMINARY STRATIGRAPHIC FRAMEWORK

Field examinations from this study resulted in the construction of a preliminary stratigraphic framework for the Indian River placer deposits. Recent field work refined the general stratigraphy by providing age constraints to units formerly grouped into the high and intermediate-level terraces. The lithostratigraphic classification scheme is divided into the following six divisions:

- modern (Holocene) alluvial channels, alluvial fans, tributary gulches and colluvium;
- modern (Holocene) low-level buried and/or abandoned alluvial terraces;
- early to late Pleistocene intermediate-level buried abandoned terraces and alluvial fans;
- early Pleistocene (pre-Reid) glaciofluvial gravel sequences;
- Pliocene high-level alluvial terraces (White Channel Gravel); and
- technogenic (tailings) deposits.

Sampling and recent mining has shown that all of these contain placer gold (Mukhanov, 2007). Table 1 is a list of sections studied from 2005 to 2007, with their proposed lithostratigraphic classifications. Site locations for the studied sections are labeled in Figure 1.

DESCRIPTION AND INTERPRETATION OF SELECTED KEY STRATIGRAPHIC SECTIONS

The following sites were chosen for description as they have expanded the Indian River stratigraphy and provided new age control on high and intermediate-level landforms. A more comprehensive description of each of the lithostratigraphic units will be prepared as part of an Open File report to be released in 2009.

Section BM06-01 (Table 1, Figs. 1 and 3) consists of an alluvial fan sequence (lithostratigraphic classification 3 – early to late Pleistocene alluvial fan) unconformably overlying a White Channel Gravel terrace (lithostratigraphic classification 5 – Pliocene high-level alluvial terrace). Radiocarbon dates indicate the lower, probably WCG gravel sequence, is >45 000 years old (Beta 226704; bottom inset, Fig. 3), whereas the upper gravel is overlain by organic pods dated at $43\,550 \pm 2000$ years (Beta 216446; top inset, Fig. 3). These pods were once a continuous layer, but were subjected to intense cryoturbation after deposition. An overlying silt unit dated at $33\,970 \pm 610$ years (Beta 216447) is flat-lying which indicates cessation of the cryoturbation, likely due to a warming period. These dates suggest a late Pleistocene age for the alluvial fan sequence. Gold values from gravel samples in the lower WCG unit varied from 461.5 mg/m³ on bedrock, upwards to 213 mg/m³ (samples WL06-65 and WL06-64, respectively, Appendix 1). A nearby transect from the bedrock contact through to the upper alluvial fan varied from 138.3 to 42.5 mg/m³ (samples WL06-67 and WL06-66, respectively, Appendix 1). Generally, the gold grain size decreased vertically from the bedrock surface and laterally from the modern valley centre.

Table 1. Lithostratigraphic classifications for sections studied in the Indian River area from 2005 to 2007.

Section number	Drainage	Preliminary lithostratigraphic classification	Owner	Latitude	Longitude
GM05-01	Indian River	1	Gimlex Enterprises	63° 44' 6"	139° 4' 43"
TAM05-01	Indian River	1	Tamarack Mining	63° 38' 15"	138° 51' 50"
BM05-02	Indian River	5	Boulder Mining	63° 45' 56"	139° 20' 55"
KF05-01	Indian River	3	Kim Ferguson	63° 45' 15"	139° 7' 39"
BM05-01	Indian River	5	Boulder Mining	63° 45' 53"	139° 21' 9"
DM05-01	Indian River	2	Dave McBurney	63° 47' 22"	139° 29' 4"
BM06-02	Indian River	3	Boulder Mining	63° 45' 42"	139° 14' 23"
BM06-01	Indian River	3,5	Boulder Mining	63° 45' 53"	139° 21' 3"
BM06-03	Indian River	5	Boulder Mining	63° 45' 48"	139° 19' 59"
BM06-04	Indian River	1	Boulder Mining	63° 45' 44"	139° 14' 31"
BM06-05	Indian River	5	Boulder Mining	63° 44' 21"	139° 4' 14"
BM06-05	Indian River	4	Boulder Mining	63° 44' 21"	139° 4' 20"
BM06-06	Indian River	5	Boulder Mining	63° 44' 12"	139° 3' 31"
BM06-07	Indian River	3	Boulder Mining	63° 44' 2"	139° 3' 12"
BM06-08	Indian River	5	Boulder Mining	63° 43' 53"	139° 2' 39"
BM06-09	Indian River	5	Boulder Mining	63° 43' 40"	139° 2' 3"
BM06-10	Indian River	1	Boulder Mining	63° 44' 42"	139° 9' 1"
BM06-11	Indian River	1	Boulder Mining	63° 46' 6"	139° 17' 8"
BM06-12	Indian River	1	Boulder Mining	63° 46' 4"	139° 17' 18"
BM06-13	Indian River	1	Boulder Mining	63° 46' 15"	139° 17' 38"
BM06-14	Indian River	4	Boulder Mining	63° 36' 35"	138° 46' 25"
BM06-15	Indian River	4	Boulder Mining	63° 36' 29"	138° 47' 28"
BM06-16	Diversion Creek	2	Boulder Mining	63° 45' 10"	139° 16' 46"
CA06-01	Indian River	5	Cam Arkenstall	63° 46' 3"	139° 21' 31"
DM06-01	Indian River	2	Dave McBurney	63° 47' 25"	139° 29' 0"
DM06-02	Indian River	2	Dave McBurney	63° 47' 21"	139° 29' 3"
DM06-03	Indian River	5	Dave McBurney	63° 46' 57"	139° 30' 49"
GM06-01	Indian River	1	Gimlex Enterprises	63° 43' 53"	139° 4' 42"
KF06-01	Indian River/Quartz Creek	3	Kim Ferguson	63° 45' 7"	139° 8' 18"
KF06-02	Quartz Creek	6	Lavona McNeil/Kim Ferguson	63° 45' 13"	139° 7' 26"
KF07-01	Indian River/Quartz Creek	3	Kim Ferguson	63° 45' 8"	139° 7' 57"
FAV07-01	Quartz Creek	5	Favron	63° 47' 10"	139° 6' 27"
CG07-01	Indian River	2	Colonial Gold	63° 36' 39"	138° 45' 44"
CG07-02	Indian River	2	Colonial Gold	63° 36' 43"	138° 45' 52"
CG07-03	Indian River	2	Colonial Gold	63° 36' 39"	138° 45' 45"
FGR07-01	Eureka Creek	5	Fine Gold Resources	63° 35' 58"	138° 50' 41"
FGR07-02	Eureka Creek	5	Fine Gold Resources	63° 35' 57"	138° 50' 33"
KS07-01	Indian River	3	Klondike Star	63° 41' 32"	138° 59' 33"
KS07-02	Indian River	3	Klondike Star	63° 41' 30"	138° 59' 23"
KS07-03	Indian River	3	Klondike Star	63° 41' 27"	138° 59' 18"
ABER07-01	Australia/Wounded Moose creeks	2	Tamarack	63° 37' 0"	138° 41' 59"
TAM07-01	Indian River	1	Tamarack	63° 36' 42"	138° 42' 55"
BM07-04	Indian River	4	Boulder Mining	63° 44' 21"	139° 4' 20"
BM07-05	Indian River	4	Boulder Mining	63° 44' 18"	139° 3' 40"
BM07-03	Indian River	4	Boulder Mining	63° 44' 18"	139° 4' 28"
BM07-02	Indian River	4	Boulder Mining	63° 44' 35"	139° 5' 19"
BM07-01	Indian River	6	Boulder Mining	63° 44' 42"	139° 8' 30"
BM07-06	Diversion Creek	1	Boulder Mining	63° 45' 10"	139° 16' 47"
GM07-01	Indian River	1	Gimlex Enterprises	63° 43' 43"	139° 4' 11"
AUS07-01	Australia Creek	2	open	63° 36' 48"	138° 40' 20"

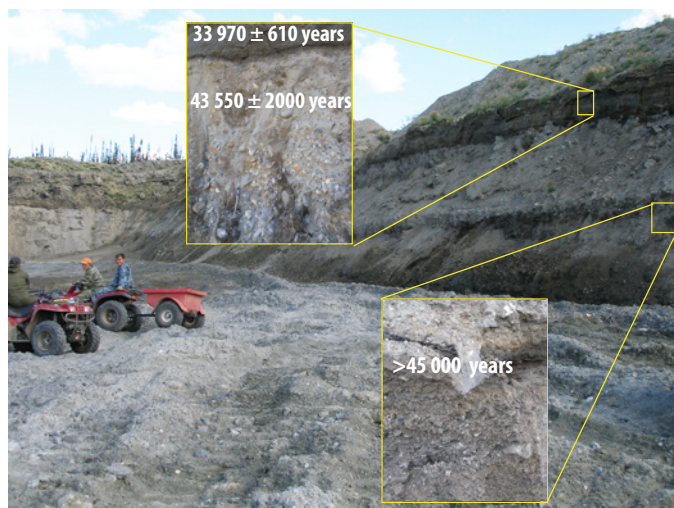


Figure 3. Section BM06-01 at Boulder Mining’s main pit on the Indian River. Exposure consists of an alluvial fan sequence (lithostratigraphic classification 3; inset top) unconformably overlying a White Channel Gravel terrace (lithostratigraphic classification 5; inset bottom).

Section BM06-02 (Table 1, Figs. 1 and 4) is interpreted to belong to lithostratigraphic classification 3 – an early to late Pleistocene alluvial fan. Geochemical analyses show that a volcanic ash located in the upper third of this alluvial fan sequence near Ophir Creek is the 80 Pup tephra, which is approximately 140 000 years old (J. Westgate, pers. comm., 2008). A lower tephra has been identified as the Ophir Creek tephra which has not been dated. Several of these fans appear to cut the high-level terraces and they are in turn truncated by the

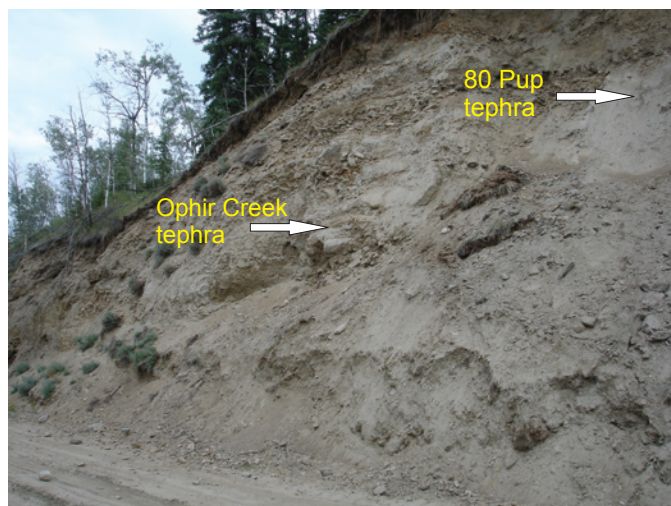


Figure 4. Section BM06-02 consists of an exposure of early to late Pleistocene alluvial fan sediments (lithostratigraphic classification 3).



Figure 5. Ilya Mukhanov and Vitalii Bryukhov taking a sample from section KF06-01 on Indian River at Quartz Creek. Exposure consists of an early to late Pleistocene intermediate-level buried terrace (lithostratigraphic classification 3).

modern Indian River. According to the tephra chronology, these fans likely have a periglacial origin coincident with the end of the marine isotope stage 6 cold period (Reid glaciation). Coarse gravel from this alluvial fan contained fine gold, less than 0.25 mm in size (Appendix 1, sample WL06-63). This fan has not been surficially mapped (Froese and Jackson, 2005c) as it has no significant surficial expression and is not discernable on air photos.

Section KF06-01 (Table 1, Figs. 1 and 5) is interpreted to belong to lithostratigraphic classification 3, an early to late Pleistocene intermediate-level buried terrace. This terrace consists of quartz-rich gravel that is overlain by locally derived, angular gravel of possible periglacial origin (sample WL06-80, Appendix 1). Organic-rich silt and wood from the contact between the two units yielded AMS radiocarbon dates of 26 630 ± 160 years (Beta 226703); 27 760 ± 170 years (Beta 226702); 33 960 ± 290 years (Beta 226701) and 48 070 ± 1130 years (Beta 227956). Inter-stratification of the lower organic-rich silt and upper pay gravel (sample WL06-79, Appendix 1) indicates that they are of a similar age and were likely deposited during periglacial conditions at the onset of the Late Wisconsinan-McConnell glaciation. This terrace is surficially mapped as colluvium (Froese and Jackson, 2005c) as it has little surface expression. The underlying gold-bearing gravel is only exposed through mining cuts.

GOLD GRAIN SIZE DISTRIBUTION AND CONCENTRATION

Selected samples that contained gold grains were grouped into the preliminary lithostratigraphic classifications in order to discern any notable trends. These are shown in Appendix 1 which notes the grain size distribution of gold, the mass of gold in each size fraction, and the overall concentration of gold in the sample (calculated from the total gravel sample volume, not shown).

DISCUSSION

The small number of samples and relatively low sample volumes, restrict us from making comprehensive statements about the grain size distribution and concentration in the various deposits sampled, however, the results of this study may be used as a preliminary indicator. Previous mining activity and past research has shown that the Indian River placer deposits contain mainly fine-grained gold (LeBarge, 2007). However, in areas where the placer gold deposit contains coarser gold than average, the amount and size of gold in our samples is likely less representative of the overall deposit (Luney, 1967; Luney and Osovetskiy, 1987).

Our gold grain size distribution results indicate that in the majority of samples, 30% of the total concentration consists of gold less than 0.25 mm in size. In several samples, the concentration of gold less than 0.1 mm in size may be up to 50% of the total concentration. Samples which were taken from early Pleistocene (pre-Reid) glaciofluvial deposits (lithostratigraphic classification 4) have very fine gold with up to 80% of their total concentration represented in the -0.25 mm size fraction. Gold greater than 1.0 mm in size was recovered in only a few samples, notably in lithostratigraphic classification 2 – modern low-level buried and/or abandoned alluvial terraces. Interestingly, this classification also had the highest average gold concentration of all the samples taken, which indicates that even a moderate amount of coarse gold in a sample can dramatically increase the grade of the overall sample. This theory would hold true at the larger deposit scale.

A coarsening-downstream trend was observed when examining gold grain size distribution of all the samples as a whole. This could indicate either a reversal in drainage, or a major influence of local bedrock sources. A local bedrock source would explain the presence of wire and

angular gold found in some of the samples. There is no evidence in our study to date (e.g., paleoflow data) to support a reversal in drainage, therefore we believe that there may be an unknown local lode gold source. In fact, the gold grain size and morphology data point to a possible undiscovered bedrock gold source somewhere on the Indian River downstream of the mouth of Ruby Creek.

Figure 6 shows the cumulative percent of gold finer than 0.25, 0.5 and 1 mm for each of the lithostratigraphic classifications calculated from the data presented in Appendix 1. However, some groupings of weights in different particle size fractions precluded their use in this Figure.

Table 2 was compiled from data in Appendix 1 and shows the average grade of gold lost if there is no recovery of -0.25 mm gold fraction, grouped by lithostratigraphic classification for selected samples.

For example, gold grain samples from lithostratigraphic classification 4 (column 1) had 93.2% of their weight on average fall into the -0.25 mm size fraction (column 2), and only 6.8% of their weight on average fall into the +0.25 mm size fraction (column 3). Since grade information is available from each sample (Appendix 1), an average grade was calculated for all grain sizes in all

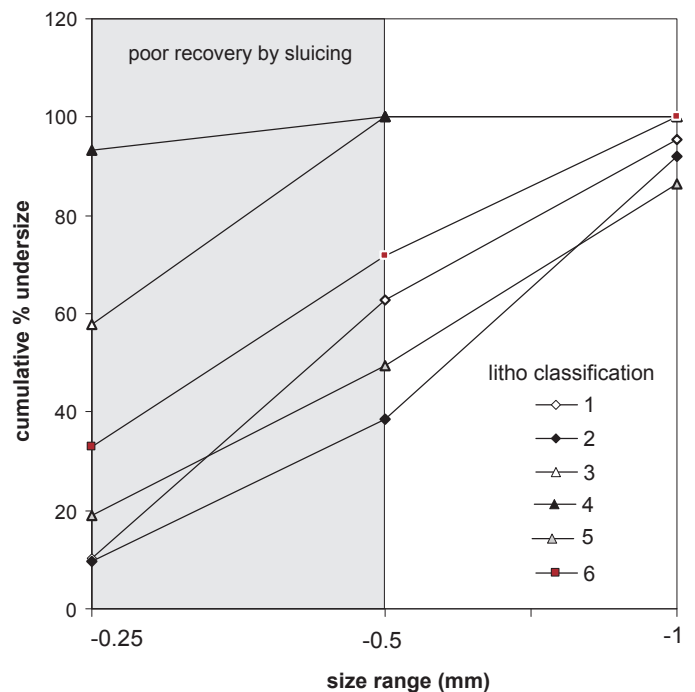


Figure 6. Gold weight by grain size for different lithostratigraphic classifications, cumulative percent.

Table 2. Cumulative percent undersize gold and potentially recoverable gold by lithostratigraphic group in selected samples.

Lithostratigraphic classification	Percentage of gold by weight, averaged over group:		Average grade of total samples in group, mg/m ³	Average grade of gold in:	
	-0.25 mm fraction	+0.25 mm fraction		+0.25 mm fraction, mg/m ³	-0.25 mm fraction (possible loss) mg/m ³
1	10.3	89.7	352	316	36
2	9.7	90.3	733	662	71
3	57.9	42.1	19	8	11
4	93.2	6.8	102	7	95
5	18.9	81.1	314	255	59
6	54.3	45.7	146	67	79

the samples in the group which had compatible weight and grain size ranges (102 mg/m – column 4). The average grade of only the +0.25 mm size in the group was then calculated (6.8% of 102 mg/m³ = 7 mg/m³ – column 5) followed by the average grade of gold in only the -0.25 mm size (102 mg/m³ – 7 mg/m³ = 95 mg/m³ – column 6). The -0.25 mm size range is generally acknowledged to be difficult to recover by conventional gravity concentration (e.g., Fricker 1984), however, an average of 95 mg/m³ of gold were recovered in our samples from lithostratigraphic subdivision 4, which normally would be lost using conventional mining methods.

By the same method, it can be seen that lithostratigraphic classifications 3 and 6 are also low in recoverable gold, with 57.9 and 54.3% of their overall weights (respectively) falling into the -0.25 mm size fraction. Our data therefore show that Indian River placer deposits containing fine gold (*i.e.*, grains smaller than 0.25 mm) may require unconventional processing equipment and metallurgical expertise, which is discussed in the following sections.

IMPLICATIONS FOR GOLD RECOVERY

The study of gold recovery from placer deposits by gravity concentration methods is, in general, under studied. Most authors focus on the implications of sluice design for improving the recovery of 'coarse' gold (e.g., Fricker, 1984), rather than investigating relationships between fine gold size and recovery. An evaluation of the performance of sluice boxes in Yukon is provided by Clarkson (1994), which focused on the recovery of gold larger than 0.2 mm, since gold of finer particle size was not believed to form an important resource. However, the results obtained in this study indicate a high proportion of fine gold in most samples and, consequently, the size

distribution of fine gold could be of great importance when determining appropriate concentration techniques. For example, this might include using 'enhanced G' concentrators such as the Knelson concentrator to effectively recover finer gold particle sizes. 'Enhanced G' is a term used to describe gravity concentrators which effect particle separation in a high gravitational environment resulting from centrifugal action.

Although reliable data is difficult to obtain, there is a general consensus that sluice boxes are not efficient tools for the recovery of fine gold and if set up incorrectly, they are also inefficient across a wide range of grain size fractions. This applies not only to small-scale operations but also to large dredges (Fricker, 1984). The use of spiral concentrators for this study permitted collection of fine gold more efficiently than commercially operated gold recovery circuits (Lunev and Osovetskiy, 1987; Mukhanov, 2007) and therefore provides a better indication of the potential recoverable resource. Although some small studies have investigated the relative performances of traditional gravity concentrators versus the Knelson concentrator (e.g., Apling *et al.*, 1997), overall, there is an absence of comprehensive studies comparing the efficiency of different gravity concentration devices to each other. In addition, dedicated studies of placer gold grain shape are important because of the effect on hindered settling velocity and hence recovery (Chapman and Houseley, 1996; Houseley *et al.*, 1997). This is particularly important in the context of recovery of placer gold where fluvial transport equates to progressive flattening. As placers evolve, the gold becomes more difficult to recover even though there is no change in the mass of the gold particles.

METALLURGICAL CONSIDERATIONS

Figure 6 shows that in the majority of samples, gold less than 0.25 mm in size comprises over 30% of the total concentration, while in a number of the gravel samples, the concentration of gold less than 0.1 mm in size reaches up to 50%. Samples which were taken from glaciofluvial deposits had gold in the <math> < 0.25 < /math> mm size fraction representing 80% of the total concentration.

While few studies have been conducted elsewhere in the world, comprehensive metallurgical studies on placer gold of this size range have been conducted in Russia (Lunev and Osovetskiy, 1987; Mukhanov, 2007; Naumov *et al.*, 1992; Patyk-Kara and Lalerov 1997; and Shilo, 2002).

These studies demonstrated that only a small fraction of placer gold is recovered by conventional sluicing. This approach has important consequences for the design of future recovery plants and the potential for profitable amounts of gold remaining in tailings (lithostratigraphic classification 6), both in the study area and throughout the Klondike.

SUMMARY OF RESULTS AND IMPLICATIONS FOR FUTURE EXPLORATION

A preliminary stratigraphic framework of six lithostratigraphic subdivisions is proposed into which all exposures in the study area are classified. Stratigraphic settings are complex and in some cases landforms are comprised of multiple overlapping lithostratigraphic assemblages. Radiocarbon dating and tephra chronology, relative stratigraphic position, geomorphic expression and preliminary gold geochemical analyses have all been used to refine this preliminary framework.

All stratigraphic subdivisions sampled contained placer gold, however, some are more problematic than others for placer exploration. Notably, since gold-bearing low-level and intermediate-level terraces may exist in areas mapped as colluvium or alluvial fans, alternate methods of exploration should be used to detect these deposits. For example, electrical resistivity followed by drilling or test-pitting would be a logical approach. In addition, detailed surficial geological mapping could identify reaches within the drainage to focus exploration.

Morphological variations in gold along the course of the Indian River strongly suggest progressive influx of material from currently undiscovered bedrock sources. Our data also suggests the possible existence of an undiscovered

bedrock gold source on Indian River downstream of the mouth of Ruby Creek.

Fine gold was shown to occur throughout the different deposits and, in some cases, comprised the majority of the gold in the sample. This gold is currently not recovered by conventional sluicing operations and could represent a considerable resource. Further study of the gold size and distribution within placer mine tailings as well as within fine-grained, low-grade gravel deposits throughout the Indian River and Klondike district would quickly identify the potential of this resource. It is recommended that this evaluation occurs in conjunction with suitable metallurgical test work.

FUTURE WORK

Tools available to further refine the stratigraphic framework include detailed gold geochemical analyses of placer gold (and potential bedrock sources) as well as lithological provenance studies. These are currently in progress and a comprehensive report which synthesizes all new results is due to be released in 2009. Ongoing fieldwork examining the stratigraphy in context with the preliminary lithostratigraphic framework is also planned. This will include additional sampling of potential placer and bedrock gold sources.

Using the methods outlined in this study to assess gold particle-size analysis in both virgin and previously worked areas has potential for identifying easily accessible, large gold resources. This methodology could also be applied advantageously in other Yukon placer districts.

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APPENDIX 1. DISTRIBUTION OF PLACER GOLD WEIGHT BY GRAIN SIZE AND TOTAL PLACER GOLD CONCENTRATION IN SELECTED SAMPLES, GROUPED BY LITHOSTRATIGRAPHIC CLASSIFICATION

Sample numbers	Lithostratigraphic classification	Weight by grain-size classification, mg					Calculated concentration, mg/m ³
		-0.1 mm	0.1 to 0.25 mm	0.25 to 0.50 mm	0.5 to 1.0 mm	+1 mm	
WL06-71	1	0.9		0	0	31.6	
WL06-91	1	0.75		7.05	0	421.6	
WL06-92	1	0.9		1.3	1.35	295.8	
WL06-103	1	0.4		2.2	5.85	384.1	
WL06-104	1	0.25		0	0	11.9	
WL06-105	1	0.3		0	0	11.1	
WL06-106	1	0.35		0.65		66.7	
WL07-120	1	0.07	0.1	0.46	0.46	49.5	
WL07-139	1	0.18	0.68	0.17	0	85.8	
WL07-140	1	0.11	0.42	7.28	3.77	876.7	
WL06-85	2	0.75		1	0	83.3	
WL06-87	2	4.95		15	20.2	2475	
WL06-88	2	3.9		10.05	22.9	2052.5	
WL06-102	2	0.05	0	0	0	2.5	
WL06-108	2	1.65		5	0	369.4	
WL07-138	2	0	0.22	4.79	14.44	1215.6	
WL07-143	2	0.12	0.16	0	0	14	
WL07-144	2	0	0.12	0	0	8.6	
WL07-145	2	0.16		0	0	11.4	
WL06-63	3	0.025	0.025	0	0	1.85	
WL06-66	3	0.55		0.3	0	42.5	
WL06-76	3	0.05		0	0	2.6	
WL06-79	3	0.2		0	0	16.7	
WL06-80	3	0.25		0	0	13.2	
WL06-84	3	0.25		0	0	13.2	
WL07-131	3	0	0.17	0.53	0	46.7	
WL07-132	3	0.07		0	0	5	
WL06-74	4	11.45		0.7	0	450	
WL06-122	4	0.25		0	0	11.9	
WL06-123	4	0.25		0	0	11.1	
WL06-124	4	0.2		0	0	9.5	
WL07-126	4	0.09		0	0	4.3	
WL07-127	4	0.1		0	0	6.3	
WL07-128	4	0	0.2	0.19	0	26	
WL07-129	4	0.2	0.1	0	0	21.4	
WL06-64	5	0.55		2.9	2.3	213	
WL06-65	5	2.7		4.3	2	461.5	
WL06-67	5	0.75		2.05	1.35	138.3	
WL06-72	5	0.55		0	0	30.6	
WL06-73	5	0.25		0	0	15.6	
WL06-75	5	1.85	0.6	0.65	0	110.7	
WL06-77	5	0.6		0.7	0	65	
WL06-78	5	0.05		0	0	2.4	
WL06-89	5	3.9		5.05	9.7	981.6	

Sample numbers	Lithostratigraphic classification	Weight by grain-size classification, mg					Calculated concentration, mg/m ³
		-0.1 mm	0.1 to 0.25 mm	0.25 to 0.50 mm	0.5 to 1.0 mm	+1 mm	
WL06-95	5		1.15	4.3	1.35	0	302.2
WL06-96	5		0.15	0	0	0	6.7
WL06-97	5		0.55	1	0	0	77.5
WL07-121	5	0.31	0.45	0	0	0	54.3
WL07-122	5	0.19	0.18	0	0	0	26.4
WL07-123	5	0.07	0.03	0	0	0	20.6
WL07-124	5	0.28	0.44	0.53	0	0	89.3
WL07-125	5	0	0.13	2.5	12.57	10.64	1845.7
WL07-136	5		2.7		0	0	168.8
WL06-69	6		1.2		0	0	47.1
WL06-70	6		0.2		0	0	11.1
WL06-107	6	0	0.05	0	0	0	2.6
WL06-125	6		0.45	0.3	0.7	0	322.2
WL07-135	6	1	1.51	1.2	0	0	185.5
WL07-137	6	0.17	0.63	0.42	0	0	81.3
WL07-148	6	0.44	0.84	0.28	1.38	0	140
WL06-90	bedrock	0	0.25		0	0	8.3
WL07-119	bedrock	0	0.34	1.69	0.92	0	184.4
WL07-130	bedrock	0	0.08	0.22	0	0	15.8

Initial results from the first year of the Permafrost Outreach Program, Yukon, Canada

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ABSTRACT

In 2007, a permafrost outreach program was initiated in Yukon, Canada by installing long-term permafrost monitoring stations near public schools in Whitehorse, Faro, Ross River, Dawson, Old Crow and Beaver Creek. Shallow boreholes were drilled near participating schools, and data loggers were installed to measure hourly air and ground temperatures at a variety of depths. Frost tubes were also installed in fall 2008 to start monitoring seasonal freezing and thawing trends in the active layer. School students are actively engaged with field data collection and interpretation of results posted on a central website. The program also provides baseline data that can be used to characterize local permafrost conditions and detect long-term changes. A snapshot of current permafrost conditions is provided for each monitoring station, based on the first year of data collection.

RÉSUMÉ

En 2007, un programme de sensibilisation au pergélisol a été lancé au Yukon en établissant des stations de surveillance à long terme du pergélisol près d'écoles publiques à Whitehorse, Faro, Ross River, Dawson, Old Crow et Beaver Creek. Des puits de forage peu profonds ont été creusés près des écoles participantes, et des enregistreurs de données ont été installés pour mesurer la température de l'air à chaque heure ainsi que la température du sol à diverses profondeurs. Des tubes de contrôle du gel ont également été installés à l'automne 2008 afin de commencer à surveiller les tendances saisonnières en matière de gel et de dégel dans la couche active. Le programme donne aux élèves la possibilité de participer à la collecte de données sur le terrain et à l'interprétation des résultats affichés sur un site Web central. De plus, le programme fournit des données de référence qui caractérisent les conditions locales du pergélisol et qui, à long terme, rendront possible la détection de toute variation de ces conditions. Un aperçu des conditions actuelles du pergélisol est fourni pour chaque station de surveillance, en fonction des données recueillies au cours de la première année de collecte.

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INTRODUCTION

The Permafrost Outreach Program (POP) was implemented in Yukon in 2007. Long-term permafrost monitoring equipment was installed in shallow boreholes drilled near six public schools in the communities of Beaver Creek, Whitehorse, Ross River, Faro, Dawson and Old Crow. The program is part of a larger circumpolar network of permafrost monitoring stations that have been set up by the University of Alaska Fairbanks at over 100 schools throughout Alaska, Yukon, Greenland, Mongolia, China, Russia, Norway and Finland.

The project has both scientific and educational components. Scientific data is collected at the monitoring sites to measure permafrost temperature and determine the thickness of the active layer (the layer above the permafrost that thaws during summer and refreezes during winter). The program is generating baseline data that will be useful for detecting long-term changes with respect to these permafrost characteristics, and in the seasonal timing of freezing and thawing within the active layer. Changes in these permafrost characteristics will potentially influence local ecosystems, hydrological regimes, terrain stability (landslides and thermokarst) and infrastructure integrity. Data from the program will also be made available to support academic research that seeks to investigate these relationships.

In addition to expanding our knowledge of the permafrost environment, the primary objective of the program is to engage school students, with the ultimate goal of inspiring a new generation of scientists to pursue similar research. Local students are actively involved in the monitoring program by assisting with equipment installation and data collection. The data are regularly uploaded to a central website (<http://www.uaf.edu/permafrost/>) where students are encouraged to explore a variety of educational resources, as well as data collected at other schools. Ongoing outreach activities are also conducted at participating schools to explain important permafrost concepts and discuss the significance of locally collected data.

The purpose of this paper is to: (1) outline the equipment and methodology used to set up the monitoring stations; (2) describe the site conditions at each station; and (3) provide a snapshot of current permafrost conditions at each station, based on the first year of air and ground temperature measurements.

EQUIPMENT AND METHODOLOGY

In spring and fall 2007, ground temperature sensors were installed in shallow (2-28 m) boreholes that were drilled at schools in Beaver Creek, Whitehorse, Faro, Ross River, Dawson and Old Crow (Table 1). In fall 2008, water-filled tubes (frost tubes) were installed within smaller boreholes that were drilled near schools in Beaver Creek, Whitehorse, Faro, Ross River, Dawson and Carmacks. Further details outlining the drilling and installation methodology and apparatus is described in the remainder of this section.

DRILLING

Ground temperature boreholes measuring 51 mm (2 inches) in diameter were augered using a variety of portable drilling equipment. An electric Bosch hammer drill with a 14A motor was used at all sites with custom-built auger stems (in 1 m lengths) and carbide drill bits (Fig. 1a). A portable (dolly-mounted), gasoline-powered, Minuteman® drill (Foremost Mobile) with a hollow stem auger attached to a water swivel was also used to perform water-jet drilling at the Robert Service School site in Dawson (Fig. 1b). At a second, forested site near Dawson, a simple percussion drill was used to drive a shaft (18 mm in diameter) into the ground by manually dropping a 30 lb weight onto it repeatedly (Fig. 1c). Smaller boreholes measuring 25 mm (1 inch) in diameter were also drilled at each site with the electric hammer drill; these smaller boreholes were used for installing either frost tubes or air temperature monitoring apparatus.

The portability of these drilling systems makes them a very cost-effective tool for performing shallow drilling in vehicle-accessible locations. However, these drilling systems cannot effectively penetrate soil containing any coarse fragments, therefore all sites were drilled in fine-grained sediments. It is also difficult to precisely log sediment characteristics such as texture and ice-content because the auger disturbs and mixes the sediment as it is brought to the surface. Despite these limitations, an experienced driller can still determine relative ice-content and general soil texture based on the speed and ease of drilling progress. For these reasons, the stratigraphic descriptions provided in the following section are considered to be approximate, with the exception of the Beaver Creek and Ross River sites, where geotechnical drilling and detailed logging was performed by professional engineering contractors.

Table 1. Summary of key parameters that characterize permafrost conditions, based on a year of data collected between 2007 and 2008.

Municipality	Beaver Creek	Whitehorse	Ross River	Faro	Dawson	Old Crow	Carmacks
School	Nelna Bessie John School	Golden Horn Elementary	Ross River School	Del Van Gorder School	Robert Service School	Chief Zzeh Gittlit School	Tantalus School
GROUND TEMPERATURE BOREHOLES					school site/ natural forest site		
latitude	62°20'16"N	60°35'35"N	61°58'46.5"N	62°13'24.5"N	64°03'40.0"N/ 64°01'54.7"N	67°34'34.8"N	N/A
longitude	140°50'9"W	134°54'18"W	132°27'9.5"W	133°20'31.3"W	139°25'49.1"W/ 139°17'41.1" W	139°49'33.8"W	N/A
elevation (m)	700	712	659	720	320/344	255	N/A
disturbed site?	no	no	yes	no	yes/no	no	
borehole depth (m)	5.8	5.0	27.7	3.9	3.4/2.0	3.15	N/A
depth of lowest temperature sensor (m)	5.0	5.0	13.0	3.9	3.4/2.0	3.0	N/A
data logger installation date	May 2, 2007	May 7, 2007	Jun. 13, 2007	May 8, 2007	Oct. 1, 2007/ Nov. 16, 2008	Oct. 2, 2007	none installed
THERMAL REGIME					(for school site only)		
active layer thickness (m) - D_{AL}	1.0	2.0	9.5	2.4	2.0	<2.0	N/A
depth of zero annual amplitude (m) - D_0	>5.0	2.0	13.0	>4.0	>3.4	>3.0	N/A
measured mean annual air temperature (°C) - T_A	-4.1	-2.2		-3.1	-3.1	N/A	N/A
mean annual ground temperature (°C)							N/A
at ground surface - T_S	-1.7	-1.0	1.0	0.5	2.7		
at top of permafrost - T_{PT}	-3.6	-0.2	-0.1	-0.9	-0.2	<-3.4	
at 3m depth - T_{3m}	-3.3	-0.1	0.9	-0.8	-0.3	-3.3	
at depth of zero annual amplitude - T_0	>-3.1	-0.2	-0.3	<-0.8	<-0.5	>-3.3	
surface offset ($T_A - T_S$)(°C)	-2.4	-1.2		-3.6	-5.8	N/A	N/A
thermal offset ($T_S - T_{PT}$)(°C)	1.9	-0.8	1.1	1.4	2.9	N/A	N/A
FROST TUBES							
latitude	N/A	60°36'22.4"N	61°58'46.5"N	62°13'36.2"N	64°03'40.0"N	N/A	62°05'19.1"N
longitude	N/A	134°52'16.9"W	132°27'9.5"W	133°21'01.4"W	139°25'49.1"W	N/A	136°17'30.0"W
elevation (m)	N/A	741	659	712	320	N/A	537
depth (m)	N/A	2.3	2.0	2.1	1.0	N/A	1.8
installation date	none installed	Nov. 19, 2008	Nov. 18, 2008	Nov. 18, 2008	Nov. 16, 2008	none installed	Nov. 16, 2008

**Figure 1.** Portable apparatus used for drilling shallow boreholes: (a) electric hammer drill; (b) gasoline-powered Minuteman water jet drill; and (c) manual percussion drill.

GROUND AND AIR TEMPERATURE DATA LOGGERS

The ground temperature boreholes were cased with a PVC pipe which measured 25 mm (1 inch) in diameter. This pipe was capped and sealed on the bottom end and it extended approximately 50 cm above ground. Up to seven soil temperature sensor cables (“Onset” brand TMCx-HD series thermistor probes) were positioned inside the borehole casing, starting at the ground surface and extending down in 50 cm or 100 cm increments. These temperature sensors have a reported accuracy of ± 0.25 °C at 0°C, without calibration.

To monitor air temperature, a shallow (~50 cm) hole 25 mm (1 inch) in diameter was also drilled into the ground approximately 1 m from each ground temperature borehole. A piece of thin PVC tube (3/4 inch or 19 mm in diameter) was inserted into this hole and positioned to extend 1 m above the ground surface. An additional

temperature sensor cable was inserted through this tube, and mounted at a height of 1 m above the ground surface. The air temperature sensor was shielded beneath a 4 inch (10.2 cm) PVC cap mounted at the top of the tube (Fig. 2a).

The air and ground temperature sensors were connected to Onset HOBO® U12 data loggers (model number U12-006) with 12-bit resolution and four external channels. The loggers were housed inside a piece of capped 4 inch (10.2 cm) PVC pipe placed above the main borehole (Fig. 2b). The data loggers were set to collect hourly data from each sensor, which allowed them to run continuously for up to 450 days without requiring downloading.

FROST TUBES

Frost tubes (Fig. 3) were constructed by filling a length of 6-8 mm (1/4 - 5/16 inch) clear flexible plastic tube with

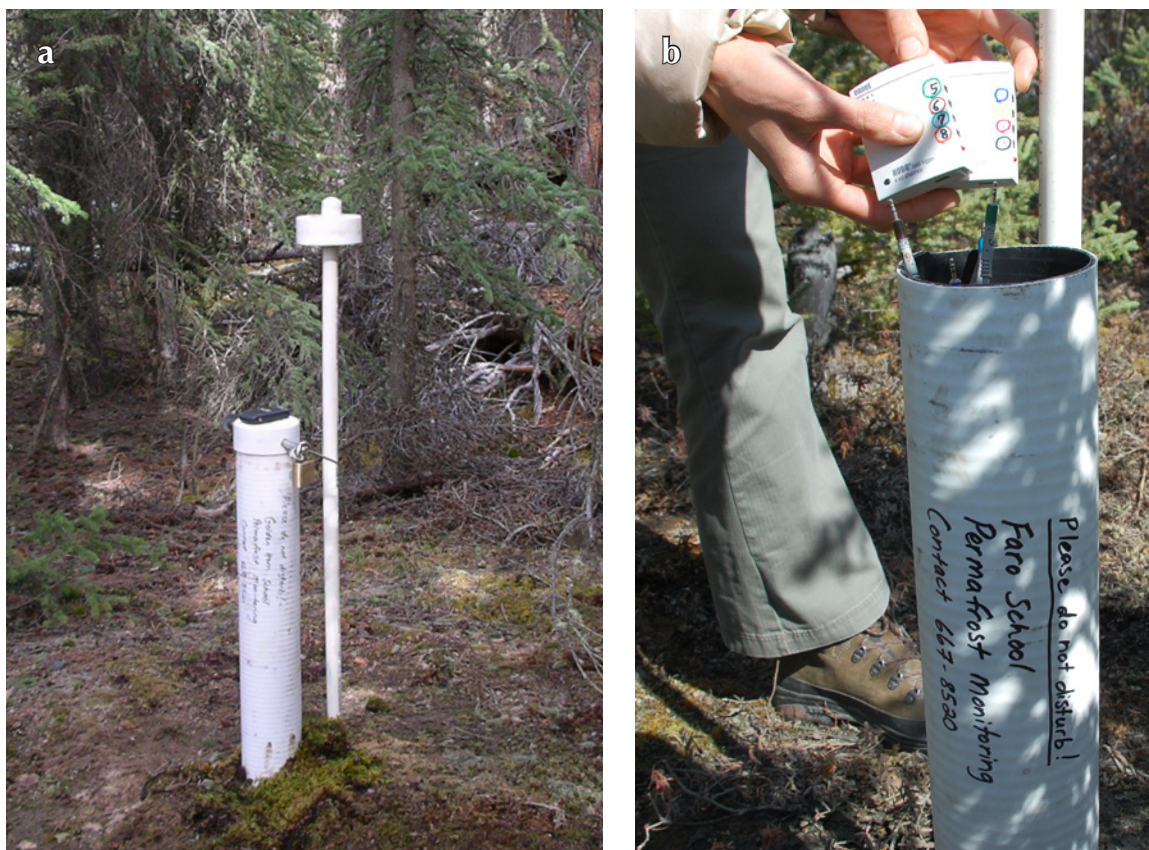


Figure 2. Typical permafrost monitoring station apparatus and configuration. (a) The larger PVC pipe houses the ground temperature sensors and data loggers. The thinner PVC pipe houses an air temperature sensor mounted at 1 m above the ground surface. (b) Four-channel Onset data loggers store hourly temperature measurements for up to 15 months.

water. The water was tinted with a small amount of food colouring to make the boundary between frozen and unfrozen liquid in the tube more distinct. The ends of the tube were sealed shut by melting them with a blow torch.

A shallow borehole, 25 mm (1 inch) in diameter, was drilled up to approximately 2 m depth, depending on site conditions. The borehole was cased with 12 mm (1/2 inch; inside diameter) PVC pipe which was open on the bottom end. This casing pipe served primarily to protect the inner tubes from physical damage and frost heaving. The casing extended above ground approximately 1 m so that the top would still be accessible under peak snow accumulation conditions. An inner casing of flexible plastic tubing (10-12 mm or 1/2 - 3/8 inch outside



Figure 3. Typical frost tube apparatus. At weekly intervals, students briefly remove the clear tube from the white PVC casing. The depth of freezing in the active layer is indicated by the lowest depth of frozen water in the clear tube.

diameter) sealed on the bottom end with epoxy putty, was inserted into the PVC casing to prevent convection, as well as house the actual frost tube. Once the frost tube was inserted securely inside the inner casing pipe, the entire installation was closed with a 12 mm (1/2 inch) PVC cap.

Graduations were marked on the tube every 5 cm below the ground surface level. This allows the depth of ground freezing to be read directly from the tube when it is briefly pulled out of the inner casing. This activity is currently performed on a weekly basis by local school students and teachers, who regularly report their measurements to Yukon Geological Survey by email. A graph depicting the progression of ground freezing and thawing in each community is continually updated on the POP's central website as new data is reported (<http://spreadsheets.google.com/pub?key=pM4dgm3fEG1Fls33iUMLjDA&oid=10&output=image>).

SITE DESCRIPTIONS

BEAVER CREEK

The Beaver Creek Permafrost Outreach Program monitoring station is located in a muskeg plain adjacent to the Alaska Highway at kilometre-post 1928.5 (Table 1). The site is approximately 5 km south of Beaver Creek and 40 m west of the Alaska Highway embankment margin. The station is located in a cluster of black spruce trees where the ground surface is slightly raised above the level of the surrounding plain. The vegetation immediately surrounding the station consists of undisturbed muskeg with scattered clusters of black spruce trees that form an unusual and distinctive polka-dot pattern when viewed on aerial photographs. The microtopography surrounding the clusters of black spruce trees is heavily tussocked.

A ground temperature borehole was drilled to 5.8 m depth using a portable electric Bosch drill on May 2, 2007 (Table 1). The ground surface at the borehole location was covered by 10-15 cm of moss, and the entire borehole was drilled through silty materials assumed to be of eolian origin, with some clay-rich layers. A thin, extremely ice-rich layer, assumed to represent the bottom of the active layer, was encountered at a depth of 1.2 m. Between 1.2 and 3 m depth, very ice-rich silt was encountered; clay-rich silt with low ice content was encountered from 3 to 3.5 m depth; and very ice-rich silt was encountered below 3.5 m depth. Ground temperature sensors within the borehole were positioned

at 0, 0.5, 1, 2, 3, 4 and 5 m depths, and an air temperature sensor was placed at 1 m above the ground surface.

The highway was constructed at this location in the early 1990s and the road embankment was built up to approximately 6 m above the level of the surrounding muskeg. Local permafrost degradation beneath, and immediately adjacent to, the highway has caused ongoing settlement and longitudinal cracking of the road surface at this location. Geotechnical boreholes were drilled approximately 70 m east and southeast of the POP borehole in 1991 (Yukon Highways and Public Works (YHPW), unpublished data). Massive ice was encountered in these boreholes between 2.7 m and 3.5 m below the surface in YHPW borehole number 157-190, and between 3.6 m and 4.6 m below the surface in YHPW borehole number 157-191. Additional geotechnical drilling completed adjacent to the highway in 1997 (approximately 20 m east of the POP borehole) revealed 5.5 m of massive ice with <5% silt inclusions between 1.8 m and 7.3 m below the ground surface (Paine and Associates, 1997).

Yukon Highways and Public Works has been monitoring ground temperatures at this location down to a depth of 8-10 m since 1997. Thermistor strings were installed by YHPW beneath the highway centre line, in the stabilization berm, and adjacent to the highway in undisturbed ground (approximately 20 m from the edge of the highway embankment).

Using this data, the thermal regime of the area was analyzed in detail by Dore (2005). He reported that ground temperatures were rising beneath the highway centre line and berm as a result of highway construction, despite local cooling climatic trends in the area between 1997 and 2003. Dore also determined that warming was greater beneath the berm than beneath the centre line, which appears to induce thawing of the underlying ice-rich ground. This may also explain why longitudinal cracks continue to develop in the road surface at this location each year.

Unpublished data from the YHPW thermistor strings between March 2006 and March 2007 reveal that the active layer was 1 m thick at the natural control site, located 20 m east of the POP borehole. They also show that ground temperatures at 8 m depth at that location fluctuate between -1.9°C and -2.7°C, with a mean annual ground temperature of -2.2 °C.

Other recent permafrost research at this site includes a satellite monitoring pilot study which attempted to use RadarSat interferometry to detect subtle ground displacement of the road and adjacent ground surface resulting from permafrost thaw during the summer of 2006 (C-CORE, 2007).

WHITEHORSE

On May 7, 2007, a ground temperature borehole was drilled in Cowley Creek Subdivision, 2.2 km southwest of Golden Horn Elementary School. The borehole was drilled to 5 m depth approximately 40 m east of Cowley Creek and about 40 m southeast of Salmon Trail (Table 1). The site is located in a mature white spruce forest with feather moss ground cover and slightly mounded microtopography. Numerous 'drunken' trees are leaning in random directions along both sides of the creek at this site, indicating the presence of degrading ice-rich permafrost in the local area.

The surface organic layer is 10 cm thick, and this is underlain by approximately 4 m of dark grey frozen silt and fine sand containing wood fragments and organics and no visible ice. A layer of ice-rich, light grey clay was encountered between 4 and 5 m depth. Ground temperature sensors within the borehole were positioned at 0, 0.5, 1, 2, 3, 4 and 4.95 m depths, and an air temperature sensor was situated 1 m above the ground surface.

A frost tube was also installed near Golden Horn Elementary School on November 19, 2008. The frost tube is located approximately 100 m north of the school (Table 1). The site is located adjacent to a mature white spruce forest, amidst willow shrubs that fringe a grassy meadow and shallow pond. Between November 26 and December 17, 2008, the frost tube indicated that the depth of freezing progressed from 30.5 to 40 cm below the ground surface.

FARO

On May 8, 2007, a ground temperature borehole was drilled to 3.9 m depth approximately 600 m southeast of Del Van Gorder School in Faro (Table 1). This site is of particular interest because permafrost degradation has caused settlement problems beneath the school gymnasium in the past.

The borehole site is located 50 m southeast of a small track that cuts between Douglas Drive and Blind Creek

Road. The site is located in a young white spruce forest with scattered birch, thick moss and Labrador tea shrubs. Old slash piles from past logging activities are found nearby, and a peat excavation pit is located approximately 200 m northwest of the site.

Soil stratigraphy at the site is composed of 10 cm of moss, underlain by 10 cm of ash, which is in turn underlain by fine sand and silt with occasional stones to a depth of 3.5 m. Higher clay contents were encountered in the sandy silt layer at 3.5 m depth, and the borehole terminated in a gravelly layer at 3.8 m depth. Ground temperature sensors within the borehole were positioned at 0, 0.5, 1, 2, 3 and 3.9 m depths within the borehole, and an air temperature sensor was placed at 1 m above the ground surface.

On November 18, 2008, a frost tube borehole was drilled to 2.1 m depth in a forested area just behind the Del Van Gorder School. The site is approximately 25 m east of the northeastern corner of the swimming pool building (Table 1). A frost tube was installed within this borehole, and weekly measurements will be made over the upcoming winter and spring by local students.

ROSS RIVER

On June 13, 2007, a deep ground temperature borehole was drilled at Ross River School to a depth of 27.7 m. The borehole was drilled by EBA Engineering Consultants using a CME75 hollow stem auger rig. The site is located inside the school yard approximately 15 m west of the school gymnasium doors (Table 1).

This site is of particular interest because permafrost degradation resulting from site disturbance has caused differential ground displacement beneath Ross River School since it was constructed in 2000. Consequently, substantial cracks continue to develop in the foundation, walls and floors of the building, despite the fact that thermosiphons have been installed around the perimeter of the school to promote ground cooling.

A simplified log of the borehole (#W14101031-BH01) is as follows: unfrozen sand from 0-4 m depth; unfrozen gravel from 4-6 m depth; silt and clay from 6-20 m depth (frozen and ice-rich below 7 m, and ice lenses up to 20 cm thick); frozen sand and clay from 20-24.5 m depth; and unfrozen, wet silt and clay with a high pore pressure below 24.5 m (EBA Engineering Consultants, 2007, unpublished data). The site has been cleared of natural organic cover and is covered with patchy grass and partly exposed mineral soil.

The borehole was lined with a steel casing, which was heaved 50 cm upward immediately following installation due to the high pore water pressures in the unfrozen silt and clay at depth. A precision thermistor string was installed in the borehole casing by EBA Engineering Consultants for engineering purposes. A 25 mm (1-inch) PVC pipe was also inserted into the casing and POP ground temperature sensors were placed within the pipe at 0.5, 1.5, 2.5, 3.5, 4.5, 9.5 and 13 m below the ground surface.

A frost tube was also installed to 200 cm depth at the same site on November 18, 2008. Between November 21 and December 9, 2008, the frost tube indicated that the depth of freezing progressed from 87 to 143 cm below the ground surface.

DAWSON

A ground temperature borehole was drilled to 3.4 m depth at Robert Service School on October 1, 2007. The borehole is located just outside the school about 5 m south of Queen Street and mid-way between 4th and 5th avenues (Table 1). Ground temperature sensors within the borehole were positioned at 0, 0.5, 1, 2, 3 and 3.4 m depths, and an air temperature sensor was placed at 1 m above the ground surface.

The soil stratigraphy in the borehole includes: topsoil and bark mulch from 0-0.3 m depth; gravel fill from 0.3-0.7 m depth; and organic-rich silt from 0.7-3.4 m depth. The drill could not penetrate below 3.4 m depth due to the presence of gravel. Previous studies have noted near-surface segregated ice lenses in trenches dug along 4th and 5th avenues (EBA Engineering Consultants, 1977, 1983).

On November 16, 2008, a frost tube was installed to 100 cm depth adjacent to the ground temperature monitoring station. Between November 18 and December 2, 2008, the frost tube indicated that the depth of freezing progressed from 27 to 34 cm below the ground surface.

Because the Dawson School permafrost monitoring station is located in an 'unnatural' setting immediately adjacent to the school, on November 16, 2008, an additional 'natural' station was installed at an undisturbed forested site. This station is located about 500 m south of the Klondike Highway and 6 km east of the Klondike River bridge. The station is located approximately 600 m along, and 25 m north of, the road leading to the municipal dump from the Klondike Highway (Table 1).

The local vegetation at the forested site consists of black spruce, tussocks, Labrador tea and blueberry. Soil stratigraphy includes 70 cm of peat overlying fine sand and silt which extends down to 2 m depth. Gravel was encountered below 2 m depth, forcing the borehole to be terminated. A distinct ice-rich layer was also noted at 1.5 m depth, which likely represents the bottom of the active layer. Ground temperature sensors within the borehole were positioned at 0, 0.5, 1 and 2 m depth.

OLD CROW

On October 2, 2007, a ground temperature borehole was drilled to 3.15 m depth near the Chief Zzeh Gittlit School. The site is located in a muskeg plain across the road from the school entrance, about 10 m north of the road (Table 1). Surrounding vegetation includes Labrador tea, blueberry, alder, willow and scattered black spruce trees 2-3 m tall. Ground temperature sensors were positioned at 0, 0.5, 1, 2 and 3 m depths within the borehole and an air temperature sensor was placed at 1 m above the ground surface.

Surficial materials encountered in the borehole include: 15 cm of moss at the ground surface, underlain by 2 m of organic-rich dark brown silt. Dark brown clay was encountered between 2 and 3.15 m depth, at which point the auger stem broke and the borehole was terminated.

The site was vandalized on July 14, 2008 and the site has not been resurrected since then. All data from the site were lost with the exception of data collected at 2 and 3 m depths (Fig. 4f) up to July 14.

CARMACKS

Because permafrost has not been documented in the area immediately surrounding the community of Carmacks, no ground temperature sensors were installed there. However, a frost tube was installed to 1.8 m depth near Tantalus School on November 16, 2008. The site (Table 1) is located near Prospector Road in a stand of aspen trees behind the baseball diamond. Soil stratigraphy in the frost tube borehole consists of fine sandy and silty alluvial sediment from 0-1.8 m depth, underlain by gravelly materials which prevented further drilling. Between November 19 and December 10, 2008, the frost tube indicated that the depth of freezing progressed from 25 to 35 cm below the ground surface.

PRELIMINARY RESULTS

Results from the first year of ground temperature monitoring are presented in Table 1 and Figure 4. A variety of key parameters that are commonly used to describe permafrost conditions are highlighted for each site. All parameters were calculated as a mean of hourly data collected over a period of one year. These data are summarized below.

Mean annual air temperature (T_A) ranged between -4.1°C in Beaver Creek and -2.2°C in Whitehorse. While the mean annual air temperature in Old Crow could not be calculated for the borehole site due to missing data, Environment Canada estimated the mean annual air temperature to be -3.4°C in 2004.

Mean annual ground surface temperature (T_S) varied between -1.7°C in Beaver Creek and 2.7°C in Dawson. The high mean annual ground surface temperature in Dawson is likely related to the fact that the ground cover at the borehole site consists of dark-coloured bark mulch.

Active layer thicknesses (D_{AL}) were interpolated from the ground temperature envelope curves (Fig. 4). At sites with natural organic cover, active layer thickness varied between 1.0 m in Beaver Creek to 2.4 m in Faro. Active layer thickness extended up to 9.5 m in Ross River, where no natural organic ground cover was present due to site disturbance.

Mean annual ground temperatures at the permafrost table (T_{PT}), that is at the top of permafrost, were -0.2°C in Whitehorse and Dawson, -0.1°C in Ross River, -0.9°C in Faro and -3.6°C in Beaver Creek (Fig. 4).

Mean annual ground temperatures at 3 m depth (T_{3m}) were -3.3°C in Beaver Creek, -0.1°C in Whitehorse, -0.8°C in Faro, -0.3°C in Dawson and 0.9°C in Ross River (Fig. 4). The anomalously warm permafrost temperature in Whitehorse is typical of marginal permafrost temperatures in the sporadic discontinuous permafrost zone.

Depth of zero annual amplitude (D_0), where seasonal temperature variation is $<0.1^\circ\text{C}$, was only intersected by the boreholes in two locations: D_0 occurred at 2.0 m in Whitehorse (Fig. 4b) and 13 m in Ross River (Fig. 4d). Mean annual ground temperature at the depth of zero annual amplitude (T_0) was -0.2°C at the Whitehorse site and -0.3°C at the Ross River site (Figs. 4b and 4d, respectively).

Frost tube data collected to date indicate that by early to mid-December 2008, seasonal frost depths ranged from

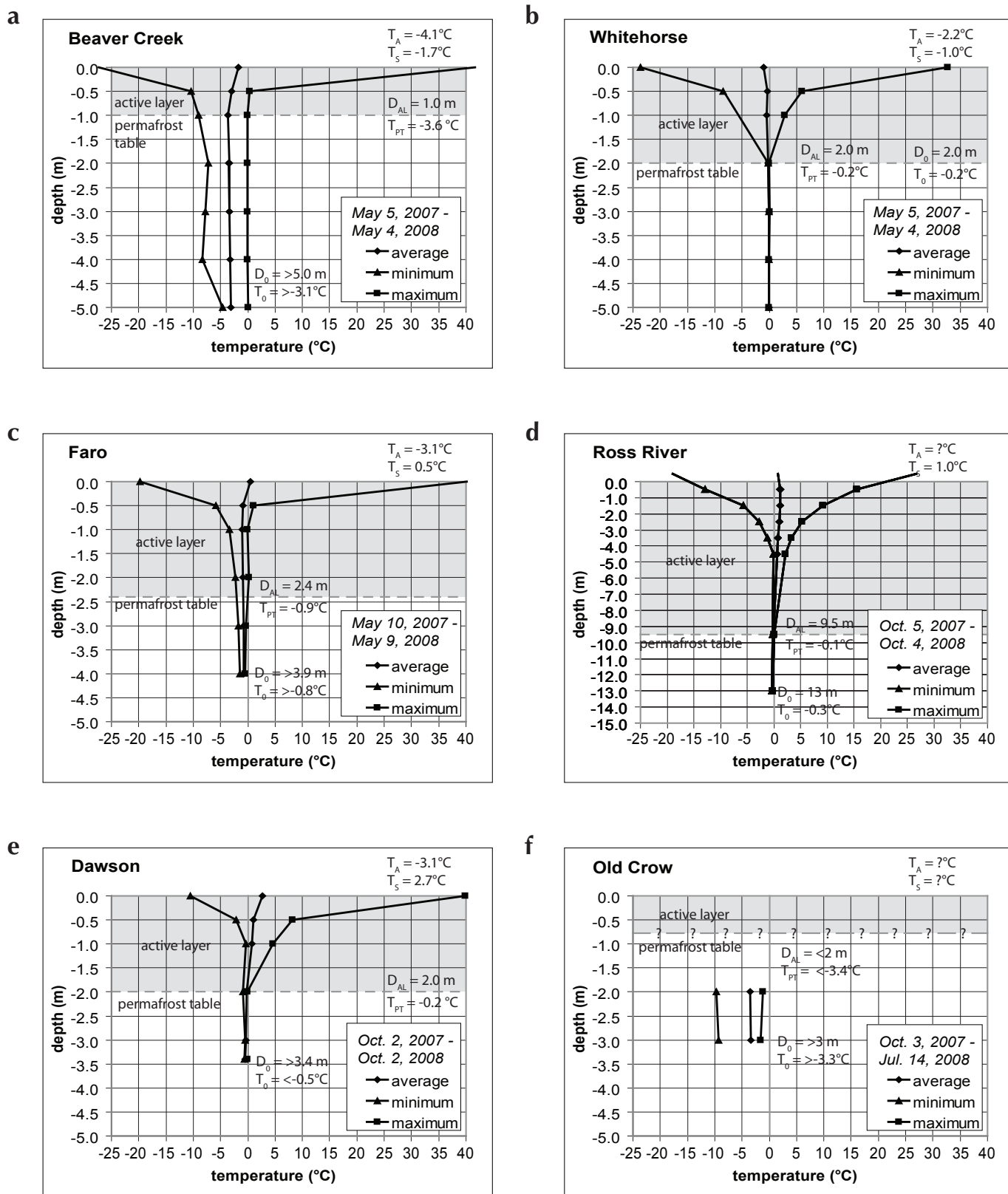


Figure 4. Ground temperature envelope curves summarize the first year of data collected at each of the six permafrost monitoring stations established near schools in 2007.

33.5 to 40 cm at the Carmacks, Dawson and Whitehorse sites. However, where no surface organic material exists and dry coarse-grained material is found near the surface, the depth of frost penetration is much higher. This condition was observed at the Ross River School site, where seasonal freezing extended down to 143 cm depth by early December 2008. More detailed seasonal freezing patterns within the active layer will be determined in winter 2009 after a year of data has been collected.

DISCUSSION

The data show that mean annual ground temperatures in permafrost at all monitoring sites are very warm ($>-1^{\circ}\text{C}$), with the exception of the Beaver Creek and Old Crow sites, where it is $>-4^{\circ}\text{C}$. It is also interesting to note that at all sites, except Old Crow, the maximum annual permafrost temperatures are at, or very close to, the thawing point (Fig. 4) which suggests the presence of degrading ice-rich permafrost. Conductive heat penetrating into the ground during these periods provides latent heat energy (which is used to thaw ground ice rather than raise the ground temperature). Recent surface disturbance near several of the POP sites has caused permafrost degradation which has produced serious consequences for nearby infrastructure. This is illustrated by ongoing subsidence problems on the Alaska Highway near Beaver Creek, and beneath the schools in Faro and Ross River.

It is important to note that due to the variation in site conditions at each borehole, significant comparisons of permafrost conditions between sites can not be made. In addition, the strong influence and variability of slope, aspect, ground cover, surficial materials and soil moisture make it difficult to extrapolate the reported permafrost conditions beyond the immediate vicinity of each borehole. The first year of data will, however, be very useful in the future for evaluating and detecting any changes in local permafrost conditions.

Public school students assisted with the installation of the air and ground temperature sensor strings and data loggers, and annual downloading of the data loggers. The data from each monitoring site were used to construct ground temperature profiles and time series graphs to illustrate temperature variations with depth at the site throughout the year. These figures were useful for demonstrating several important concepts to students, including: the thickness of the active layer, permafrost

temperature, ground temperature variations with depth on any given day, seasonal air temperature variations, and seasonal ground temperature variations at any given depth.

These temperature variation patterns have important implications for infrastructure design and maintenance, and slope stability in permafrost terrain. Permafrost plays a strong role in slope stability in south and central Yukon with respect to its influence on soil moisture (Huscroft *et al.*, 2004; Lipovsky *et al.*, 2006, 2008; Lipovsky and Huscroft, 2007; Lyle, 2006). Any changes in active layer thickness or thawing of ice-rich permafrost on slopes would therefore directly influence landslide susceptibility.

The frost tubes are a simple apparatus students of all ages can use to monitor seasonal freezing variations within the local active layer. Seasonal frost depth depends on near-surface ground conditions such as snow depth, surface organic layer character, soil texture, soil moisture content and antecedent air temperature. Compilation and analysis of circumpolar frost tube data will allow students and scientists to better understand both local and global seasonal freezing patterns.

It is important to monitor changes in frost depth, timing of freezing and thawing, and the total length of the freezing period, since these factors can potentially affect buried municipal infrastructure, building construction timelines, terrain stability and plant growth. The frost tube data will also be useful for testing and running computer models of soil and ecosystem dynamics. For example, the frost tube data can be incorporated into hydrologic computer models used for flood forecasting by regional weather service providers.

The relationships between permafrost, climate and the physical environment are complex and vary spatially and temporally. Northern climatic systems and physical environments also have a particularly important influence on global climate. Monitoring the thermal state of permafrost by measuring ground temperatures in a wide network of boreholes is one method that can be used to understand global climatic trends. Recent reports on climate change highlight the need for establishing and maintaining long-term observation networks to support this work (ACIA, 2004, 2005). The Permafrost Outreach Program is a simple and effective method of developing a sustainable scientific infrastructure to support both local and global-scale permafrost and climate change research in the future.

SUMMARY

The Permafrost Outreach Program (POP) was implemented in 2007 to engage local school students in local permafrost research, and to begin collecting long-term baseline permafrost data around the territory. The program provides opportunities for elementary and high school students to participate with field research, and in doing so, allows them the opportunity to learn about the complex relationships between permafrost, the active layer, global climate, and the physical environment.

Shallow boreholes were drilled in 2007 and 2008 near six Yukon schools. The boreholes were drilled up to 6 m depth, primarily using an electric hammer drill, which is a very cost-effective tool for shallow drilling in fine-grained soils. At each site, frost tubes, temperature sensors and data loggers were installed to monitor permafrost temperatures, air temperatures and seasonal freezing patterns in the active layer.

Data collected for POP in 2007 and 2008 provide a snapshot of current permafrost conditions which will be useful for detecting and characterizing future changes in permafrost conditions. These data will be a valuable resource for both local and global scientific research efforts, and will also have important implications for a variety of land use activities in the territory, including infrastructure design and maintenance.

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A summary of Rock-Eval data for the Bonnet Plume Basin, Yukon: Implications for a previously unrecognized oil play

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ABSTRACT

Previous studies based on regional geology, sediment type and stratigraphic thickness, concluded that the Bonnet Plume Basin in northeastern Yukon has gas potential, but insignificant oil potential. However, these studies were not based on samples collected from within the basin. For this study, in total, 226 rock samples collected from outcrop and drill core throughout the Bonnet Plume Basin were analyzed by Rock-Eval 6 programmed pyrolysis and combustion to assess the petroleum source-rock potential of the strata. The results indicate that the Road River Formation (Cambrian to Devonian) has no source rock potential, but the Bonnet Plume Formation (Cretaceous to Tertiary) has gas and perhaps oil potential. Potential oil generation in the Bonnet Plume Formation is attributed to the occurrence of liptinite-bearing coal and previously unrecognized, siliceous, oil shale. A hydrocarbon-rich tar associated with a naturally burning coal seam was also discovered in the Bonnet Plume Formation.

RÉSUMÉ

Des études antérieures fondées sur la géologie régionale, le type de sédiment et l'épaisseur des couches stratigraphiques ont conclu que le bassin de Bonnet Plume dans le nord est du Yukon a un potentiel gazier, mais un potentiel pétrolier négligeable. Ces études n'étaient toutefois pas fondées sur des échantillons prélevés à l'intérieur du bassin. Nous avons analysé 226 échantillons de roche prélevés dans des affleurements ou des carottes de forage dans l'ensemble du bassin de Bonnet Plume à l'aide d'une pyrolyse et d'une combustion Rock-Eval 6 programmées dans le but d'évaluer le potentiel pétrolier de la roche mère de ces strates. Les résultats indiquent que la Formation de Road River (Cambrien-Dévonien) n'a aucun potentiel comme roche mère, mais que la Formation de Bonnet Plume (Crétacé-Tertiaire) a un potentiel gazier et possiblement pétrolier. La production de pétrole potentielle dans la Formation de Bonnet Plume est attribuée à la présence de charbon contenant de la liptinite et d'un shale bitumineux siliceux auparavant inconnu. Un goudron riche en hydrocarbures associé à un filon de charbon à combustion naturelle a également été découvert dans la Formation de Bonnet Plume.

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INTRODUCTION

The Bonnet Plume Basin is one of eight oil and gas basins identified in Yukon (Fig. 1). As a 'frontier' basin, no oil or gas wells have been drilled and no seismic surveys have been attempted, although an east-west gravity profile was completed across the basin in the late 1970s (Sobczak and Long, 1980). The Bonnet Plume Basin has long been recognized for the occurrence of thick lignite coal seams (*i.e.*, up to 17 m, Cameron and Beaton, 2000), including one that is naturally burning (de Sainville, 1898). In addition, Paleozoic strata are thought to be petroliferous, with 'tar' described as oozing from outcrops in several places (Camsell, 1906). Extensive coal exploration, including detailed geologic mapping, trenching and drilling, was undertaken in the late 1970s to early 1980s, resulting in the discovery of the largest coal resource in the Yukon: an estimated 2800 megatonnes (Cameron and Beaton, 2000). Link *et al.* (1989) reported total organic carbon (TOC) values up to 9.6% (*i.e.*, an excellent petroleum source rock) and Type I kerogen (*i.e.*, oil-prone) and Type II kerogen (*i.e.*, oil- and gas-prone) in Paleozoic strata from wells north of the basin. However, based on regional geology, sediment type and stratigraphic thickness, Hannigan (2000) concluded that the Bonnet Plume Basin has gas potential, but insignificant oil

potential. Specifically, lower Paleozoic clastic and carbonate strata are thought to be potential source rocks, as are Cretaceous clastic strata (Hannigan, 2000). The median estimate for the total gas potential in the Bonnet Plume Basin is 896 Bcf of in-place gas, and the extensive coal deposits indicate that it has significant coalbed methane potential as well (Hannigan, 2000). Nevertheless, Hannigan's (2000) report was not based on samples collected from within the basin. The present study reports the results from Rock-Eval 6 analyses of outcrop and drill core samples collected throughout the Bonnet Plume Basin in order to assess the petroleum source-rock potential of the strata.

GEOLOGIC SETTING

The Bonnet Plume Basin (Fig. 2) is a physiographic and structural depression near the eastern margin of the Frontal Belt of the Cordilleran Orogen in northeastern Yukon (Norris and Hopkins, 1977; Hannigan, 2000). It formed in early Late Cretaceous time by down-dropping Paleozoic strata along regional faults, and contains up to 7500 m of clastic and carbonate sediments ranging from Precambrian to Tertiary in age (Mountjoy, 1967; Norris and Hopkins, 1977; Hannigan, 2000). The oldest strata are Precambrian metasedimentary rocks of the Wernecke Supergroup. This is overlain unconformably by a thick Paleozoic succession of marine limestone and mudstone, including Illtyd, Slats Creek, Taiga, Rabbit Kettle, Bouvette, Canol, Imperial and Road River formations (Norris and Hopkins, 1977; Hannigan, 2000). The Bonnet Plume Formation unconformably overlies the Paleozoic sedimentary rocks, and is informally subdivided into the lower Bonnet Plume Formation and the upper Bonnet Plume Formation (Mountjoy, 1967). The lower Bonnet Plume Formation (Middle to Late Albian) is up to 1500 m thick, and consists of interbedded conglomerate, sandstone, mudstone and bituminous coal deposited in a marginal marine to fluvial environment (Rouse and Srivastava, 1972; Norris and Hopkins, 1977; Long, 1978; Nichols and Sweet., 1993). The upper Bonnet Plume Formation (Maastrichtian to Paleocene) is up to 400 m thick, and consists of fluvial sandstone, mudstone and lignite (Rouse and Srivastava, 1972; Norris and Hopkins, 1977; Long, 1978; Nichols and Sweet 1993). Long (1986) suggested that lower Bonnet Plume coals were deposited in fan-marginal and lowland-moor settings, whereas upper Bonnet Plume Formation coals were deposited in a lowland-moor environment. Only the Road River Formation (Cambrian to Devonian) and Bonnet Plume

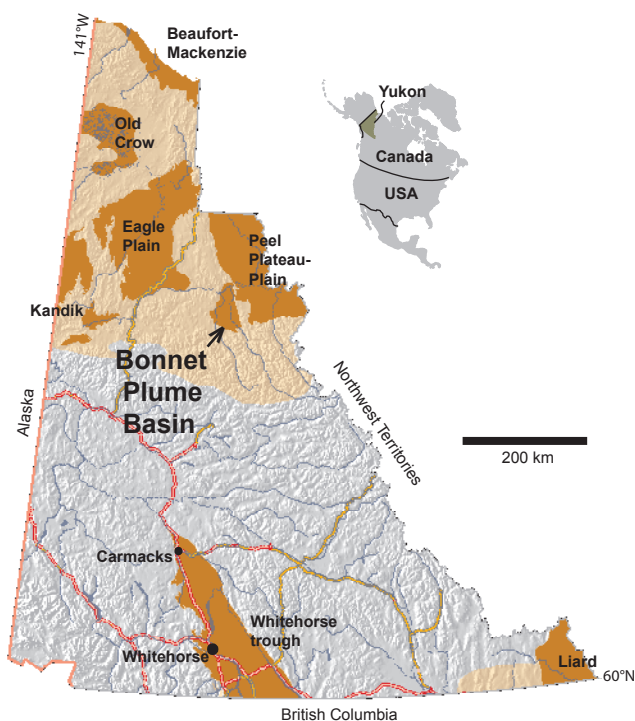


Figure 1. Petroleum basins in Yukon (from Oil and Gas Branch, Yukon Government, 2007).

Formation (Cretaceous to Tertiary) crop out in the Bonnet Plume Basin.

METHODS

A total of 226 samples were collected from outcrop and drill core throughout the Bonnet Plume Basin. Source rock quantity, quality and thermal maturation level were determined by Rock-Eval 6 programmed pyrolysis and combustion using standard techniques by the Geological Survey of Canada in Calgary, Alberta. Technical details of the Rock-Eval apparatus, procedures and applications are available in Espitalie *et al.* (1985), Peters (1986), Peters and Casa (1994), Tyson (1995), Lafargue *et al.* (1998),

Behar *et al.* (2001) and Fowler *et al.* (2005), whereas a less technical summary is provided by Lowey and Long (2006). Table 1 provides definitions for commonly used Rock-Eval parameters and presents a summary of guidelines for interpreting source rock quantity, quality and maturation using Rock-Eval.

RESULTS

ROAD RIVER FORMATION

With regards to source rock quantity, TOC ranges from 0.35 to 2.30% (Appendix 1) with a mean of 1.25%, indicating a poor to good source rock; S_1 ranges from 0

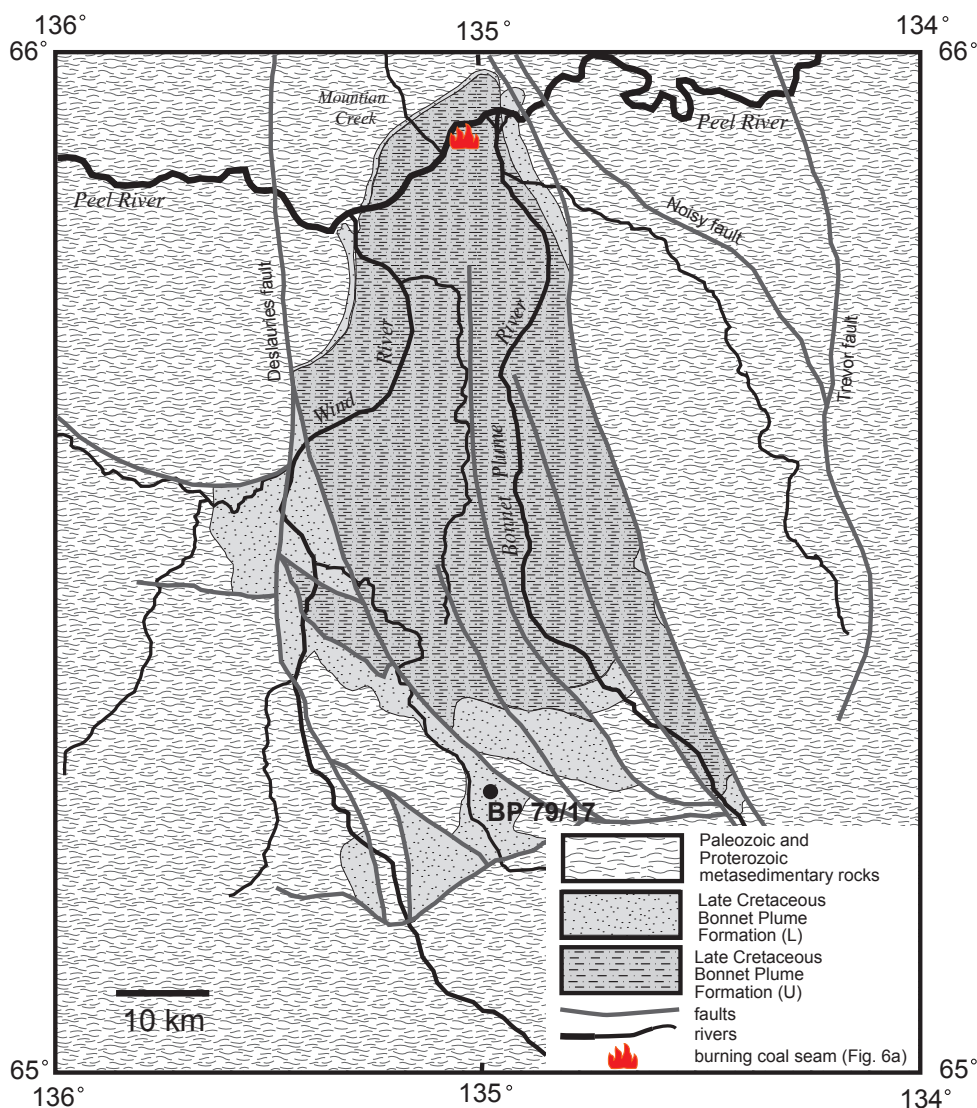


Figure 2. Geologic setting of the Bonnet Plume Basin, Yukon. Flame symbol indicates location of naturally burning coal seam (modified from Long, 1978; and Norris, 1982).

to 0.71 mg HC/g rock with a mean of 0.128 mg HC/g rock, indicating a poor to fair source rock; and S_2 ranges from 0.01 to 0.16 mg HC/g rock with a mean of 0.04 mg HC/g rock, indicating a poor source rock. With regards to source rock quality, HI ranges from 1.00 to 140.00 mg HC/g TOC with a mean of 3.33 mg HC/g TOC indicating no hydrocarbons to gas are present; and the S_2/S_3 ratio ranges from 0.01 to 0.31 with a mean of 0.17, indicating no hydrocarbons are present. Based on the S_2 vs. TOC plot (Fig. 3a) and the HI vs. T_{max} plot (Fig. 3b), only Type III, or gas-prone is present. With regards to source rock thermal maturation, T_{max} ranges from 288 to 542°C with a mean of 352°C, indicating the rock ranges from thermally immature to postmature with respect to oil generation (Fig. 3b). Note that due to low S_2 values (*i.e.*, values of S_2 < 0.2 mg HC/g rock), subsequent Rock-Eval parameters are considered unreliable (Peters, 1986). Hence, Figure 3 should be interpreted with caution.

LOWER BONNET PLUME FORMATION

With regards to source rock quantity, TOC ranges from 0.14 to 62.79% (Appendix 2) with a mean of 4.77%, indicating a poor to excellent source rock; S_1 ranges from 0 to 0.82 mg HC/g rock with a mean of 0.10 mg HC/g rock, indicating a poor source rock; and S_2 ranges from 0.02 to 36.92 mg HC/g rock with a mean of 4.77 mg HC/g rock, indicating a poor to excellent source rock. With regards to source rock quality, HI ranges from 10.00 to 409.00 mg HC/g TOC with a mean of 83.64 mg HC/g TOC indicating no hydrocarbons to oil are present; and the S_2/S_3 ratio ranges from 0.02 to 15.50 with a mean of 1.91, indicating no hydrocarbons to oil are present. Based on the S_2 vs. TOC plot (Fig. 4a) and the HI vs. T_{max} plot (Fig. 4b), Type III, or gas-prone kerogen and Type II, or gas- and oil-prone kerogen is present. With regards to source rock thermal maturation, T_{max} ranges from 402° to 471°C with a mean of 435°C, indicating the rock ranges from thermally immature to postmature with respect to oil generation (Fig. 4b).

Table 1. Guidelines for interpreting source rock quantity, quality and maturation, and commonly used Rock-Eval parameters. From Epstein et al. (1977), Espitalie et al. (1985), Peters (1986), Traverse (1988), Peters and Cassa (1994) and Fowler et al. (2005).

QUANTITY	¹ TOC (wt. %)	² S ₁ (mg HC/g rock)	³ S ₂ (mg HC/g rock)		
Poor	<0.5	<0.5	<2.5		
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		
QUALITY	⁴ HI (mg HC/g TOC)	⁵ S ₂ /S ₃	⁶ Kerogen Type		
None	<50	<1	IV		
Gas	50-200	1-5	III		
Gas and oil	200-300	5-10	II/III		
Oil	300-600	10-15	II		
Oil	>600	>15	I		
MATURATION	⁷ Ro (%)	⁸ T _{max} (°C)	⁹ CAI	¹⁰ TAI	
Immature	0.2-0.6	<435	<1.0	1.5-2.6	
	Early	0.6-0.65	435-445	1.0-2.0	2.6-2.6
Mature	Peak	445-450	2.0-3.0	2.7-2.9	
	Late	0.9-1.35	450-470	3.0-4.0	2.9-3.3
	Postmature	>1.35	>470	>4.0	>3.3

¹TOC=total organic carbon

²S₁=hydrocarbons thermally distilled from sample ('free hydrocarbons')

³S₂=hydrocarbons generated by pyrolytic degradation of kerogen in sample ('potential hydrocarbons')

⁴HI=Hydrogen Index=($S_2 \times 100 / \text{TOC}$)

⁵S₂/S₃=(pyrolyzed hydrocarbons/carbon dioxide generated during pyrolysis)

⁶Kerogen Type IV~ reworked-oxidized organic matter ('dead carbon')

III~ terrestrial plants

II/III~ marine organic matter/terrestrial plants

I~ lacustrine and marine algae

⁷Ro=random vitrinite reflectance

⁸T_{max}=Rock-Eval oven temperature at which the maximum amount of S_2 is generated

⁹CAI=conodont alteration index

¹⁰TAI=spore and pollen thermal alteration index

Also, the Oxygen Index [OI=($S_3 \times 100 / \text{TOC}$)] is used in HI vs. OI plots to assess kerogen type.

UPPER BONNET PLUME FORMATION

With regards to source rock quantity, TOC ranges from 0.01 to 58.74% (Appendix 3) with a mean of 14.96%, indicating a poor to excellent source rock; S_1 ranges from 0 to 12.44 mg HC/g rock with a mean of 1.24 mg HC/g rock, indicating a poor to excellent source rock; and S_2 ranges from 0 to 116.66 mg HC/g rock with a mean of 23.39 mg HC/g rock, indicating a poor to excellent source rock. With regards to source rock quality, HI ranges from 0 to 414.00 mg HC/g TOC with a mean of 97.45 mg HC/g TOC indicating no hydrocarbons to oil is present; and the

S_2/S_3 ratio ranges from 0 to 11.31 with a mean of 1.39, indicating no hydrocarbons to oil is present. Based on the S_2 vs. TOC plot (Fig. 5a) and the HI vs. T_{max} plot (Fig. 5b), Type III, or gas-prone kerogen and Type II, or gas- and oil-prone kerogen is present. With regards to source rock thermal maturation, T_{max} ranges from 274 to 608°C with a mean of 426°C, indicating the rock ranges from thermally immature to postmature-mature with respect to oil generation (Fig. 4b).

Also associated with the upper Bonnet Plume Formation is a naturally burning coal (Fig. 6a). It occurs on the right limit of the Peel River opposite Mountain Creek (Fig. 2), and has been burning for over 100 years (de Sainville, 1898). Associated with the burning coal is a previously unrecognized tar (Fig. 6b). When fresh, the tar is black, vitreous, hot to touch and has a distinct chemical odour.

Although Rock-Eval analysis has not been completed, the tar contains 42.8% resins and asphaltenes (hydrocarbon-like compounds containing mainly sulphur, nitrogen and oxygen), 24.5% aromatic hydrocarbons and 7.7% saturated hydrocarbons (K. Osadetz, writ. comm., 2008). The tar is physically and chemically similar to tar derived from the pyrolysis of coal and oil shale (Cane, 1976; Meyers, 1982).

DISCUSSION AND CONCLUSIONS

The Road River Formation contains small to moderate amounts of TOC, negligible to small amounts of S_1 and small amounts of S_2 , indicating that overall, it is a poor source rock. HI values and the S_2/S_3 ratio suggest that only gas would be present. The majority of the T_{max}

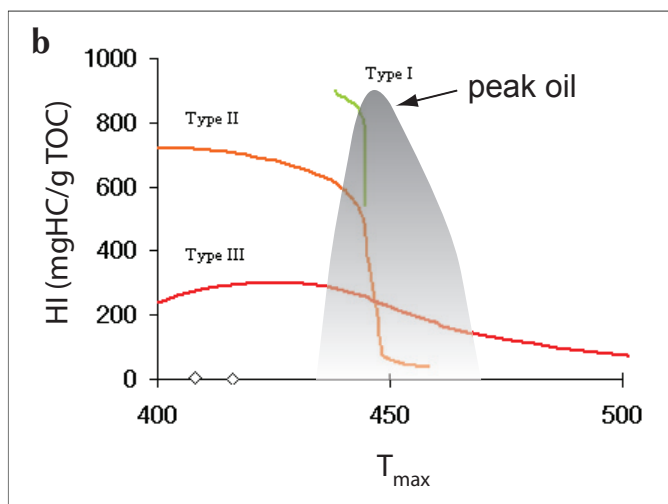
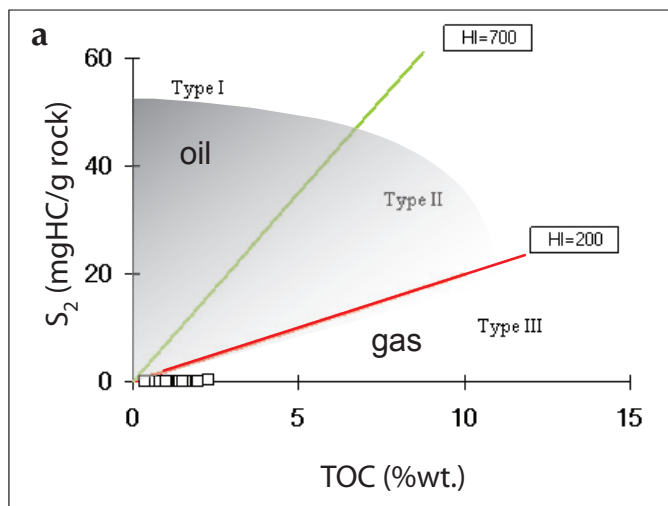


Figure 3. (a) S_2 vs. TOC plot, Road River Formation. **(b)** HI vs. T_{MAX} plot, Road River Formation.

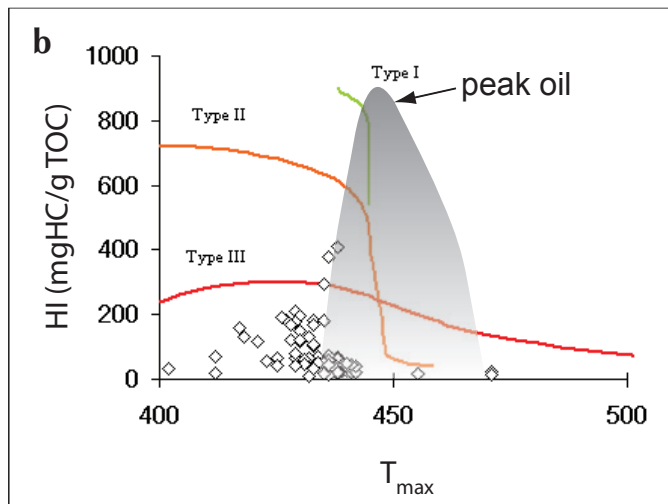
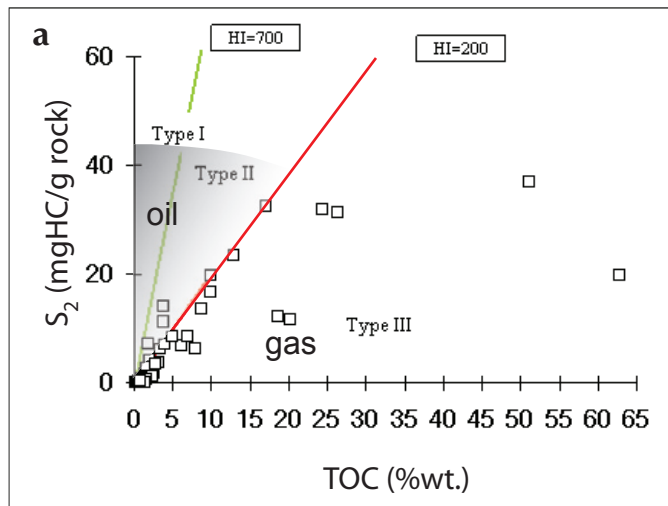


Figure 4. (a) S_2 vs. TOC plot, lower Bonnet Plume Formation. **(b)** HI vs. T_{MAX} lower Bonnet Plume Formation.

values are probably unreliable due to the low S_2 values, and so the thermal maturity of the strata within the basin is uncertain. However, based on vitrinite reflectance and the conodont alteration index, Link and Bustin (1989) determined that the Road River Formation north of the Bonnet Plume Basin is postmature and that thermal maturity increases southwards. In addition, Link *et al.* (1989) concluded that the Road River Formation currently has poor source-rock potential, but probably generated oil in Devonian to Carboniferous time.

The lower Bonnet Plume Formation contains small to large amounts of TOC (note that coal is defined as greater than 50% by weight carbonaceous material, Neuendorf *et al.*, 2005), small to moderate amounts of S_1 , and small to large amounts of S_2 , indicating that overall, it is an

excellent source rock. HI values, the S_2/S_3 ratio and the S_2 vs. TOC and the HI vs. T_{max} plots suggest that gas and possibly oil are present. The presence of Type II kerogen (*i.e.*, organic matter of marine origin that is oil- and gas-prone) is supported by the occurrence of dinoflagellate cysts (Nichols and Sweet, 1993), which indicate the lower Bonnet Plume Formation is, in part, marginal marine in origin. The T_{max} values indicate the rock is mainly thermally immature to early mature with respect to oil generation. According to Cameron and Beaton (2000), maximum random vitrinite reflectance values ($R_{o,max}$) for the lower Bonnet Plume range from 0.55 to 0.65, whereas D.G.F. Long (writ. comm., 2002) states that the average $R_{o,max}$ value is 0.47. In general, the vitrinite reflectance values agree with the maturation level determined by Rock-Eval analysis. Also, coal rank in the

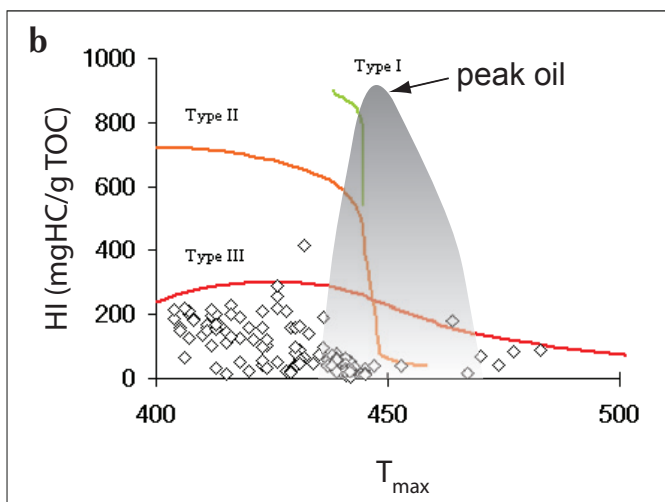
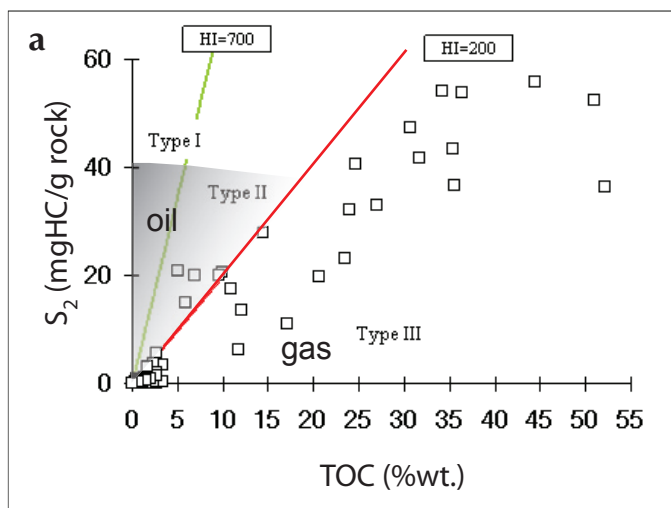


Figure 5. (a) S_2 vs. TOC plot, upper Bonnet Plume Formation. (b) HI vs. T_{MAX} , upper Bonnet Plume Formation.



Figure 6. (a) Naturally burning coal seam, upper Bonnet Plume Formation, Peel River, Yukon. Note associated tar (dark black patches). (b) Close-up of hydrocarbon-rich tar associated with the burning coal seam (scale is 7 cm long).

lower Bonnet Plume Formation is sub-bituminous A to high volatile C bituminous (Long, 1986; Cameron and Beaton, 2000), corresponding to the beginning half of the oil window (Fowler *et al.*, 2005). Economic accumulations of petroleum are thought to occur if coal rank is less than, or equal to, high-volatile bituminous (Stack *et al.*, 1982). In addition, oil generation is marginally supported by the composition of the coal, which contains up to 9.7% liptinite (D.G.F. Long, writ. comm., 2002). According to Peters and Cassa (1994), 15 to 20% liptinite is required for coal to generate oil.

The upper Bonnet Plume Formation contains small to large amounts of TOC, negligible to large amounts of S_1 and negligible to large amounts of S_2 , indicating that overall, it is an excellent source rock. HI values, the S_2/S_3 ratio, the S_2 vs. TOC and the HI vs. T_{max} plots suggest that gas and possibly oil are present. The T_{max} values indicate the rock is mainly thermally immature to early mature with respect to oil generation. According to D.G.F. Long (writ. comm., 2002), the average Ro_{max} values for the upper Bonnet Plume is 0.31, in general agreement with the maturation level determined by Rock-Eval analysis. Also, coal rank in the upper Bonnet Plume Formation is lignite (Cameron and Beaton, 2000), corresponding to pre-oil window conditions (Fowler *et al.*, 2005). However, oil generation is supported by the composition of lignite, which contains up to 19% liptinite (D.G.F. Long, writ. comm., 2002), and the previously unrecognized tar.

Potential oil generation in the Bonnet Plume Formation is attributed to the occurrence of liptinite-bearing coal and previously unrecognized oil shale. Numerous studies have shown that coal provides the source for commercial oil accumulations in several sedimentary basins (Hendrix *et al.*, 1995, and references therein). Oil-prone coal is not only characterized by high HI and S_2 values, but also high S_1 values: that is, it is thermally mature with respect to oil generation (Tissot and Welte, 1984). As an example, sample W1-79 from the upper Bonnet Plume Formation (Appendix 3) displays characteristics similar to oil-prone coal with HI=203, S_2 =104.68 mg HC/g rock and S_1 =6.35 mg HC/g rock. Note that Peters (1986) cautioned that Rock-Eval analysis tends to overestimate the liquid-hydrocarbon generative potential of coal. Several rock samples from the Bonnet Plume Formation are also similar to siliceous oil shale (*i.e.*, clay minerals are predominant), rather than carbonate-rich oil shale (Duncan, 1976; Yen and Chilingar, 1976). Oil shale is characterized by high TOC and S_2 values, but low S_1 values: that is, it is thermally immature with respect to oil generation (Hunt,

1996). As an example, sample BP 79/17-201.2 from the lower Bonnet Plume Formation (Appendix 2) displays characteristics similar to oil shale with TOC=16.99%, S_2 =32.28 mg HC/g rock and S_1 =0.74 mg HC/g rock. In conclusion, the Bonnet Plume Formation is gas-prone and possibly oil-prone. Additional field and laboratory work is planned to follow-up on this previously unrecognized oil play.

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APPENDIX 1

Results of Rock-Eval analysis, Road River Formation

Sample	Qty	T _{max}	S ₁	S ₂	S ₃	PI	S ₂ /S ₃	PC(%)	TOC(%)	HI	OI
GL07-20A	70.3	408	0.01	0.02	0.37	0.46	0.26	0.01	0.35	6	106
GL07-21A	50.1	330	0.05	0.04	0.19	0.55	0.26	0.02	1.98	2	10
GL07-22A	70.3	312	0.01	0.01	0.33	0.46	0.26	0.02	1.55	1	21
GL07-23A	70.6	416	0.00	0.01	0.67	0.28	0.26	0.02	0.81	1	83
GL07-24A	70.1	328	0.01	0.01	0.26	0.34	0.26	0.01	0.70	1	37
GL08-34A	70.8	301	0.12	0.03	0.35	0.82	0.09	0.03	1.59	2	22
GL08-35A	70.4	341	0.02	0.02	0.95	0.52	0.02	0.03	0.88	2	108
GL08-36A	70.3	309	0.11	0.06	0.41	0.64	0.15	0.03	1.42	4	29
GL08-37A	50.3	291	0.71	0.16	0.55	0.81	0.29	0.10	2.30	7	24
GL08-37B	70.0	298	0.08	0.04	0.21	0.67	0.19	0.02	1.05	4	20
GL08-38A	50.4	525	0.01	0.01	0.91	0.66	0.01	0.04	1.35	1	67
GL08-39A	70.5	288	0.25	0.05	0.44	0.83	0.11	0.04	1.42	4	31
GL08-40A	70.6	296	0.45	0.08	0.26	0.85	0.31	0.05	0.81	10	32
GL08-41A	69.9	299	0.08	0.03	0.27	0.74	0.11	0.02	1.50	2	18
GL08-59A	70.6	542	0.01	0.03	1.43	0.14	0.02	0.05	1.02	3	140

APPENDIX 2

Results of Rock-Eval analysis, lower Bonnet Plume Formation

Depth (metres)	Sample	Qty	T _{max}	S ₁	S ₂	S ₃	PI	S ₂ /S ₃	PC (%)	TOC (%)	HI	OI	Coal (c)
	GL08-58A	10.6	412	0.79	36.92	30.61	0.02	1.21	5.71	51.13	72	60	c
40.2	BP 79/17	70.5	417	0.33	13.60	5.58	0.02	2.44	1.51	8.65	157	65	
41.8	BP 79/17	25.9	421	0.75	31.14	15.47	0.02	2.01	3.73	26.37	118	59	
42.3	BP 79/17	50.5	418	0.82	31.82	14.33	0.03	2.22	3.67	24.43	130	59	
44.0	BP 79/17	69.6	425	0.21	12.14	11.77	0.02	1.03	1.83	18.53	66	64	
45.0	BP 79/17	70.4	439	0.01	0.20	1.84	0.03	0.11	0.08	0.68	29	271	
47.0	BP 79/17	70.0	433	0.05	2.29	1.25	0.02	1.83	0.27	2.24	102	56	
48.5	BP 79/17	70.6	436	0.46	14.09	1.09	0.03	12.93	1.29	3.73	378	29	
49.5	BP 79/17	70.9	430	0.06	2.43	1.09	0.02	2.23	0.27	1.99	122	55	
50.9	BP 79/17	70.5	439	0.01	0.43	1.21	0.02	0.36	0.08	0.99	43	122	
52.5	BP 79/17	70.8	438	0.03	1.04	0.55	0.03	1.89	0.12	1.50	69	37	
54.0	BP 79/17	71.0	437	0.02	0.77	1.40	0.02	0.55	0.12	1.34	57	104	
55.6	BP 79/17	70.8	437	0.02	0.55	1.59	0.03	0.35	0.11	1.39	40	114	
57.0	BP 79/17	70.5	438	0.02	0.70	0.40	0.03	1.75	0.09	1.04	67	38	
58.5	BP 79/17	70.2	440	0.01	0.15	1.18	0.06	0.13	0.05	0.58	26	203	
59.5	BP 79/17	70.8	438	0.01	0.17	1.16	0.03	0.15	0.06	0.70	24	166	
61.0	BP 79/17	70.2	438	0.01	0.19	1.19	0.04	0.16	0.06	0.55	35	216	

APPENDIX 2, CONTINUED

Depth (metres)	Sample	Qty	T _{max}	S ₁	S ₂	S ₃	PI	S ₂ /S ₃	PC (%)	TOC (%)	HI	OI	Coal (c)
62.0	BP 79/17	70.6	435	0.01	0.24	0.85	0.02	0.28	0.05	0.82	29	104	
63.8	BP 79/17	70.8	439	0.01	0.56	2.14	0.02	0.26	0.12	1.19	47	180	
66.2	BP 79/17	71.0	434	0.03	1.18	1.65	0.02	0.72	0.17	1.67	71	99	
68.5	BP 79/17	70.2	425	0.01	0.36	6.49	0.02	0.06	0.30	0.91	40	713	
69.6	BP 79/17	70.1	436	0.02	0.82	0.50	0.03	1.64	0.10	1.07	77	47	
71.0	BP 79/17	70.8	436	0.01	0.42	0.33	0.03	1.27	0.06	0.70	60	47	
73.8	BP 79/17	70.3	438	0.01	0.15	1.34	0.07	0.11	0.06	0.55	27	244	
75.4	BP 79/17	70.9	412	0.00	0.04	1.70	0.08	0.02	0.06	0.22	18	773	
76.7	BP 79/17	70.4	471	0.01	0.05	0.23	0.12	0.22	0.02	0.23	22	100	
87.8	BP 79/17	70.4	430	0.10	3.69	1.27	0.03	2.91	0.41	3.15	117	40	
88.6	BP 79/17	70.2	427	0.35	23.52	4.23	0.01	5.56	2.31	12.90	182	33	
90.5	BP 79/17	70.9	441	0.01	0.14	1.52	0.09	0.09	0.06	0.56	25	271	
93.6	BP 79/17	70.5	438	0.01	0.11	1.23	0.04	0.09	0.06	0.54	20	228	
94.5	BP 79/17	70.2	442	0.00	0.14	0.45	0.03	0.31	0.03	0.58	24	78	
110.0	BP 79/17	70.3	430	0.07	2.91	0.79	0.02	3.68	0.30	1.97	148	40	
111.0	BP 79/17	70.3	434	0.01	0.63	2.01	0.02	0.31	0.12	1.26	50	160	
112.5	BP 79/17	70.2	437	0.01	0.66	1.54	0.02	0.43	0.11	1.27	52	121	
121.5	BP 79/17	70.1	442	0.01	0.45	1.47	0.02	0.31	0.09	1.04	43	141	
128.7	BP 79/17	70.1	440	0.01	0.31	1.64	0.03	0.19	0.08	0.75	41	219	
130.3	BP 79/17	70.8	437	0.01	0.61	1.62	0.02	0.38	0.11	1.20	51	135	
131.0	BP 79/17	70.2	435	0.27	11.21	1.33	0.02	8.43	1.05	3.81	294	35	
134.0	BP 79/17	70.8	435	0.02	0.55	0.68	0.03	0.81	0.08	1.00	55	68	
135.7	BP 79/17	70.8	429	0.10	4.14	0.58	0.02	7.14	0.39	1.96	211	30	
137.0	BP 79/17	70.1	437	0.01	0.41	1.00	0.02	0.41	0.07	0.93	44	108	
141.5	BP 79/17	70.8	432	0.03	1.77	0.44	0.02	4.02	0.18	1.37	129	32	
143.5	BP 79/17	70.3	441	0.01	0.63	2.22	0.02	0.28	0.13	1.36	46	163	
144.5	BP 79/17	70.8	435	0.01	0.65	1.45	0.02	0.45	0.11	1.22	53	119	
156.5	BP 79/17	70.7	433	0.22	6.13	1.64	0.03	3.74	0.64	3.36	182	49	
159.1	BP 79/17	70.6	429	0.05	1.69	2.78	0.03	0.61	0.27	2.56	66	109	
161.5	BP 79/17	70.5	436	0.01	0.39	0.39	0.03	1.00	0.05	0.66	59	59	
163.0	BP 79/17	70.6	435	0.01	0.52	3.14	0.02	0.17	0.15	1.14	46	275	
164.5	BP 79/17	70.0	438	0.20	7.44	0.48	0.03	15.50	0.67	1.82	409	26	
165.5	BP 79/17	10.5	402	0.11	19.82	17.34	0.01	1.14	3.67	62.79	32	28	c
169.3	BP 79/17	70.8	435	0.05	2.71	0.52	0.02	5.21	0.27	1.50	181	35	
170.7	BP 79/17	20.5	430	0.24	19.76	2.81	0.01	7.03	1.89	9.96	198	28	
173.0	BP 79/17	70.5	440	0.02	0.61	0.41	0.03	1.49	0.08	1.21	50	34	
174.4	BP 79/17	70.7	436	0.00	0.03	1.38	0.08	0.02	0.05	0.25	12	552	
180.5	BP 79/17	70.9	429	0.14	6.95	1.77	0.02	3.93	0.71	3.89	179	46	
182.0	BP 79/17	70.8	471	0.00	0.02	0.26	0.15	0.08	0.02	0.14	14	186	
190.8	BP 79/17	70.2	433	0.10	6.67	2.27	0.02	2.94	0.72	6.19	108	37	
192.3	BP 79/17	70.5	433	0.29	16.61	3.10	0.02	5.36	1.63	9.84	169	32	
194.9	BP 79/17	70.4	455	0.01	0.08	0.45	0.09	0.18	0.03	0.38	21	118	
197.3	BP 79/17	70.6	428	0.05	3.35	1.23	0.01	2.72	0.38	2.74	122	45	
201.2	BP 79/17	50.4	426	0.74	32.28	6.57	0.02	4.91	3.23	16.99	190	39	
208.7	BP 79/17	70.5	435	0.01	0.72	2.30	0.02	0.31	0.14	1.36	53	169	
208.5	BP 79/17	70.5	436	0.02	0.64	1.61	0.03	0.40	0.12	1.39	46	116	
220.2	BP 79/17	70.1	432	0.01	0.51	0.46	0.02	1.11	0.07	1.14	45	40	
224.2	BP 79/17	70.8	432	0.01	0.84	0.50	0.02	1.68	0.11	1.30	65	38	
311.5	BP 79/17	70.5	429	0.05	6.28	3.93	0.01	1.60	0.77	7.83	80	50	
313.5	BP 79/17	70.3	428	0.14	8.37	2.04	0.02	4.10	0.85	5.04	166	40	
316.5	BP 79/17	70.1	423	0.23	11.64	7.78	0.02	1.50	1.69	20.21	58	38	
317.4	BP 79/17	70.5	435	0.00	0.13	0.41	0.02	0.32	0.03	0.61	21	67	
327.8	BP 79/17	70.5	431	0.02	1.12	0.62	0.02	1.81	0.14	1.77	63	35	
335.5	BP 79/17	70.7	434	0.01	0.39	0.35	0.03	1.11	0.06	0.77	51	45	

APPENDIX 2, CONTINUED

Depth (metres)	Sample	Qty	T _{max}	S ₁	S ₂	S ₃	PI	S ₂ /S ₃	PC (%)	TOC (%)	HI	OI	Coal (c)
337.0	BP 79/17	70.3	431	0.01	0.76	0.59	0.02	1.29	0.11	1.61	47	37	
338.2	BP 79/17	70.3	433	0.01	0.23	0.64	0.05	0.36	0.05	0.66	35	97	
347.4	BP 79/17	70.6	431	0.02	1.09	1.94	0.02	0.56	0.18	2.32	47	84	
349.8	BP 79/17	70.7	429	0.02	0.69	2.85	0.02	0.24	0.21	1.61	43	177	
356.4	BP 79/17	70.1	432	0.00	0.14	0.75	0.03	0.19	0.06	1.41	10	53	
358.2	BP 79/17	70.0	430	0.14	8.34	1.82	0.02	4.58	0.84	6.94	120	26	
359.5	BP 79/17	70.5	438	0.01	0.18	0.45	0.03	0.40	0.04	0.73	25	62	

APPENDIX 3

Results of Rock-Eval analysis, upper Bonnet Plume Formation

Sample	Qty	T _{max}	S ₁	S ₂	S ₃	PI	S ₂ /S ₃	PC(%)	TOC (%)	HI	OI	coal (c)
W4-9	70.4	445	0.04	0.22	0.86	0.14	0.26	0.05	0.72	31	119	
W4-11	70.8	474	0.03	0.12	0.25	0.19	0.48	0.02	0.30	40	83	
W4-12	10.2	378	0.50	36.37	26.74	0.01	1.36	5.20	52.16	70	51	c
W4-15	70.4	432	0.13	1.49	2.33	0.08	0.64	0.25	2.21	67	105	
W4-34	70.3	444	0.02	0.29	8.93	0.06	0.03	0.49	1.30	22	687	
W4-37	70.9	453	0.08	0.39	0.60	0.17	0.65	0.07	0.92	42	65	
W4-41	70.3	423	0.07	0.55	1.66	0.11	0.33	0.15	1.37	40	121	
W4-42	70.1	415	1.23	13.47	14.57	0.08	0.92	2.06	12.00	112	121	
W4-43	10.3	412	12.44	85.46	35.10	0.13	2.43	10.41	50.18	170	70	
W4-44	10.3	396	7.19	91.35	39.78	0.07	2.30	11.11	58.74	156	68	c
W4-45	10.3	414	4.65	68.16	31.63	0.06	2.15	8.03	41.86	163	76	c
W4-46	10.3	404	4.19	90.33	32.83	0.04	2.75	10.11	48.45	186	68	c
W4-47	10.5	405	3.71	54.08	27.34	0.06	1.98	6.63	34.22	158	80	c
W4-48	20.8	405	2.74	53.77	26.98	0.05	1.99	6.58	36.38	148	74	c
W4-49	70.1	410	1.96	32.17	20.53	0.06	1.57	4.11	24.02	134	85	c
W4-50	70.3	418	2.01	27.76	11.06	0.07	2.51	3.14	14.50	191	76	c
W4-51	10.4	408	4.41	80.91	34.94	0.05	2.32	9.24	42.77	189	82	c
W4-52	10.2	413	4.49	77.35	29.91	0.05	2.59	8.58	43.82	177	68	c
W4-53	70.6	420	0.04	0.17	1.01	0.18	0.17	0.06	0.71	24	142	
W4-61	70.6	428	0.02	0.15	0.60	0.13	0.25	0.04	0.62	24	97	
W1-14	10.5	418	1.77	60.78	36.23	0.03	1.68	7.23	48.19	126	75	
W1-17	10.7	415	1.13	72.66	36.33	0.02	2.00	8.25	50.97	143	71	c
W1-481m	70.4	436	0.01	0.50	0.36	0.02	1.39	0.06	0.68	74	53	
W1-23	70.6	439	0.08	1.12	1.38	0.07	0.81	0.15	1.39	81	99	
W1-31	70.8	477	0.08	0.54	0.57	0.13	0.95	0.08	0.65	83	88	
W1-32	70.3	426	0.11	6.12	13.30	0.02	0.46	1.19	11.68	52	114	
W1-33	20.5	430	0.55	19.76	20.68	0.03	0.96	2.78	20.61	96	100	c
W1-34	70.5	447	0.04	0.36	0.78	0.11	0.46	0.06	0.85	42	92	
W1-36	70.3	470	0.12	0.67	0.88	0.15	0.76	0.10	0.98	68	90	
W1-45	70.7	441	0.02	0.27	0.71	0.07	0.38	0.06	0.99	27	72	
W1-46	70.4	464	0.20	0.78	0.49	0.20	1.59	0.12	0.43	181	114	
W1-51	70.5	426	0.34	5.70	1.53	0.06	3.73	0.57	2.60	219	59	
W1-61	10.0	412	1.53	36.68	27.89	0.04	1.32	5.00	35.49	103	79	c
W1-62	70.1	483	0.12	0.97	1.66	0.11	0.58	0.18	1.11	87	150	
W1-63	10.2	416	2.39	41.58	22.31	0.05	1.86	5.08	31.61	132	71	c
W1-64	10.6	416	5.29	83.06	23.85	0.06	3.48	8.75	36.27	229	66	c
W1-65	10.2	411	4.33	70.51	29.79	0.06	2.37	7.97	44.03	160	68	c
W1-66	10.4	411	4.74	68.23	31.28	0.06	2.18	7.85	40.38	169	77	c
W1-67	10.5	407	3.64	55.91	37.12	0.06	1.51	7.20	44.46	126	83	c

APPENDIX 3, CONTINUED

Sample	Qty	T _{max}	S ₁	S ₂	S ₃	PI	S ₂ /S ₃	PC(%)	TOC (%)	HI	OI	coal (c)
W1-68	10.5	411	3.14	66.02	34.21	0.05	1.93	7.67	43.92	150	78	c
W1-69	50.1	423	1.62	20.69	6.31	0.07	3.28	2.20	9.92	209	64	
W1-76	10.3	412	3.77	92.11	42.47	0.04	2.17	10.23	46.91	196	91	c
W1-77	20.4	413	3.00	47.35	23.41	0.06	2.02	5.56	30.61	155	76	c
W1-78	10.7	413	4.22	97.14	38.93	0.04	2.50	10.59	48.17	202	81	c
W1-79	10.6	407	6.35	104.68	37.93	0.06	2.76	11.26	51.53	203	74	c
W1-80	10.6	408	3.59	93.44	41.67	0.04	2.24	10.40	51.74	181	81	c
W1-81	10.1	390	3.68	74.03	38.35	0.05	1.93	8.91	50.24	147	76	c
W1-82	10.4	413	3.46	75.56	32.77	0.04	2.31	8.41	37.93	199	86	c
W1-83	10.3	396	2.23	69.95	49.61	0.03	1.41	9.18	56.51	124	88	c
W1-84	10.3	407	5.12	114.29	40.61	0.04	2.81	12.47	54.01	212	75	c
W1-85	10.6	413	4.60	83.19	34.82	0.05	2.39	9.42	48.82	170	71	c
W1-87	10.7	388	2.22	75.82	41.74	0.03	1.82	9.25	56.54	134	74	c
W1-88	10.5	404	5.22	116.66	40.18	0.04	2.90	12.40	54.19	215	74	c
W1-89	20.5	412	4.25	64.88	20.08	0.06	3.23	6.92	29.85	217	67	c
W1-90	10.7	387	1.83	52.47	44.19	0.03	1.19	7.46	50.91	103	87	c
W1-91	10.2	406	3.96	105.97	35.42	0.04	2.99	11.12	47.88	221	74	c
W1-94	70.8	424	0.05	0.59	1.04	0.08	0.57	0.09	0.56	105	186	
W1-95	70.4	430	0.02	0.18	0.46	0.11	0.39	0.04	0.41	44	112	
W2-3	70.2	416	0.03	0.08	0.30	0.26	0.27	0.02	0.04	200	750	
W2-5	70.4	435	0.01	0.02	0.65	0.38	0.03	0.02	0.03	67	2167	
W2-15	25.7	421	0.90	43.36	24.21	0.02	1.79	5.17	35.31	123	69	
W2-17	70.8	431	0.11	1.80	2.07	0.06	0.87	0.24	1.99	90	104	
W2-20	25.1	423	0.66	22.97	17.83	0.03	1.29	3.05	23.44	98	76	
W2-21	20.3	420	1.70	71.64	28.28	0.02	2.53	7.88	45.23	158	63	
W2-25	70.6	432	0.65	20.93	1.85	0.03	11.31	1.92	5.05	414	37	
W2-26	70.3	436	0.03	0.26	0.60	0.10	0.43	0.04	0.44	59	136	
W2-27	70.0	434	0.02	0.26	1.74	0.06	0.15	0.07	0.55	47	316	
W2-28	70.7	406	0.61	11.07	23.04	0.05	0.48	2.23	17.12	65	135	
W2-29	70.6	437	0.03	0.65	0.77	0.04	0.84	0.09	1.03	63	75	
W2-30	70.7	431	0.03	0.24	0.99	0.13	0.24	0.06	0.39	62	254	
W2-31	50.7	429	0.53	17.40	7.16	0.03	2.43	1.91	10.89	160	66	
W2-32	70.5	437	0.02	0.51	4.30	0.04	0.12	0.18	1.17	44	368	
W2-33	70.6	442	0.03	0.28	0.64	0.10	0.44	0.05	0.48	58	133	
W2-37	70.3	441	0.10	0.47	0.41	0.18	1.15	0.07	0.71	66	58	
W2-49	70.4	440	0.07	0.84	1.51	0.08	0.56	0.14	1.61	52	94	
W2-50	10.7	423	1.21	69.47	27.57	0.02	2.52	7.58	43.90	158	63	c
GL07-25A	70.4	339	0.01	0.03	0.15	0.20	0.20	0.01	0.01	300	1500	
GL07-26A	70.7	415	0.01	0.13	0.43	0.08	0.30	0.04	0.79	16	54	
GL07-26B	70.5	441	0.01	0.11	1.25	0.11	0.09	0.06	1.09	10	115	
GL07-26C	70.7	413	0.05	0.55	1.74	0.08	0.32	0.15	1.55	35	112	
GL07-26F	10.4	375	8.46	97.27	17.36	0.08	5.60	10.60	56.86	171	31	
GL08-21A	70.4	430	0.01	0.15	1.58	0.03	0.09	0.07	0.41	37	385	
GL08-22A	69.9	430	0.02	0.54	0.40	0.03	1.35	0.07	0.68	79	59	
GL08-23A	70.4	426	1.65	14.92	2.33	0.10	6.40	1.54	5.80	257	40	
GL08-24A	70.6	436	0.02	0.95	0.41	0.02	2.32	0.10	0.96	99	43	
GL08-25A	70.3	438	0.01	0.97	0.56	0.01	1.73	0.11	1.26	77	44	c
GL08-26A	70.0	430	0.07	3.27	1.72	0.02	1.90	0.38	3.37	97	51	
GL08-26B	70.3	439	0.01	0.67	0.37	0.01	1.81	0.08	1.02	66	36	
GL08-27A	69.9	428	1.08	20.00	7.07	0.05	2.83	2.19	9.53	210	74	
GL08-28A	70.5	442	0.01	0.07	0.73	0.07	0.10	0.03	2.68	3	27	
GL08-29A	70.3	441	0.01	0.61	0.35	0.02	1.74	0.07	1.24	49	28	
GL08-30A	50.4	304	0.71	0.36	0.57	0.66	0.63	0.11	3.30	11	17	

APPENDIX 3, CONTINUED

Sample	Qty	T _{max}	S ₁	S ₂	S ₃	PI	S ₂ /S ₃	PC(%)	TOC (%)	HI	OI	coal (c)
GL08-32A	71.0	396	0.01	0.01	0.15	0.43	0.07	0.01	1.42	1	11	
GL08-33A	70.6	424	0.00	0.01	0.18	0.26	0.06	0.01	0.03	33	600	
GL08-33B	70.8	608	0.01	0.02	0.24	0.26	0.08	0.01	0.04	50	600	
GL08-34A	70.8	301	0.12	0.03	0.35	0.82	0.09	0.03	1.59	2	22	
GL08-35A	70.4	341	0.02	0.02	0.95	0.52	0.02	0.03	0.88	2	108	
GL08-36A	70.3	309	0.11	0.06	0.41	0.64	0.15	0.03	1.42	4	29	
GL08-37A	50.3	291	0.71	0.16	0.55	0.81	0.29	0.10	2.30	7	24	
GL08-37B	70.0	298	0.08	0.04	0.21	0.67	0.19	0.02	1.05	4	20	
GL08-38A	50.4	525	0.01	0.01	0.91	0.66	0.01	0.04	1.35	1	67	
GL08-39A	70.5	288	0.25	0.05	0.44	0.83	0.11	0.04	1.42	4	31	
GL08-40A	70.6	296	0.45	0.08	0.26	0.85	0.31	0.05	0.81	10	32	
GL08-41A	69.9	299	0.08	0.03	0.27	0.74	0.11	0.02	1.50	2	18	
GL08-42A	70.8	439	0.02	0.80	1.98	0.02	0.40	0.13	1.30	62	152	
GL08-44A	70.3	433	0.05	2.58	0.76	0.02	3.39	0.26	1.84	140	41	
GL08-44B	70.5	440	0.01	0.24	0.63	0.02	0.38	0.05	0.95	25	66	
GL08-44C	70.7	441	0.01	0.31	0.67	0.02	0.46	0.05	0.97	32	69	
GL08-44D	70.9	443	0.01	0.35	1.94	0.01	0.18	0.09	1.09	32	178	
GL08-44E	70.5	447	0.01	0.48	0.59	0.02	0.81	0.07	1.16	41	51	
GL08-44F	70.6	423	0.01	0.05	0.31	0.12	0.16	0.02	0.09	56	344	
GL08-44G	70.9	467	0.00	0.03	0.45	0.07	0.07	0.02	0.16	19	281	
GL08-44H	70.2	445	0.01	0.06	0.40	0.18	0.15	0.03	0.33	18	121	
GL08-45A	70.6	430	0.07	3.68	0.88	0.02	4.18	0.36	2.32	159	38	
GL08-45B	70.0	443	0.01	0.41	0.48	0.02	0.85	0.06	1.08	38	44	
GL08-46A	70.1	439	0.01	0.28	0.46	0.04	0.61	0.05	0.93	30	49	
GL08-46B	70.2	435	0.03	1.99	1.84	0.01	1.08	0.28	2.66	75	69	
GL08-46C	70.4	442	0.01	0.09	0.31	0.06	0.29	0.02	0.33	27	94	
GL08-46D	70.6	445	0.00	0.02	0.39	0.04	0.05	0.02	0.16	12	244	
GL08-46E	70.3	429	0.01	0.12	0.47	0.10	0.26	0.04	0.51	24	92	
GL08-47A	70.4	442	0.00	0.20	0.65	0.02	0.31	0.04	0.64	31	102	
GL08-51B	70.3	418	0.61	1.37	0.88	0.31	1.56	0.22	2.68	51	33	
GL08-53A	70.4	438	0.04	0.78	0.86	0.05	0.91	0.13	1.94	40	44	
GL08-54A	50.7	424	1.55	33.09	18.54	0.04	1.78	4.04	27.06	122	69	
GL08-54B	70.6	431	0.02	0.67	1.20	0.02	0.56	0.12	1.46	46	82	
GL08-54C	70.1	426	0.76	20.02	3.75	0.04	5.34	1.94	6.93	289	54	
GL08-55A	70.8	441	0.00	0.15	0.30	0.03	0.50	0.03	0.68	22	44	
GL08-55B	70.6	442	0.00	0.05	0.17	0.07	0.29	0.01	0.22	23	77	
GL08-55C	70.6	429	0.01	0.13	0.54	0.05	0.24	0.04	0.70	19	77	c
GL08-56A	70.0	436	0.07	3.04	0.80	0.02	3.80	0.30	1.60	190	50	
GL08-56B	50.1	431	1.52	40.67	15.14	0.04	2.69	4.41	24.61	165	62	c
GL08-56C	70.2	439	0.00	0.16	0.60	0.03	0.27	0.04	0.69	23	87	
GL08-57A	70.4	274	0.00	0.00	0.26	1.00	0.00	0.01	0.01	0	2600	

U-Pb age and geochemical studies of Mississippian and Cretaceous plutonic rocks in south-central McQuesten map area, Yukon

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ABSTRACT

The Reid Lakes batholith (RLB) in southwestern McQuesten map area (115P) has previously been tentatively assigned a mid-Cretaceous age, although two K-Ar ages from the northwestern part of the batholith indicated that at least part of the body must be late Paleozoic or older. U-Pb dating of two lithologically distinct samples from the southeastern part of the RLB yields Early Mississippian crystallization ages (341.5 ± 0.7 Ma and 355.7 ± 0.9 Ma). A sample of the Moose Creek pluton, which is on the northeast side of the Tintina fault zone, but was previously interpreted to be part of the RLB, yielded a U-Pb age of 92.0 ± 0.3 Ma. The Moose Creek pluton is therefore correlated with the mainly 95-93 Ma South Lansing plutonic suite which intrudes rock units of Ancestral North America, whereas the RLB is a multi-phase, Early Mississippian intrusion into metamorphic rocks of the Yukon-Tanana terrane.

RÉSUMÉ

Antérieurement, un âge du Crétacé moyen avait été provisoirement attribué au Batholite de Reid Lakes (BRL), dans le sud-ouest de la région de la carte McQuesten (115P), bien que deux âges obtenus par datation K-Ar dans la partie nord-ouest du batholite indiquaient qu'au moins une partie du corps plutonique devait être du Paléozoïque tardif ou plus ancien. La datation U-Pb de deux échantillons différents sur le plan lithologique, prélevés dans la partie sud-est du BRL, livre des âges de cristallisation du Mississippien précoce ($341,5 \pm 0,7$ Ma et $355,7 \pm 0,9$ Ma). Nous avons obtenu un âge U-Pb de $92,0 \pm 0,3$ Ma pour un échantillon du Pluton de Moose Creek qui se situe du côté nord-est de la zone de failles de Tintina, mais que des interprétations antérieures avaient associé au BRL. Par conséquent, nous pouvons établir une corrélation entre le Pluton de Moose Creek et la suite plutonique de South Lansing qui date essentiellement de 95 à 93 Ma et pénètre dans les unités lithostratigraphiques du protocontinent nord-américain, tandis que le BRL est une intrusion multiphasée du Mississippien précoce dans les roches métamorphiques du terrane de Yukon-Tanana.

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INTRODUCTION

Plutonic rocks underlie a substantial portion of the southern McQuesten map area (115P) in west-central Yukon. On most previous geological maps (e.g., Bostock, 1942; Wheeler and McFeeley, 1991; Gordey and Makepeace, 2003), one large body in the south-central part of the map area (here termed the Reid Lakes batholith) has been shown to straddle the Tintina fault zone (TFZ), which transects the McQuesten map area (Fig. 1). This body has previously been interpreted to be of

mid-Cretaceous age, and if it does cross the TFZ, it would provide an important constraint on the timing of displacement along the fault. Two samples collected along the Stewart River near the northwestern edge of the Reid Lakes batholith (Fig. 1) previously yielded K-Ar biotite ages of 253.4 ± 5.8 Ma and 201.9 ± 3.7 Ma (Mortensen, in Hunt and Roddick, 1992), indicating that at least part of the batholith must be older than Cretaceous. In addition, intrusive rock units on the northeastern side of the TFZ (here termed the Moose Creek pluton) are compositionally distinct from those on the southwestern

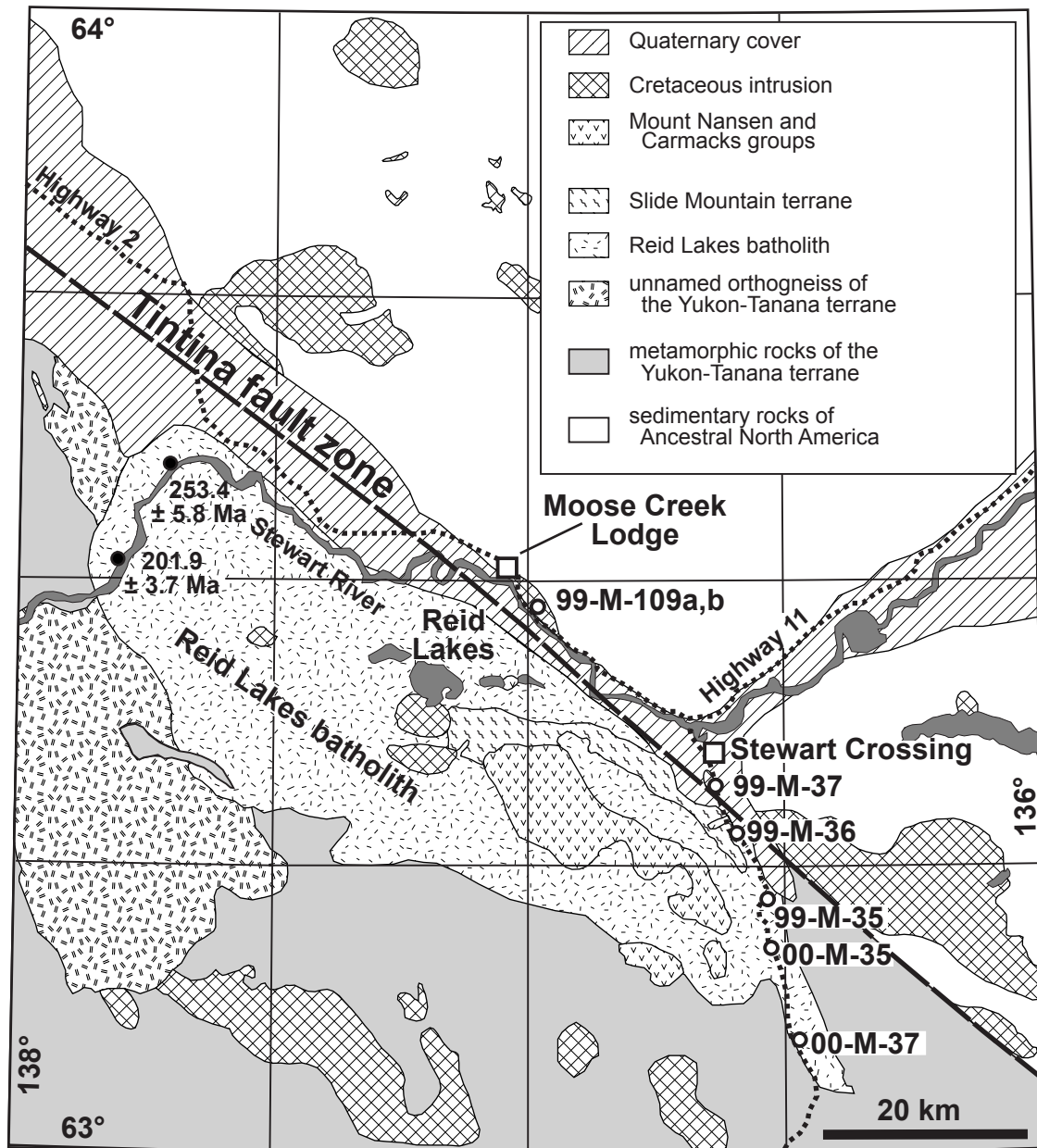


Figure 1. Simplified geology map of the McQuesten map area (modified from Colpron, 2006), illustrating the locations of K-Ar ages for the Reid Lakes batholith (filled circles) and locations for geochemical and dating samples (open circles).

side of the fault zone. In the most recent geological compilation map of central and southern Yukon (Colpron, 2006), the batholith is shown to consist of two parts, one part on the northeast side of the TFZ is believed to be Cretaceous, whereas the larger part southwest of the TFZ is inferred to be Paleozoic. In order to better constrain the age and tectonic significance of intrusive rocks in this area, samples of the Moose Creek pluton (northeastern side of the TFZ) and the southeastern portion of the Reid Lakes batholith (southwestern side of the TFZ) were collected from roadcuts along the Klondike Highway. U-Pb zircon dating and lithogeochemical studies have been carried out to determine the crystalline ages and geochemical character of these rock units.

GEOLOGICAL SETTING AND LITHOLOGY OF INTRUSIVE UNITS

The Reid Lakes batholith underlies a large, poorly exposed area in the southwestern portion of the McQuesten map sheet (115P; Fig. 1). It is intruded by several undated bodies of granite interpreted to be of Cretaceous age, and is overlain by sequences of volcanic and sedimentary rocks that have been tentatively assigned to the Slide Mountain terrane and the Mount Nansen Group (Fig. 1). The batholith intrudes into metamorphic rocks of the Yukon-Tanana terrane. The nature of the contact between the batholith and several bodies of foliated intrusive rocks of the Yukon-Tanana terrane on the northwest and southwest sides is uncertain. Most exposures of the Reid Lakes batholith along the Klondike Highway consist of medium to coarse-grained, massive to locally weakly foliated, moderately altered hornblende-biotite granodiorite. One of the most southerly exposures of the Reid Lakes batholith is compositionally somewhat different from the rest of the body, and consists of massive

hornblende-biotite granodiorite with abundant pinkish K-feldspar phenocrysts from 2-4 cm in diameter; this phase is also locally cut by narrow aplite and pegmatite veins. The Moose Creek pluton is exposed in scattered roadcuts along the Klondike Highway from just southeast of the Moose Creek Lodge to approximately 7 km southeast of Stewart Crossing (Fig. 1). Most of the rocks included within the Moose Creek pluton comprise massive, fine to medium-grained, biotite granite that are locally K-feldspar megacrystic. The granite is locally cut by abundant aplite and pegmatite dykes that contain minor garnet and tourmaline.

ANALYTICAL METHODS

Sample location information and brief descriptions of the seven intrusive samples that were analyzed in this study are listed in Table 1. Geochemical analyses for four samples of the Reid Lakes batholith and three samples from the Moose Creek pluton were determined at the ALS Chemex laboratories in North Vancouver, using XRF methods for major elements, ICP-MS methods for trace and rare earth elements, and volumetric methods following mixed-acid digestion for measurement of ferrous iron content. Several aliquots of in-house geochemical monitors were analysed along with the unknown samples to ensure the analytical reliability. Analytical data are given in Table 2. Analytical techniques for U-Pb dating studies by ID-TIMS and LA-ICP-MS at the Pacific Centre for Isotopic and Geochemical Research are as described by Mortensen *et al.* (1995, 2007). Minor modifications to the LA-ICP-MS methods employed in this study include using the Plešovice zircon (Sláma *et al.*, 2007) as the main external zircon standard, and a 197 Ma in-house zircon monitor for all analyses. In this study, a total of 16 line scans were collected for each sample. The time resolved

Table 1. Sample locations and rock descriptions.

Sample number	Unit name	UTM Zone	Northing	Easting	Rock type	Magnetic susceptibility
99-M-35	Reid Lakes batholith	8	7010836	423599	hbl-bt granodiorite	0.4
99-M-36	Reid Lakes batholith	8	7016702	420450	hbl-bt granodiorite	0.41
00-M-35	Reid Lakes batholith	8	7008100	422750	hbl-bt granodiorite	0.35
00-M-37	Reid Lakes batholith	8	7006432	423449	porphyritic hb-bt granodiorite	0.31
99-M-37	Moose Creek pluton	8	7022396	418950	bt-ms granite	0.17
99-M-109a	Moose Creek pluton	8	7039252	401691	megacrystic granite	0.13
99-M-109b	Moose Creek pluton	8	7039252	401691	aplite dyke	0.06

Note: hbl = hornblende; bt = biotite; and ms = muscovite. Magnetic susceptibility measurements represent an average of 10 individual susceptibility measurements made on the outcrop using a hand-held magnetic susceptibility meter, and are given in $\times 10^{-3}$ SI units.

Table 2. Geochemical analyses of intrusive rock samples.

SAMPLE	99-M-37	99-M-109a	99-M-35	99-M-36	00-M-37
Al ₂ O ₃	14.75	14.15	16.03	17.21	14.41
CaO	2.39	1.77	6.88	8.5	4.7
Fe ₂ O ₃	3.32	2.35	6.99	7.93	6.25
K ₂ O	5.04	4.47	1.77	1.1	4.55
MgO	0.8	0.58	3.34	3.72	2.73
MnO	0.07	0.07	0.13	0.15	0.11
Na ₂ O	2.52	2.79	2.45	2.45	1.95
P ₂ O ₅	0.13	0.1	0.16	0.19	0.19
SiO ₂	68.86	70.57	58.78	54.17	61.02
TiO ₂	0.34	0.26	0.72	0.8	0.6
LOI	0.63	1.96	1.88	2.11	2.2
TOTAL	98.85	99.07	99.13	98.33	98.71
FeO	2.6	1.91	4.34	5.2	4.08
Fe ₂ O ₃ /FeO	0.16	0.12	0.5	0.41	0.52
Ba	968	775	563	379	998
Ce	90	53.5	37.5	31.5	138.5
Cs	5.3	6.7	0.7	0.6	3.1
Co	12.5	14.5	23.5	25	18.5
Dy	3.5	3.5	3.2	2.7	5.3
Er	1.6	2.1	1.9	1.7	3
Eu	1.3	0.9	1	1.2	1.4
Gd	6.5	4.3	3.6	3	6.8
Ga	18	19	17	19	19
Hf	5	5	4	2	5
Ho	0.6	0.7	0.6	0.5	1
La	47.5	28	18.5	16	77
Pb	30	35	<5	<5	15
Lu	0.1	0.4	0.3	0.3	0.4
Nd	38	21.5	16.5	14	48
Ni	<5	<5	5	5	15
Nb	15	15	8	7	18
Pr	10	5.8	4.4	3.6	14.6
Rb	203	198	49	30	170
Sm	7.4	4.1	3.4	2.6	8
Sr	389	386	388	527	392
Ta	6	6	2.5	2	3.5
Tb	0.9	0.7	0.5	0.5	1.1
Th	26	20	10	5	22
Tm	0.1	0.3	0.3	0.2	0.4
W	119	119	56	42	48
U	2.5	16.5	0.5	1	2
V	35	25	135	160	95
Yb	1	2	1.8	1.5	2.6
Y	14	21	16.5	14	27
Zr	130	120	120	74	160

signal from each analysis was carefully examined and portions of the signal that reflect the effects of post-crystallization Pb-loss and/or the presence of older inherited zircon cores were excluded from calculation of the final isotopic ratios. Analytical data for the ID-TIMS and LA-ICP-MS U-Pb dating study are reported in Tables 3 and 4, respectively. Interpreted crystallization ages are based on a weighted average of the calculated ²⁰⁶Pb/²³⁸U ages for a total of 14 to 15 individual analyses from each sample. Errors for the calculated ages are given at the 2 sigma level.

GEOCHEMISTRY OF INTRUSIVE ROCK UNITS

Three samples of the Reid Lakes batholith (99-M-35, 99-M-36 and 00-M-37) and two samples of the Moose Creek pluton (99-M-37 and 99-M-109a) were analyzed (Table 2). The Reid Lakes batholith samples range from diorite to quartz diorite in composition and are metaluminous to weakly peraluminous, whereas the Moose Creek pluton samples yield granodiorite to granite compositions and are peraluminous in composition (Figs. 2a and 2b). All of the samples fall in the 'volcanic arc granite/syn-collisional granite' field on a Nb vs. Y plot (Fig. 2c). Calculated ferrous/ferric iron ratios indicate that the Reid Lakes batholith and Moose Creek samples are both relatively reduced, which corresponds to their low, but different, measured magnetic susceptibilities (Tables 1 and 2).

U-PB DATING RESULTS

Two samples of the Reid Lakes batholith were dated using U-Pb zircon methods. Both samples yielded abundant coarse euhedral zircons, with no visible cores. Four fractions of strongly abraded zircon from sample 99-M-35 (Fig. 1) were analyzed using ID-TIMS methods (Table 3). This sample consists of medium to coarse-grained, equigranular, moderately altered but unfoliated hornblende-biotite granodiorite. Despite the strong abrasion, all four fractions were moderately discordant (Fig. 3a), indicating that a significant amount of post-crystallization lead loss had occurred. Sixteen line scans of zircons from this same sample were subsequently analysed using LA-ICP-MS methods (Table 4). All of these analyses were concordant (Fig. 3b), although two analyses yielded ²⁰⁶Pb/²³⁸U ages that are statistically anomalous. A weighted average of the ²⁰⁶Pb/²³⁸U ages for the remaining 14 analyses is 341.5 ± 0.7 Ma (mean square of weighted deviates, or MSWD, = 0.5; probability of fit, or POF, = 0.9). This is taken as the best estimate for the

Table 3. ID-TIMS U-Pb analytical data for sample 99-M-35.

Sample description ^a	Wt (mg)	U (ppm)	Pb (ppm) ^b	²⁰⁶ Pb/ ²⁰⁴ Pb (meas.) ^c	Total common Pb (pg)	% ²⁰⁸ Pb ^c	²⁰⁶ Pb/ ²³⁸ U ^d (± % 1σ)	²⁰⁷ Pb/ ²³⁵ U ^d (± % 1σ)	²⁰⁷ Pb/ ²⁰⁶ Pb ^d (± % 1σ)	²⁰⁶ Pb/ ²³⁸ U age (Ma; ± % 2σ)	²⁰⁷ Pb/ ²⁰⁶ Pb age (Ma; ± % 2σ)
A: N1,+149	0.064	201	11.7	11630	4	16.7	0.05359 (0.16)	0.3945 (0.21)	0.05338 (0.11)	336.5 (1.0)	345.0 (5.2)
B: N1,+149	0.080	191	10.6	7851	6	16.8	0.05080 (0.14)	0.3761 (0.21)	0.05371 (0.10)	319.4 (0.9)	358.7 (4.6)
C: N1,+149	0.101	172	9.9	8916	6	18.2	0.05178 (0.11)	0.3811 (0.18)	0.05338 (0.10)	325.4 (0.7)	344.8 (4.6)
D: N1,+149	0.067	180	10.6	11130	4	18.3	0.05343 (0.17)	0.3928 (0.22)	0.05332 (0.10)	335.5 (1.1)	342.6 (4.5)

^aN1 = non-magnetic at one degree side slope on Frantz magnetic separator; grain size given in microns

^bradiogenic Pb, corrected for blank, initial common Pb, and spike

^ccorrected for spike and fractionation as determined from replicate analyses of NBS common Pb standards

^dcorrected for blank, fractionation and initial common Pb

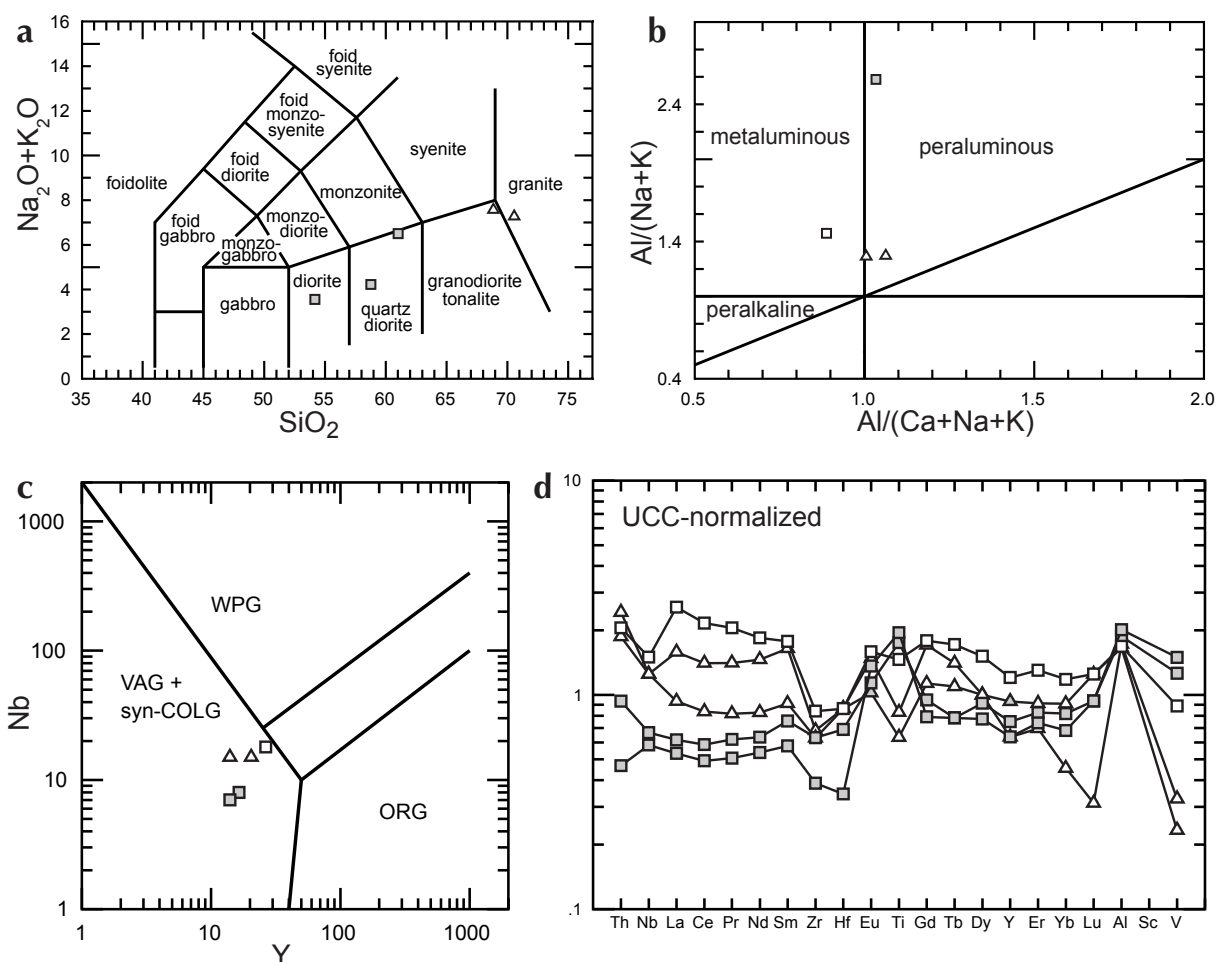


Figure 2. Discriminant plots of geochemical analyses of Reid Lakes batholith and Moose Creek pluton samples: **(a)** total alkalis versus silica (LeBas et al., 1986); **(b)** Shand alkalinity diagram; **(c)** Niobium versus Yttrium discriminant plot; WPG = within plate granite; VAG = volcanic arc granite; COLG = collisional granite; ORG = orogenic granite (Pearce et al., 1984); **(d)** Upper continental crust (UCC) normalized trace and rare earth element plot (normalized to values of McClennan, 2001); Moose Creek pluton samples are represented by open triangles, Reid Lakes batholith samples 99-M-35 and 99-M-36 are indicated by grey squares, and sample 00-M-35 is indicated by open squares.

crystallization age of the sample. The anomalously old ages for the two analyses indicate the presence of a minor component of slightly older xenocrystic or inherited zircon component in the sample.

A second sample of the Reid Lakes batholith (sample 00-M-37; Fig. 1) was collected approximately 4 km to the southeast of sample 99-M-35. This sample was from the K-feldspar porphyritic phase of the batholith described above. Zircons from this sample were similar in appearance to those from sample 99-M-35. Sixteen analyses were carried out on zircons from within sample

00-M-37 (Table 4; Fig. 4a). Fifteen of the analyses yielded overlapping concordant analyses. A weighted average of the $^{206}\text{Pb}/^{238}\text{U}$ ages for the fifteen analyses is 355.9 ± 0.8 Ma (MSWD = 0.3; POF = 1.0), which is taken as the best estimate for the crystallization age of the sample. A single analysis yields a somewhat younger age, reflecting significant post-crystallization Pb-loss.

A sample of massive, K-feldspar megacrystic biotite granite of the Moose Creek pluton was collected approximately 5 km southeast of the Moose Creek Lodge (sample 99-M-109a, Fig. 1). The sample yielded a moderate

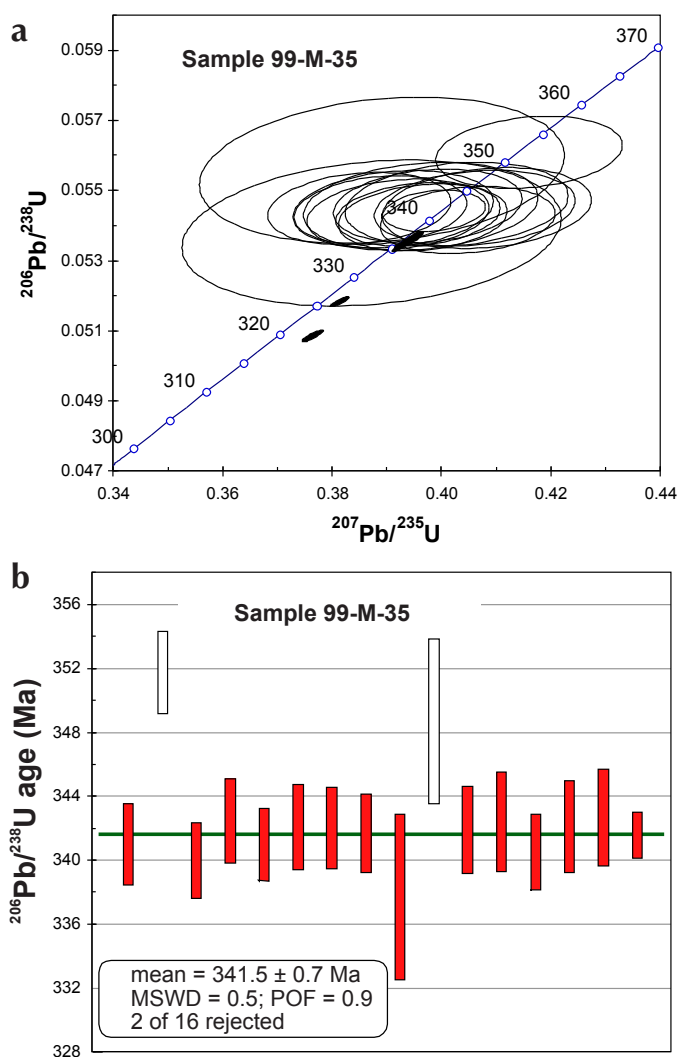


Figure 3. Concordia diagram illustrating: (a) U-Pb zircon analyses for sample 99-M-35 by ID-TIMS (solid ellipses) and LA-ICP-MS (open ellipses) methods; and (b) plot of $^{206}\text{Pb}/^{238}\text{U}$ ages for zircons from sample 99-M-35 completed using LA-ICP-MS methods. Errors are shown at the two sigma level (rejected analyses shown by open bars).

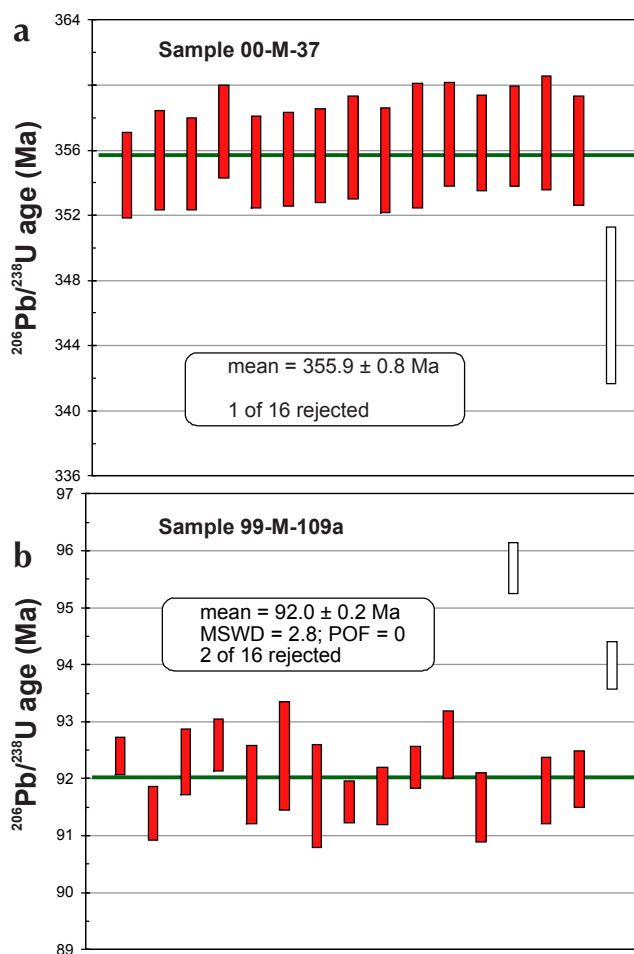


Figure 4. Plots of $^{206}\text{Pb}/^{238}\text{U}$ ages for zircons from samples 00-M-37 (a) and 99-M-109a (b) completed using LA-ICP-MS methods. Errors are shown at the two sigma level (rejected analyses are represented by open bars).

Table 4. LA-ICP-MS U-Pb analytical data for samples 99-M-35 and 00-M-37.

Analysis	Isotope ratios (1 sigma error)						Calculated ages (1 sigma error)						Ion count rate (cps)							
	²⁰⁷ Pb/ ²⁰⁶ Pb	error	²⁰⁷ Pb/ ²³⁵ U	error	²⁰⁶ Pb/ ²³⁸ U	error	²⁰⁷ Pb/ ²⁰⁶ Pb	error	²⁰⁷ Pb/ ²³⁵ U	error	²⁰⁶ Pb/ ²³⁸ U	error	202	204	206	207	208	232	235	238
Sample 99-M-35																				
a	0.05248	0.00083	0.39204	0.00681	0.05432	0.00041	306.2	35.79	335.9	4.97	341	2.52	57	0	18022	946	4126	3978	2185	18817
b	0.05376	0.00082	0.41601	0.00697	0.05609	0.00042	360.8	33.97	353.2	5	351.8	2.58	0	0	23215	1249	5765	5466	2723	23519
c	0.05435	0.0008	0.40481	0.00653	0.05416	0.00039	385.4	32.63	345.1	4.72	340	2.39	6	37	21902	1191	5705	5566	2673	23018
d	0.05255	0.00085	0.39749	0.00705	0.05456	0.00043	309.3	36.24	339.8	5.13	342.5	2.64	49	26	22566	1187	5338	5386	2717	23585
e	0.05323	0.00075	0.39575	0.00614	0.05432	0.00037	338.7	31.69	338.6	4.47	341	2.28	48	0	19323	1029	4393	4145	2375	20359
f	0.05348	0.0009	0.40614	0.0075	0.0545	0.00044	349.1	37.68	346.1	5.41	342.1	2.69	0	9	15887	850	3149	2936	1915	16714
g	0.05238	0.00086	0.38497	0.00684	0.05449	0.00042	302	36.76	330.7	5.02	342	2.57	34	22	19501	1022	5000	5189	2433	20558
h	0.05283	0.0008	0.38885	0.00645	0.05444	0.0004	321.5	34.04	333.5	4.72	341.7	2.45	0	0	21076	1115	5297	5287	2631	22278
i	0.05362	0.00181	0.38723	0.01416	0.05379	0.00085	355.1	74.25	332.3	10.37	337.7	5.22	98	2	8461	454	1475	1178	1080	9085
j	0.05362	0.00174	0.38911	0.01363	0.05558	0.00085	355	71.33	333.7	9.96	348.7	5.17	86	31	7837	420	1096	919	997	8158
k	0.0532	0.00094	0.39118	0.00748	0.05447	0.00045	337.2	39.3	335.2	5.46	341.9	2.75	37	0	14546	775	3858	3887	1830	15479
l	0.0539	0.0011	0.3962	0.00877	0.05455	0.00051	366.8	45.6	339.9	6.38	342.4	3.13	0	31	11544	623	2745	2634	1456	12289
m	0.05418	0.00078	0.39659	0.00631	0.05423	0.00039	378.4	32.36	339.2	4.59	340.5	2.4	46	42	29687	1611	8443	9253	3773	31904
n	0.05324	0.00092	0.4083	0.00782	0.0545	0.00047	338.9	38.74	347.6	5.64	342.1	2.86	0	19	25861	1379	5526	5412	3142	27711
o	0.05325	0.00101	0.40279	0.00834	0.05461	0.00049	339.2	42.26	343.7	6.03	342.7	3.01	39	0	14146	754	3295	3381	1746	15154
p	0.05351	0.00046	0.39866	0.00382	0.05442	0.00024	350.3	19.39	340.7	2.78	341.6	1.44	74	19	87053	4668	15048	16298	10929	93752
Sample 00-M-37																				
a	0.05349	0.00082	0.41966	0.00708	0.05652	0.00043	349.7	34.34	355.8	5.06	354.5	2.62	0	0	46288	2476	7699	7626	5570	48311
b	0.05361	0.00096	0.42061	0.00825	0.05668	0.0005	354.4	39.93	356.5	5.89	355.4	3.04	25	3	28758	1542	4232	4083	3460	29935
c	0.05425	0.0009	0.42208	0.00771	0.05665	0.00047	381.3	36.99	357.5	5.5	355.2	2.84	58	0	34793	1889	5024	4965	4223	36246
d	0.05406	0.0009	0.42431	0.00779	0.05697	0.00047	373.3	37.29	359.1	5.55	357.2	2.88	91	34	49263	2666	7309	7055	5927	51030
e	0.05367	0.00089	0.41421	0.00754	0.05666	0.00047	357	37.09	351.9	5.41	355.3	2.84	61	0	51428	2766	7247	7129	6294	53582
f	0.05564	0.00093	0.43112	0.00791	0.05669	0.00047	437.5	36.35	364	5.61	355.5	2.87	12	0	38914	2170	8245	7969	4744	40528
g	0.05361	0.0009	0.42157	0.00781	0.05673	0.00048	354.5	37.67	357.2	5.58	355.7	2.9	31	26	55342	2975	11848	11317	6649	57603
h	0.05512	0.00101	0.42855	0.00862	0.05682	0.00052	416.9	40.11	362.1	6.12	356.2	3.16	64	0	43519	1853	5470	5547	4074	34843
i	0.05343	0.00102	0.42227	0.00882	0.05669	0.00053	347.2	42.45	357.7	6.3	355.4	3.24	35	0	32309	1733	4477	3922	3864	33672
j	0.0542	0.00123	0.42552	0.01058	0.05683	0.00063	379.1	50.06	360	7.54	356.3	3.85	17	34	18779	1022	2565	2252	2261	19523
k	0.05349	0.001	0.42247	0.00867	0.05693	0.00052	349.6	41.81	357.8	6.19	357	3.18	14	10	24706	1328	3819	3570	2957	25642
l	0.05309	0.00092	0.41361	0.00782	0.05686	0.00049	332.5	38.51	351.5	5.62	356.5	2.96	17	0	45317	2418	9517	9692	5500	47102
m	0.05328	0.00096	0.42431	0.00841	0.05692	0.00051	340.7	40.19	359.1	5.99	356.9	3.11	43	0	39820	2134	7637	7328	4729	41355
n	0.05195	0.00107	0.40534	0.00918	0.05695	0.00058	283.2	46.53	345.5	6.64	357.1	3.53	40	0	29329	1533	5405	5273	3555	30448
o	0.05433	0.00105	0.41913	0.00893	0.05678	0.00055	384.7	42.77	355.4	6.39	356	3.36	0	0	44850	2453	6940	6694	5500	46712
p	0.05577	0.00157	0.42051	0.01306	0.05523	0.00079	442.8	61.29	356.4	9.34	346.5	4.83	24	21	26154	1469	5344	5218	3281	28008
Sample 99-M-109a																				
a	0.04915	0.00045	0.09759	0.0009	0.01444	0.00005	155.1	21.34	94.5	0.83	92.4	0.33	17	7	46301	2278	1762	6036	22024	189472
b	0.05057	0.00066	0.09927	0.00128	0.01428	0.00007	221.1	29.83	96.1	1.18	91.4	0.47	80	0	38943	1973	5125	19300	18731	161196
c	0.04717	0.00078	0.09437	0.00154	0.01442	0.00009	57.4	38.18	91.6	1.43	92.3	0.57	93	0	22549	1066	451	1761	10641	92459
d	0.04899	0.00062	0.09671	0.00122	0.01447	0.00007	147.2	29.65	93.7	1.13	92.6	0.46	0	1	38121	1874	1048	3807	18229	155782
e	0.05033	0.00097	0.09818	0.00186	0.01436	0.00011	210.5	43.86	95.1	1.72	91.9	0.68	0	13	22590	1143	994	3808	10930	92994
f	0.05038	0.0014	0.09975	0.00273	0.01443	0.00015	212.5	63.17	96.5	2.52	92.4	0.95	0	11	11204	568	592	1496	5340	45914
g	0.05272	0.00134	0.10313	0.00258	0.01433	0.00014	316.5	56.71	99.7	2.38	91.7	0.9	108	0	13601	722	833	2828	6560	56153
h	0.04862	0.00049	0.09637	0.00097	0.01431	0.00006	129.4	23.44	93.4	0.9	91.6	0.37	66	38	51291	2514	1182	4506	24414	211979
i	0.04774	0.0007	0.09435	0.00138	0.01432	0.00008	85.4	35.36	91.5	1.28	91.7	0.51	0	0	25688	1238	654	2246	12261	106143
j	0.04796	0.00049	0.0944	0.00097	0.0144	0.00006	96.1	25.03	91.6	0.9	92.2	0.37	0	6	41446	2009	938	3352	19860	170281
k	0.04926	0.0008	0.09797	0.00158	0.01447	0.00009	160.3	37.67	94.9	1.46	92.6	0.59	38	0	25751	1283	748	2563	12212	105349
l	0.0472	0.00089	0.09326	0.00174	0.01429	0.0001	58.8	44.74	90.5	1.62	91.5	0.61	31	0	15568	743	694	2372	7429	64475
m	0.05537	0.0006	0.11406	0.00124	0.01496	0.00007	426.9	23.78	109.7	1.13	95.7	0.45	0	55	95919	5386	3991	6235	43897	379515
n	0.05178	0.00082	0.10096	0.00159	0.01435	0.00009	275.7	35.79	97.7	1.46	91.8	0.58	55	35	21828	1147	1090	3088	10553	90075
o	0.04756	0.00066	0.09321	0.0013	0.01437	0.00008	76.6	33.47	90.5	1.21	92	0.5	21	15	25832	1248	1483	5310	12423	106484
p	0.0477	0.00051	0.09605	0.00104	0.01469	0.00007	83.7	26.07	93.1	0.97	94	0.42	0	0	104507	5068	2005	6670	48914	421306

number of pale yellow zircons, some of which contained visible cloudy inherited cores. Fourteen LA-ICP-MS U-Pb analyses (Table 4; Fig. 4b), excluding two outliers, yielded a weighted mean ²⁰⁶Pb/²³⁸U age of 92.0 ± 0.2 Ma (MSWD = 2.8; POF = 0), which is taken as the best estimate for the crystallization age of this sample.

DISCUSSION

Results of the study confirm that the Reid Lakes batholith on the southwest side of the TFZ is entirely distinct from the Moose Creek pluton that is immediately adjacent to it on the northeast side of the TFZ, in terms of lithology, geochemistry and crystallization age. Therefore, the juxtaposition of these unrelated intrusive bodies does not constrain the timing of displacement on the fault zone. The two phases of the Reid Lakes batholith described

here yield U-Pb zircon ages that suggest correlation with Early Mississippian intrusive rock units in the Glenlyon map area to the southeast (Tatlain and Ragged plutonic suites of Colpron *et al.*, 2006). Normalized trace and rare earth element patterns for the Reid Lakes batholith samples (Fig. 2d) also support this correlation. The composition and U-Pb zircon age of the Moose Creek pluton indicates that it is part of the South Lansing plutonic suite of Mortensen *et al.* (2000).

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'Windy-McKinley' terrane, western Yukon: new data bearing on its composition, age, correlation and paleotectonic settings

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ABSTRACT

New geochronological and geochemical data from the 'Windy-McKinley'* terrane provide insight into the age, correlation and paleotectonic settings of the various subdivisions of the terrane. U-Pb zircon age determinations for felsic meta-volcanic rocks of the White River formation and gabbro intrusions are Late Devonian and late Middle Triassic respectively. These new age determinations substantiate the proposed correlation of these components of 'Windy-McKinley' terrane with the succession on strike to the northwest which hosts the volcanogenic massive sulphide deposits in the Delta District, Alaska. Trace-element geochemical data from Triassic gabbro intrusions into the Mirror Creek and White River formations, and diabase and gabbro of the Harzburgite Peak-Eikland Mountain ophiolite suggest that magmatism in both subdivisions occurred in supra-subduction zone settings. However, the age of the ophiolite is not known, therefore mafic magmatism may not be coeval across the terrane and may have formed above different subduction zones at different times.

*Quotes are used to indicate that the assignment to Windy and McKinley terranes is obsolete, but a new name has not yet been assigned.

RÉSUMÉ

Les nouvelles données géochronologiques et géochimiques obtenues sur le terrane de Windy-McKinley donnent une idée de l'âge, de la corrélation et du cadre paléotectonique des diverses subdivisions du terrane. D'après les datations (zircons) à l'U/Pb par ablation au laser ICP-MS, les roches métavolcaniques felsiques de la Formation de White River et les intrusions métagabbroïques datent respectivement du Dévonien tardif et du Trias moyen tardif. Ces nouvelles datations justifient la corrélation proposée de ces composantes du terrane Windy-McKinley avec la succession suivant le décrochement vers le nord ouest, qui contient des dépôts sulfurés massifs volcanogènes dans le district de Delta (Alaska). Les données géochimiques sur les éléments traces des intrusions de gabbro du Trias dans les Formations de Mirror Creek et de White River et sur les éléments traces du diabase et du gabbro du complexe d'ophiolite du pic Harzburgite et de la montagne Eikland suggèrent que dans les deux sous-divisions, le magmatisme est survenu dans un contexte de supra-zone de subduction. Toutefois, l'âge de l'ophiolite est inconnu. Par conséquent, le magmatisme mafique pourrait ne pas être du même âge dans l'ensemble du terrane et pourrait s'être produit au dessus de zones de subduction différentes et à des moments différents.

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INTRODUCTION

The 'Windy-McKinley' terrane of western Yukon is a poorly exposed assemblage of schists and ophiolitic rocks that are along strike from, and have been correlated with, rocks of the Windy and McKinley terranes of the Alaska Range (Wheeler and McFeeley, 1991; Monger *et al.*, 1991; Silberling *et al.*, 1992; Gordey and Makepeace, 2001; Fig. 1). Based on reconnaissance mapping in the early 1970s (Tempelman-Kluit, 1974), the correlation with the Windy and McKinley terranes of the Alaska Range has since been placed in doubt owing to several recent studies of the 'Windy-McKinley' terrane of Yukon which have documented the lithological character of the terrane in greater detail and provided preliminary insights into its origin and evolution (Canil and Johnston, 2003; Mortensen and Israel, 2006; Murphy, 2007; Murphy *et al.*, 2007, 2008). The terrane is now known to be composed of two lithostratigraphic assemblages, an imbricated ophiolitic assemblage (Canil and Johnston, 2003) known as the Harzburgite Peak – Eikland Mountain ophiolite,

and an assemblage of variably deformed schists of meta-sedimentary and meta-igneous protoliths (White River and Mirror Creek formations, Murphy *et al.*, 2007, 2008). The schist assemblage has been extensively intruded by variably deformed gabbro of late Middle Triassic age (Mortensen and Israel, 2006). Murphy *et al.* (2008) proposed that the schist and gabbro assemblage correlates with rocks of the Jarvis and Hayes Glacier belts of Alaska's Delta volcanogenic massive sulphide (VMS) district (Dashevsky *et al.*, 2003; Dusel-Bacon *et al.*, 2006 and references therein), citing the association of Triassic gabbro and felsic metavolcanic rocks, an association rarely found in the Cordillera. The age of the Harzburgite Peak – Eikland Mountain ophiolite has not been determined, hindering attempts at correlation; Murphy (2007) proposed correlation with the Chulitna terrane, a mid-Paleozoic supra-subduction zone ophiolite on the opposite side of the Denali fault (Claudice *et al.*, 2001 and references therein).

In this paper, we present new data on the composition, age, correlation and paleo-tectonic settings of the two

lithostratigraphic assemblages of 'Windy-McKinley' terrane. We present preliminary U-Pb age determinations on igneous zircons from felsic meta-volcanic rocks from the White River formation and Triassic gabbro bodies that have implications for the proposed correlation of these rocks with the rocks of the Delta VMS District. Secondly, we present preliminary U-Pb age determinations on detrital zircons from meta-clastic rocks of 'Windy-McKinley' and Yukon-Tanana terranes that bear on potential correlations and terrane affinities. Finally, we present preliminary whole rock geochemical data from mafic rocks of the undated Harzburgite Peak – Eikland Mountain ophiolite and Triassic gabbro that establish them as products of supra-subduction zone magmatism. This conclusion affirms the proposed correlation of the ophiolitic rocks with a supra-subduction zone ophiolite on the

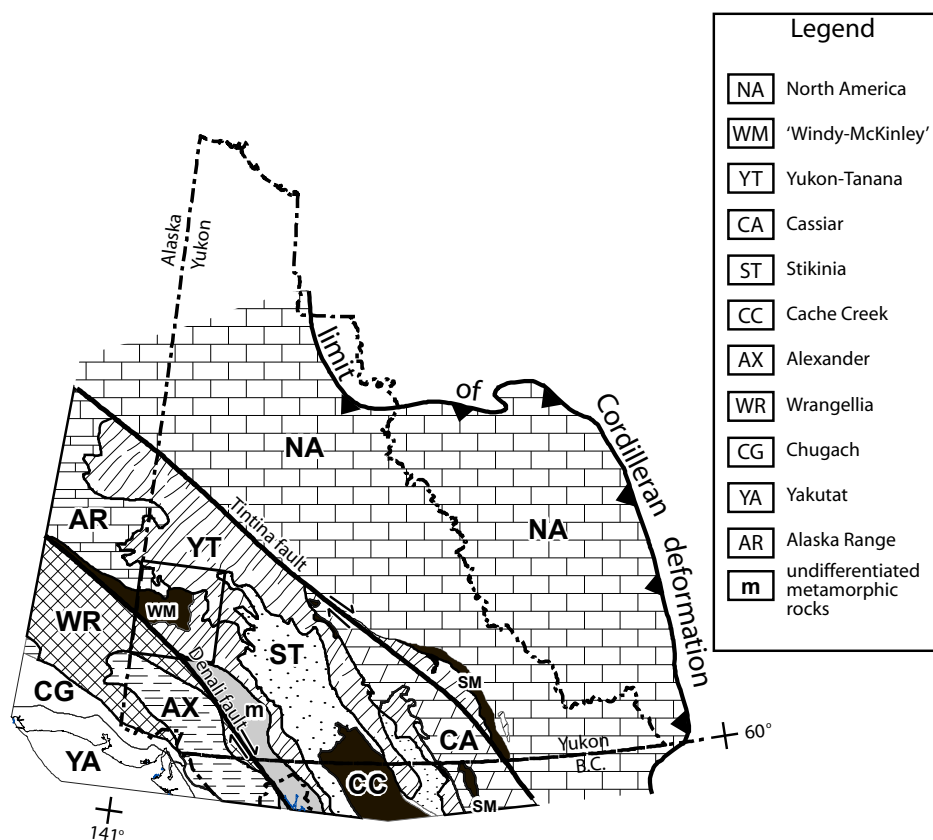


Figure 1. Terrane map illustrating the distribution of 'Windy-McKinley' terrane in western Yukon and eastern Alaska (modified after Colpron *et al.*, 2006). Box indicates area of focus of this paper.

opposite side of the Denali fault, part of the Chulitna terrane of Alaska.

‘WINDY-MCKINLEY’ TERRANE, STEVENSON RIDGE AND KLUANE LAKE AREAS

The two lithostratigraphic assemblages of ‘Windy-McKinley’ terrane have been documented throughout western Stevenson Ridge area (115JK; Murphy, 2007; Murphy *et al.*, 2007, 2008) and have been traced southwardly into northern Kluane Lake area (115FG; Fig. 2). The meta-sedimentary and meta-volcanic schist and gabbro assemblages occur to the west and structurally beneath the Harzburgite Peak – Eikland Mountain ophiolite, and both overlie Yukon-Tanana terrane along a thrust fault.

Murphy *et al.* (2008) divided the schist assemblage into two formations, the felsic (and lesser mafic) meta-volcanic and meta-sedimentary White River formation and the variably carbonaceous and calcareous meta-clastic Mirror Creek formation. Both of these rock units are spatially associated, but in unknown contact relationships, with a quartz-rich meta-clastic unit, herein called the Scottie Creek formation. Murphy *et al.* (2007, 2008) correlated the Scottie Creek formation with the Yukon-Tanana terrane; however, spatial association of the Scottie Creek formation with bodies of gabbro, and new detrital zircon data presented herein support the interpretation that this unit is in stratigraphic succession with the White River and Mirror Creek formations.

All of the schist formations are intruded by, and locally deformed together with, variably foliated gabbro. Gabbro intruding the Mirror Creek formation was previously reported to be late Middle Triassic in age (ca. 228 Ma, Mortensen and Israel, 2006). This paper presents new U-Pb geochronological results that document the ages of gabbro bodies which intrude, or are interfoliated with, rocks of the Mirror Creek, White River and Scottie Creek formations.

The Harzburgite Peak – Eikland Mountain ophiolite extends from northeast to southwest across Stevenson Ridge map area and has been traced southeasterly into Kluane Lake map area where it occurs in a tight synformal keel (Fig. 2). The ophiolite is imbricated (Canil and Johnston, 2003; Murphy *et al.*, 2008) and upper mantle harzburgite, lower crustal gabbro and dunite, and mid-crustal diabase micro-gabbro are generally the best

preserved and exposed parts of the ophiolite. Supracrustal rocks, mainly multi-coloured chert and argillite, occur rarely (Murphy, 2007; Wellesley Lake formation of Murphy *et al.*, 2007, 2008). Preliminary geochemical analyses of diabase from the ophiolite revealed compositions transitional between normal and enriched mid-ocean ridge basalt (Murphy *et al.*, 2008). Below, we present geochemical data from a more comprehensive suite of samples that supports a supra-subduction zone setting for the ophiolite.

U-PB GEOCHRONOLOGICAL STUDIES

Five preliminary U-Pb igneous and six preliminary detrital zircon age determinations are reported here. One sample of felsic meta-volcanic rock of the White River formation was collected from outcrops southeast of the confluence of the White and Donjek rivers. Four samples of foliated gabbro were collected. Of these four samples, one sample is from an isolated body of foliated gabbro within a Cretaceous pluton, but on strike from similar bodies of gabbro spatially associated with the Scottie Creek formation. Another sample is from a large body of gabbro interfoliated with a band of felsic metavolcanic rocks from which the dating sample of the White River formation was collected. The remaining two samples are from bodies of weakly deformed gabbro which intrude the Mirror Creek formation along the Alaska Highway. Finally, of the six detrital samples, three are meta-sandstone from the Mirror Creek formation, two are from the Scottie Creek formation, and one is from the oldest (structurally deepest) quartz-rich meta-clastic unit of Yukon-Tanana terrane. Zircon and baddeleyite recovered from igneous and detrital samples were analyzed using both conventional ID-TIMS and laser ablation LA-ICP-MS U-Pb methods at the Pacific Centre for Isotopic and Geochemical Research. Analytical methods are as described in Mortensen (this volume). As these data are preliminary, we present only plots of the data, in the following formats: concordia diagrams, weighted mean plots, or probability plots; data tables will be presented when the age determinations are finalized.

AGE OF THE WHITE RIVER FORMATION

Of twenty zircons extracted from a sample of quartz- and feldspar-porphyrific, crystal-lithic meta-tuff of the White River formation (Fig. 3a), nine zircons were less than 5% discordant. A weighted average of their $^{206}\text{Pb}/^{238}\text{U}$ ages is 363.0 ± 3.1 Ma and is interpreted as the crystallization age for this rock (Fig. 3b).

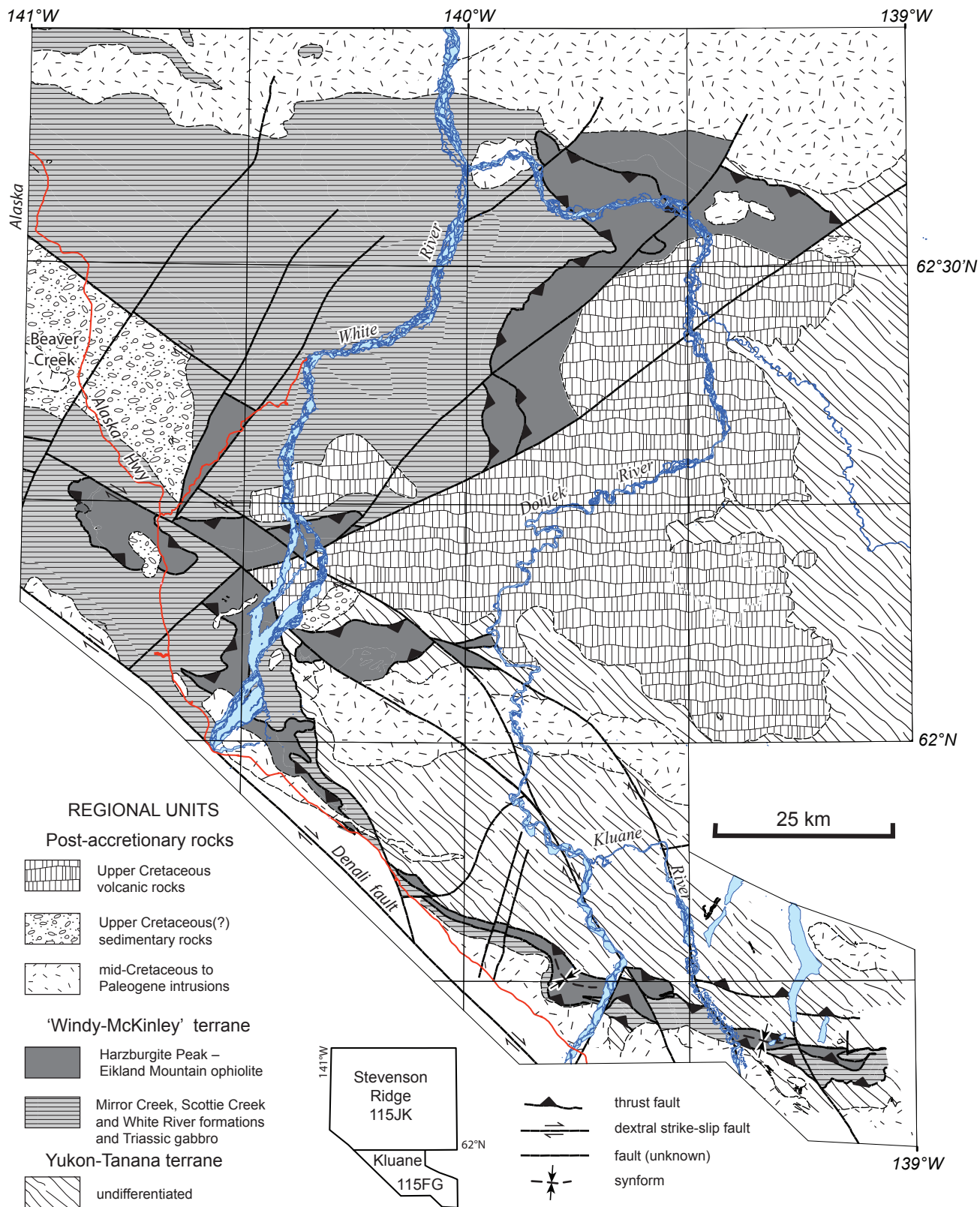


Figure 2. Simplified geology of western Stevenson Ridge and northern Klauene Lake map areas, modified from Murphy et al., (2007).

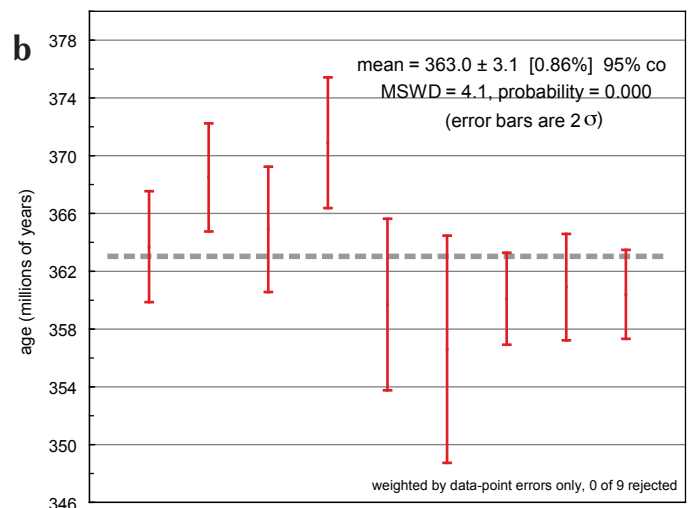


Figure 3. (a) Foliated quartz- and feldspar-porphyrific crystal-lithic tuff of White River formation; sample for dating collected at this outcrop. (b) Weighted mean $^{236}\text{U}/^{208}\text{Pb}$ age of sample collected from outcrop shown in (a).

AGE OF GABBRO

Small amounts of zircon and/or baddeleyite were recovered from four samples of gabbro. Both baddeleyite and air-abraded zircons were analyzed from samples 01M-06 and 01M-08 (which are in close proximity to each other). For sample 01M-06, two fractions of air-abraded zircon give overlapping concordant analyses resulting in a $^{206}\text{Pb}/^{238}\text{U}$ age of 228.2 ± 0.8 Ma (Fig. 4a), which is inferred to be the crystallization age of the gabbro. A third fraction of zircon and a single fraction of unabraded baddeleyite yield slightly younger $^{206}\text{Pb}/^{238}\text{U}$ ages, reflecting the effects of minor post-crystallization Pb-loss. Three fractions of abraded zircon from sample 01M-08 (Fig. 4b) give a range of relatively young $^{206}\text{Pb}/^{238}\text{U}$ ages; however, a single fraction of unabraded baddeleyite gives a $^{206}\text{Pb}/^{238}\text{U}$ age of 227.1 ± 0.6 Ma, which is in excellent agreement with the zircon age from sample 01M-06. The younger ages from the three zircon analyses is interpreted to result from post-crystallization Pb-loss. Sample 04M-41 yielded a very small amount of baddeleyite, which was analyzed in two fractions. Both fractions yield concordant analyses (Fig. 4c). The best estimate for the crystallization age of 04M-41 is given by the older, more precise $^{206}\text{Pb}/^{238}\text{U}$ age, at 227.2 ± 0.6 Ma. A fourth sample of gabbro (sample 07DM-167) yielded abundant zircon, and was analyzed using LA-ICP-MS methods. The weighted average of the $^{206}\text{Pb}/^{238}\text{U}$ ages from 20 individual analyses is 230.9 ± 2.7 Ma (Fig. 4d), which is interpreted as the crystallization age of the sample.

These preliminary ages for four bodies of variably foliated gabbro range from ca. 227 to 231 Ma, indicating that late Middle Triassic gabbro intruded all the formations of the schist assemblage of the ‘Windy-McKinley’ terrane, a conclusion previously inferred on the basis of their similar geochemical compositions (Murphy *et al.*, 2008).

DETRITAL ZIRCON ANALYSES

Our analyses show that each stratigraphic unit has a distinctive detrital zircon signature. Samples from the Mirror Creek and Scottie Creek formations are similar in the older portions of their detrital zircon spectra, but differ in the younger; both differ from the Yukon-Tanana terrane sample.

Yukon-Tanana terrane grit

The sample of Yukon-Tanana terrane grit (Fig. 5) yielded a relatively simple bimodal pattern with prominent age peaks at 1.7 to 2.0 Ga and 2.5 to 2.8 Ga. Single zircon ages at ca. 2.1 and 2.9 Ga just outside these intervals may indicate a greater peak width, however a bimodal pattern would still be apparent.

Scottie Creek formation grit

The samples from the Scottie Creek formation (Fig. 5) are more complex. Both samples have a broad multimodal peak between 1.0 and 1.5 Ga, a prominent 1.7 to 2.0 Ga peak, and a broad multimodal peak between 2.6 and 2.8 Ga. One sample has a single zircon at ca. 340 Ma and

multi-grain peaks at ca. 1.6, 2.35 and 2.45 Ga; these latter intervals are represented by single grains in the other sample. Sample 06DM178 also has single grains at 2.80 to 2.85 Ga and 2.85 to 2.90 Ga.

Mirror Creek formation meta-sandstone

The detrital age spectra for samples of the Mirror Creek formation (Fig. 5) are similar to those of the Scottie Creek formation for ages older than 1.0 Ga, but also include Neoproterozoic and Lower Paleozoic zircons. A prominent multi-grain peak at ca. 450 Ma is common to

all Mirror Creek samples, a two-grain peak at ca. 550 Ma occurs in two of the samples, and one sample has single grain peaks at ca. 650 and 700 Ma.

WHOLE-ROCK GEOCHEMICAL DATA

Three sets of samples were systematically collected during the 2006 to 2008 field seasons for whole-rock geochemical analysis. One set of samples targeted diabase and micro-gabbro from the upper to mid-crustal part of the Harzburgite Peak – Eikland Mountain ophiolite.

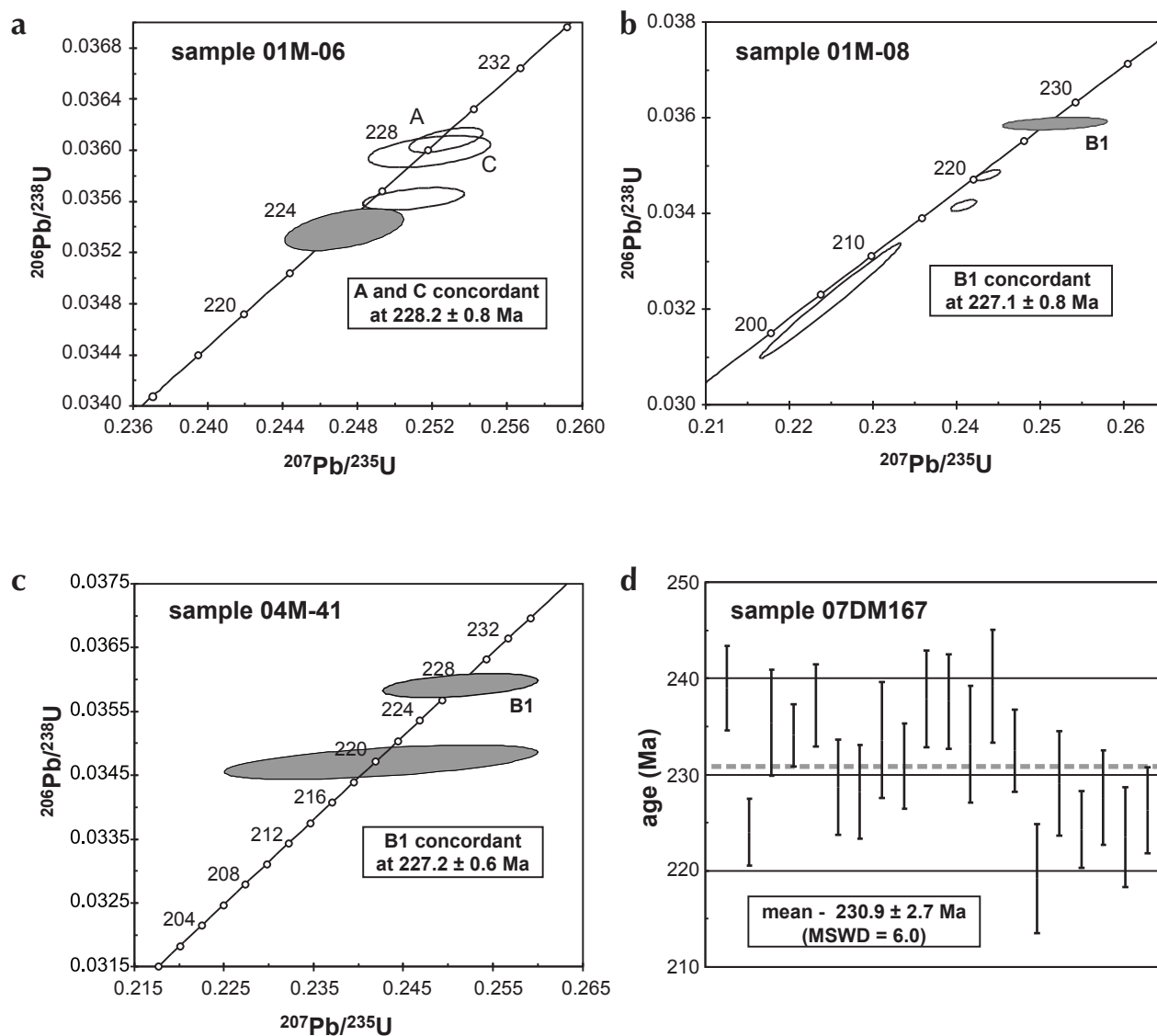


Figure 4. U-Pb analyses for zircon and baddeleyite from gabbro of the schist-gabbro subdivision of 'Windy-McKinley' terrane. Figures 4a-c are plots of ID-TIMS analyses. Error ellipses (zircon = open ellipses; baddeleyite = grey ellipses) are at the $2\text{-}\sigma$ level. Figure 4d is a plot of analyses from sample 07DM-167, which was determined using laser ablation ICP-MS methods. Error bars on individual analyses are at the $2\text{-}\sigma$ level. MSWD refers to the "mean square of the weighted deviates".

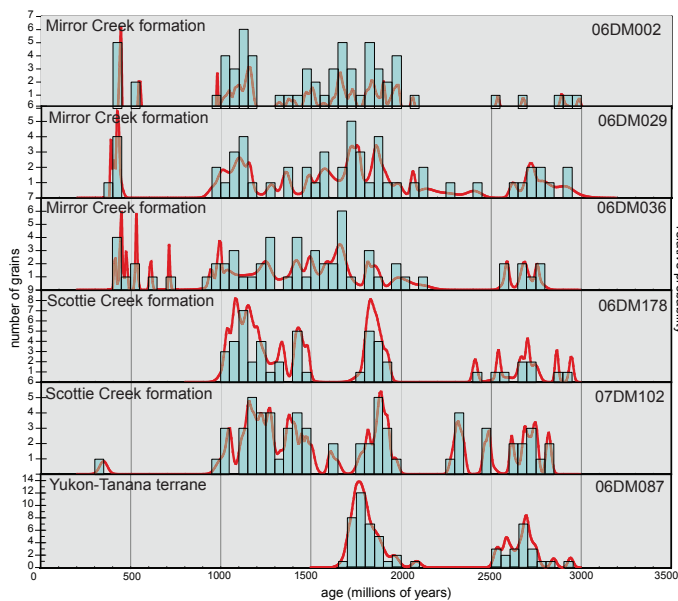


Figure 5. Probability distribution plots showing detrital zircon age distributions for two formations of ‘Windy-McKinley’ terrane (Mirror Creek and Scottie Creek formations) and Yukon-Tanana terrane. See text for discussion.

A second set of samples of foliated greenstone of unknown protolith, yet spatially associated with chert and argillite, was collected from the supracrustal part of the ophiolite. The third set of samples is from bodies of Triassic gabbro intruding the schist assemblage. Samples were selected and prepared to be free of weathered surfaces, veins and alteration before being sent to Activation Laboratories of Ancaster, Ontario for research-grade analyses. In 2007, major element analyses were done by XRF and trace elements by ICP fusion mass spectrometry. In 2008, all elements were analyzed by ICP fusion mass spectrometry. Owing to the relative resistance of certain trace elements to changes in composition during epigenetic processes such as sea-floor metamorphism, orogenic metamorphism or metasomatism, most geochemical studies of deformed and/or metamorphosed igneous rocks in orogenic belts utilize the concentrations of trace-element in their analyses (e.g., Shervais and Metcalf, 2003; Piercey *et al.*, 2006), a practice which was followed during our analyses.

HARZBURGITE PEAK – EIKLAND MOUNTAIN OPHIOLITE

Seventeen samples from the ophiolite were analyzed. Eleven of these are from massive to weakly plagioclase-porphyritic diabase or micro-gabbro occurring above

coarse-grained gabbro in the ophiolite succession. The remaining six of these samples are from bodies of variably foliated greenstone spatially associated with the chert and argillite in the supracrustal part of the ophiolite, but of unknown protolith. The ophiolite is imbricated so the original succession is not preserved and therefore, the relative ages of the samples with respect to each other have not been established.

With three exceptions, all samples are tholeiitic basaltic in composition (Fig. 6a,b); the exceptions are three samples of andesite in the supracrustal part of the ophiolite which are transitional to calc-alkalic in affinity. In detail, the sample set can be divided into three geochemical suites, a light-rare-earth-element (LREE)-enriched suite, a non-LREE-enriched suite with Th/Nb ratios >1, and a non-LREE-enriched suite with Th/Nb ratios <1 (Fig. 6c-e). The LREE-enriched suite comprises mainly samples from the supracrustal part of the ophiolite; it is characterized by flat primitive-mantle normalized heavy-rare-earth-element (HREE) profiles with relatively sharp enrichments of Eu and lighter elements, and a Th/Nb ratio >>1. The non-LREE-enriched suites have generally flat primitive-mantle-normalized patterns and differ only in their Th/Nb ratios. The non-LREE-enriched suite with Th/Nb ratios <1 is enriched in concentrations of all trace-elements relative to average normal (NMORB) and enriched mid-ocean ridge (EMORB) compositions and have different patterns of enrichment relative to average ocean island basalts (OIB; Fig. 6f). When compared to the average compositions of different types of subduction-generated basalts, the non-LREE-enriched suite with Th/Nb >1 are more enriched in trace-element concentrations than a typical island arc tholeiite (IAT), but show some similarities to average LREE-enriched tholeiite (L-IAT; Fig. 6g) and with back-arc basin basalts (BABB) from the Lau Basin (Fig. 6g). The LREE-enriched suite is similar to calc-alkaline basalt typical of relatively mature island arcs (CAB; Fig. 6h).

TRIASSIC GABBRO

Twenty samples of Triassic gabbro were analyzed. All samples are basaltic in composition with tholeiitic to transitional affinities (Fig. 7a,b). All samples are generally rare-earth-element-enriched relative to primitive mantle (Figs. 7c,d) and are slightly more enriched in the lighter rare-earth elements. Two suites are apparent in the trace-element patterns, one with a Th/Nb ratios <1 and the other with Th/Nb ratios >1. When compared with the trace-element compositions of basalts from modern tectonic settings, the Th/Nb <1 suite most strongly

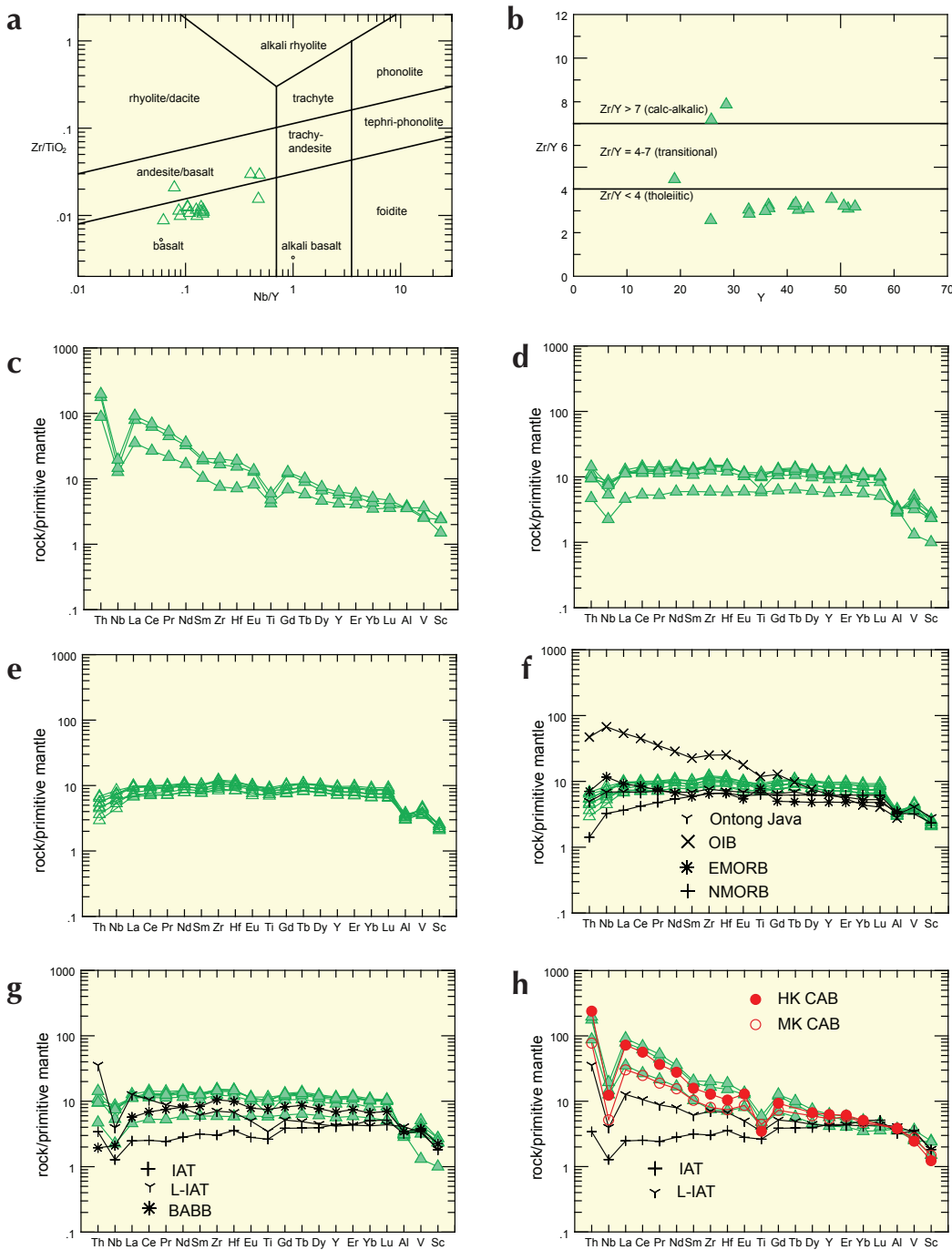
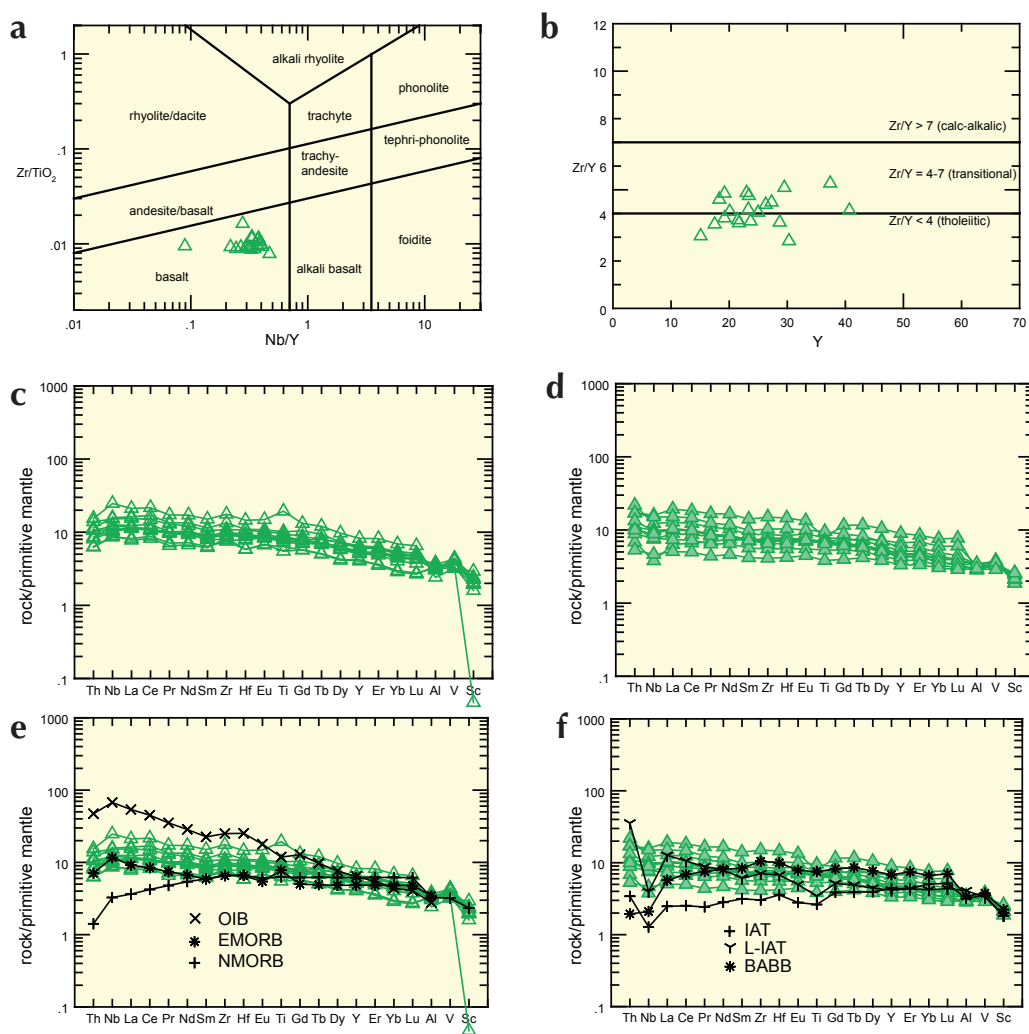


Figure 6. (opposite page) Trace-element geochemical characteristics of diabase and foliated greenstone from the Harzburgite Peak – Eikland Mountain ophiolite. (a) A revised Winchester-Floyd composition diagram (Winchester and Floyd, 1977); and (b) Zr/Y vs. Y diagram (Barrett and McLean, 1999). (c-h) Primitive mantle-normalized trace-element plots (values for primitive mantle from Sun and McDonough, 1989): (c-e) three suites from Harzburgite Peak – Eikland Mountain ophiolite; and (f-h) three suites compared with basalts from modern tectonic settings. OIB = ocean island basalt; EMORB = enriched mid-ocean basalt; NMORB = normal mid-ocean ridge basalt; IAT = island arc tholeiite; L-IAT = light rare-earth-element-enriched island arc tholeiite; BABB = back-arc basin basalt; HK CAB = high potassium calc-alkaline basalt; MK CAB = medium potassium calc-alkaline basalt. OIB, EMORB, NMORB values are from Sun and McDonough (1989). IAT values are from Piercey (2001) and Piercey et al. (2004). L-IAT values are from Shinjo et al., 2000. BABB values are from Ewart et al. (1994) and CAB, from Stoltz et al. (1990). See text for discussion.

Figure 7. Trace-element geochemical characteristics of late Middle Triassic gabbro. **(a)** A revised Winchester-Floyd composition diagram (Winchester and Floyd, 1977); **(b)** Zr/Y vs. Y diagram (Barrett and McLean, 1999). **(c-h)** Primitive mantle-normalized trace-element plots: **(c-e)** two suites defined by trace-element plots; **(f-h)** two suites compared with basalts from modern tectonic settings. Primitive mantle values from Sun and McDonough (1989) and abbreviations as in Figure 6. See text for discussion.



resembles an EMORB composition, although generally more enriched in all the trace-elements (Fig. 7e). The Th/Nb > 1 suite, as with one of the Harzburgite Peak – Eikland Mountain ophiolite suites, resembles compositions from modern arc settings (Fig. 7f).

DISCUSSION

The analytical data presented herein bear directly on the age, correlation, mineral potential and paleo-tectonic settings of the different subdivisions of ‘Windy-McKinley’ terrane.

U-Pb crystallization ages for the White River formation and the gabbro bodies intruding the schist subdivision of ‘Windy-McKinley’ terrane are identical to U-Pb age determinations for felsic metavolcanic rocks (Dusel-Bacon *et al.*, 2006; Dashevsky *et al.*, 2003) and gabbro (Dashevsky *et al.*, 2003) in the Delta district in the eastern

Alaska Range located along strike approximately 150 km west-northwest of the Yukon-Alaska border. The new data presented here lend substance to the correlation between the areas proposed by Murphy *et al.* (2008). The White River formation is coeval with the Drum unit of the Delta District which hosts several volcanogenic massive sulphide (VMS) deposits, hence our new age data are metallogenically significant.

The new detrital zircon data forms the basis of a tentative stratigraphic interpretation and correlations for the schist subdivision of ‘Windy-McKinley’ terrane. The presence of a single Early Mississippian detrital zircon in the Scottie Creek formation implies an Early Mississippian or younger age. This single grain, although preliminary and in need of corroboration, suggests that the Scottie Creek formation stratigraphically overlies the Late Devonian White River formation. Furthermore, it invites correlation with the lithologically similar Tok River unit of the Delta district

which overlies the Drum unit (Dashevsky *et al.*, 2003). The lower grade of metamorphism and lower degree of deformation of the Mirror Creek formation relative to both the Scottie Creek or White River formations, and its detrital zircon modes younger than those of the Scottie Creek formation, suggest that the Mirror Creek formation is stratigraphically younger than the Scottie Creek formation. We tentatively correlate the Mirror Creek formation with the lithologically similar upper part of the Hayes Glacier belt of the Delta District, which overlies the Jarvis belt containing the Drum and Tok River units (Dashevsky *et al.*, 2003).

The rocks of the Delta District have traditionally been correlated westwardly with sequences in the Alaska Range. Nokleberg *et al.* (1992) correlated the Late Devonian felsic meta-volcanic-bearing rocks of the Jarvis belt with coeval rocks in the Bonnifield District in the northern Alaska Range and the Hayes Glacier belt, with similar rocks in the central Alaska Range south of the Hines Creek fault. Wilson *et al.* (1998) correlated rocks south of the Hines Creek fault with the Upper Devonian Yanert Fork sequence and the positionally overlying Upper Triassic unit Trcs of the Healy quadrangle to the west (Csetjey *et al.*, 1992; Pingston terrane of Jones *et al.*, 1982); all of these units are voluminously and extensively intruded by gabbro and diabase. Dusel-Bacon *et al.* (2006) correlated the rocks of the Delta District with the Bonnifield District and interpreted them both as being part of the para-autochthonous North American continental margin.

Owing to the notable absence of bodies of gabbro in the Bonnifield District, we favour a correlation of the schist-gabbro assemblages of the Delta District and the 'Windy-McKinley' terrane with the Yanert Fork sequence and unit Trcs in the central Alaska Range south of the Hines Creek fault, rather than with the para-autochthonous North American continental margin rocks of the Bonnifield District. This correlation defines a belt of rocks that superficially resembles both the allochthonous Yukon-Tanana terrane and the rocks of the para-autochthonous North American continental margin, but differs in key ways. The presence of voluminous late Middle Triassic gabbro distinguishes the 'Windy-McKinley' belt lithologically from nearby parts of Yukon-Tanana terrane and implies an Early Mesozoic history distinct from the Yukon-Tanana terrane. Detrital zircon age spectra from the Scottie Creek and Mirror Creek formations differ from both nearby Yukon-Tanana terrane and para-autochthonous North American margin spectra in their

large populations of 1.0 to 1.6 Ga zircons, and in the case of the Mirror Creek formation, significant Neoproterozoic, Cambrian and Silurian zircon populations (Nelson and Gehrels, 2007; Bradley *et al.*, 2007, 2008; Dusel-Bacon, pers. comm., 2008; Fig. 5). These latter ages are common in rocks of the Insular terranes (Bradley *et al.*, 2007; Colpron and Nelson, in press), suggesting that they may be a possible source for the Mirror Creek formation.

Lithological and detrital zircon differences notwithstanding, the 'Windy-McKinley' belt could still be of Laurentian affinity, or in part, a post-amalgamation sequence overlapping terranes of the Laurentian and Insular realms. Late Middle Triassic gabbro sills intrude para-autochthonous North American rocks of the Tombstone thrust sheet in western Yukon (Tempelman-Kluit, 1970; Thompson *et al.*, 1992; Mortensen and Thompson, 1990), as well as the correlative Beaver Creek thrust sheet in Alaska, north of Fairbanks (Weber *et al.*, 1992; Tempelman-Kluit, 1984; Gabrielse *et al.*, 2006; Mortensen, unpublished data). Relatively minor populations of 1.0 to 1.6 Ga zircons occur locally in Yukon-Tanana terrane, as well as in autochthonous and para-autochthonous rocks of the North American continental margin (Wickersham grit of Alaska and correlative Hyland Group of Yukon, Ross *et al.*, 2005; Bradley *et al.*, 2007, 2008). The source of these zircons is not known. Basement rocks of this age are not exposed in the northern Cordillera, but they have been inferred to be in the subsurface based on occurrences of clasts containing zircons of that age found in diatremes (Jefferson and Parrish, 1989; Milidragovic, 2008). Neoproterozoic, Cambrian and Silurian zircons in the Mirror Creek formation were likely derived from the non-Laurentian Insular terranes, which make up most of northern, western and southern Alaska, and southwestern Yukon (Bradley *et al.*, 2007); some of these terranes were sutured to northwestern Laurentia as early as Middle Devonian (Lane, 2007; Colpron and Nelson, in press). Till *et al.* (2007) and Csetjey *et al.* (1992) documented depositional contacts of unit Trcs with the para-autochthonous continental margin sequence in the Kantishna Hills west of the Bonnifield District, and with the Yanert Fork sequence between the Hines Creek and McKinley strands of the Denali fault. In the westernmost part of the area between the Hines Creek and McKinley strands, unit Trcs is located near, but in unknown relationship with, the Farewell terrane. The Yanert Fork sequence and unit Trcs also occur south of the McKinley strand, near the northernmost exposures of the Insular superterrane. The Mirror Creek formation and westwardly

correlative Upper Triassic clastic rocks of unit Trcs could therefore be an overlap sequence onto rocks of both Laurentian (Yukon-Tanana terrane and para-autochthonous North American margin rocks of Yukon-Tanana upland) and non-Laurentian origin.

The geochemical data from the late Middle Triassic gabbro and the Harzburgite Peak – Eikland Mountain ophiolite provide some insight into the paleo-tectonic setting(s) of the magmatic episode(s). When compared with modern basaltic rocks from well constrained tectonic settings, the trace-element geochemical character of both the late Middle Triassic gabbro and, in particular, the ophiolite, is most like the geochemical character of rocks from suprasubduction zone settings (e.g., Shervais and Metcalf, 2003). Each episode has one suite that resembles either NMORB or EMORB compositions, but is overall more enriched across the spectrum of rare-earth elements. Another suite having $\text{Th}/\text{Nb} > 1$ resembles LREE-enriched island arc tholeiites and back-arc basin basalts. When plotted on a Th/Yb versus Nb/Yb diagram (Pearce and Peate, 1995), the Triassic gabbro samples plot in a cluster around the EMORB composition, but offset from the mantle enrichment array in the direction of subduction zone enrichment (Fig. 8). Similarly, the ophiolite samples plot in a cluster around the primitive mantle and NMORB compositions, but are also offset in the direction of subduction zone enrichment. The exceptions are the three samples of andesitic composition from the supracrustal levels of the ophiolite which plot with upper continental crust values; this composition may reflect crustal contamination. Although not conclusive, all of these characteristics suggest a suprasubduction zone setting for both the Triassic gabbro and the ophiolite.

The geochemical data from the ophiolite provides some support for its correlation with parts of the Chulitna terrane (Jones *et al.*, 1982; Clautice *et al.*, 2001), a suprasubduction zone ophiolite located in the southern Alaska Range south of the Denali fault (Murphy, 2007). Doubt was shed on this correlation by Murphy *et al.* (2008) on the basis of the non-arc-like geochemical characteristics of a small set of samples from the ophiolite; our more comprehensive sampling has revealed a more arc-like character, thereby permitting a correlation with the Chulitna terrane. If correlative, the Harzburgite Peak – Eikland Mountain ophiolite would then be Devonian to Permian in age and therefore older than the Triassic gabbro intruding the schist subdivision, further implying that the Harzburgite Peak – Eikland Mountain ophiolite and Triassic gabbros formed above different

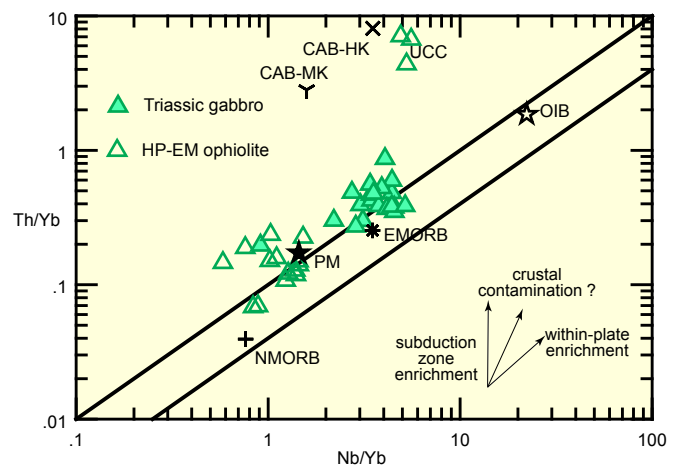


Figure 8. Th/Yb vs. Nb/Yb diagram (Pearce and Peate, 1995) comparing samples of Triassic gabbro with those from the Harzburgite Peak – Eikland Mountain ophiolite (HP-EM ophiolite). The plot illustrates enrichments due to subduction zone processes and/or contamination. Abbreviations as in Figure 6. See text for discussion.

subduction zones. Geochronological data from the ophiolite are necessary to establish the age of the ophiolite before its correlation and relationship with the Triassic gabbro can be further evaluated.

CONCLUSIONS

1. New ages from the felsic metavolcanic rocks and gabbro of ‘Windy-McKinley’ terrane substantiate the proposed correlation of these rocks with the rocks of the Delta District, Alaska. This correlation makes the ‘Windy-McKinley’ terrane prospective for volcanogenic massive sulphide deposits.
2. Detrital zircon data from the different formations of the schist-gabbro subdivision, and the difference in degree of deformation and metamorphism between the Mirror Creek and other formations of the subdivision, suggest that the Late Devonian White River formation is overlain by the Scottie Creek formation followed by the Mirror Creek formation. This stratigraphic succession is similar to that of the Delta District, further supporting the proposed correlation.

3. The correlation of the Delta District can be extended westward to include rocks between the Hines Creek and McKinley strands of the Denali fault, the Yanert Fork sequence and Pingston terrane. This belt of 'Windy-McKinley'-like rocks is distinguished from rocks of the para-autochthonous part of Yukon-Tanana terrane to the north with which they were originally correlated, on the basis of voluminous late Middle Triassic mafic magmatism and differences in detrital zircon characteristics.
4. The trace-element geochemical character of Triassic gabbro of the schist-gabbro subdivision and mafic rocks of the Harzburgite Peak – Eikland Mountain ophiolite suggest a suprasubduction zone setting for both.
5. A suprasubduction zone setting for the Harzburgite Peak – Eikland Mountain ophiolite permits a proposed correlation with disrupted ophiolitic rocks of the Chulitna terrane. If correlative, the Harzburgite Peak – Eikland Mountain ophiolite would be mid-Paleozoic in age. The Triassic gabbro would therefore have formed above a younger subduction zone.

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What's the Yukon Territory made of? Earth materials portrayed on a geological highway map

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ABSTRACT

The Yukon Geological Survey (YGS), in collaboration with the Geological Survey of Canada (GSC), is preparing a geological highway map (1:2 000 000 scale) of the territory with a shaded relief base. Unlike a regular geological map whose legend shows rock formations in chronological order, this map emphasizes earth materials – nine rock types and six kinds of unconsolidated deposits – with less regard for their age. This map also shows major faults, hot springs, the location of other geological features of interest to the public, as well as primary and secondary road networks, communities and parks.

The geological highway map is accompanied by a series of illustrated time-slices of the tectonic evolution and glacial history of the territory. It is intended to be a territory-wide synthesis of Yukon's geology – for residents as well as the rubber-tired tourist.

RÉSUMÉ

La Commission géologique du Yukon, en collaboration avec la Commission géologique du Canada, prépare une carte géologique routière à relief (échelle de 1:2 000 000) du Yukon représentant le relief par ombres portées. Contrairement à une carte géologique régulière dont la légende illustre les formations rocheuses en ordre chronologique, cette carte met l'accent sur les matériaux de la Terre – neuf types de roches et six types de dépôts meubles – en tenant peu compte de leur âge. Cette carte montre également les failles de premier ordre, les sources thermales, l'emplacement d'autres entités géologiques d'intérêt pour le public, de même que les réseaux routiers primaires et secondaires, les villages et les parcs.

La carte géologique et routière est accompagnée d'une série temporelle d'images représentant l'évolution tectonique et l'historique glaciaire du territoire. Elle se veut une synthèse de la géologie de l'ensemble du territoire à l'intention des visiteurs intéressés à la géologie et des yukonais.

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INTRODUCTION

Yukon Territory, smaller than all but four Canadian provinces, is traversed by eight major highways which extend to all its borders except the northwest (Fig. 1). Travelers are well served by widely available territorial road maps, maps in booklets for cities and towns, and a comprehensive road log (Department of Highways and Public Works, 2005). These freely available sources label most of the prominent geographic features, but they contain little to no information about Yukon's geological heritage. This is unfortunate because all belts of the western Canadian mountain region (the Cordilleran orogen) are crossed by Yukon's highways, which provide relatively inexpensive access to interesting geology and many geology features have nearby roadside pull-outs. The geological highway map and brochures currently

being developed as an outreach initiative by Yukon Geological Survey (YGS) will enhance the traveler's experience by providing easy-to-read literature about nearby rocks and surficial deposits. The brochures recommend 'geo-stops' en route and provide a souvenir or quick reference after a trip.

Geological highway maps are a hybrid product; typically they show the distribution of simplified rock formations overlain by culturally important features – more than are typically shown on a standard geological map. Geological highway maps have been made for all Canadian provinces and most American states. They attempt to make earth science relevant to a broader audience than technical geology reports and maps, and seek to include in their audience those who have little interest in science or may not know much about geology. The geological highway

map needs to be informative, comprehensible, colourful and fun. In contrast to most geological maps that are published for academic purposes, a geological highway map will often be used in recreational activities, for example, on a traveling vacation.

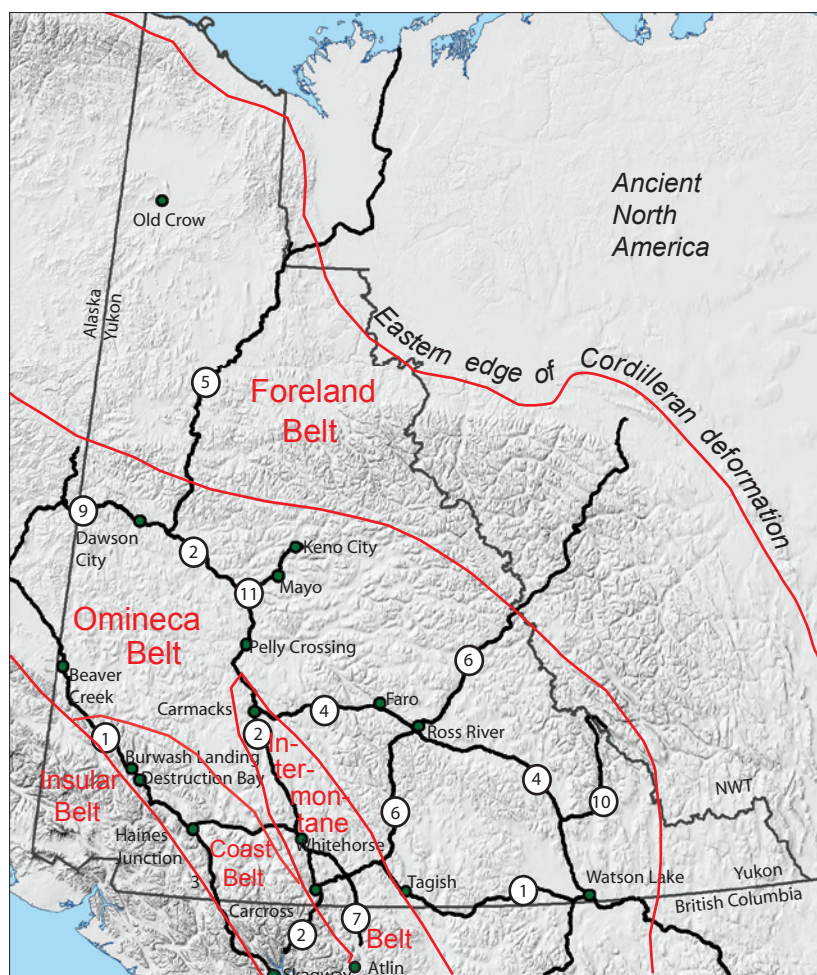


Figure 1. Highway network of Yukon (circled numbers as denoted by Department of Highways and Public Works), with major tectonic elements (modified from Gabrielse et al., 1991).

DIFFERENT PORTRAYALS OF YUKON GEOLOGY

As a political entity, the Yukon territory is geologically fortunate; it is well endowed with mineral resources and contains many impressive geological landscapes. Almost every vista includes hills or mountains but the underlying geology varies – from the flat-lying 'soft' rocks of the Peel Plateau in the northeast, to the steep-dipping, transposed and juxtaposed rocks of the St. Elias Mountains in the southwest. Small-scale maps which show the geology of the entire Yukon reflect many prior decisions about combining and defining rock packages in order to portray the complexity of this part of the Cordilleran orogen.

In one of the earliest maps of this type, Young (1913) showed ten rock units in Yukon (Fig. 2). Subsequent editions of the geological map of Canada refined both the ages of sedimentary formations and the classification of metamorphic rocks (cf. Geological Survey of Canada 1945, 1955; Douglas, 1969; Wheeler

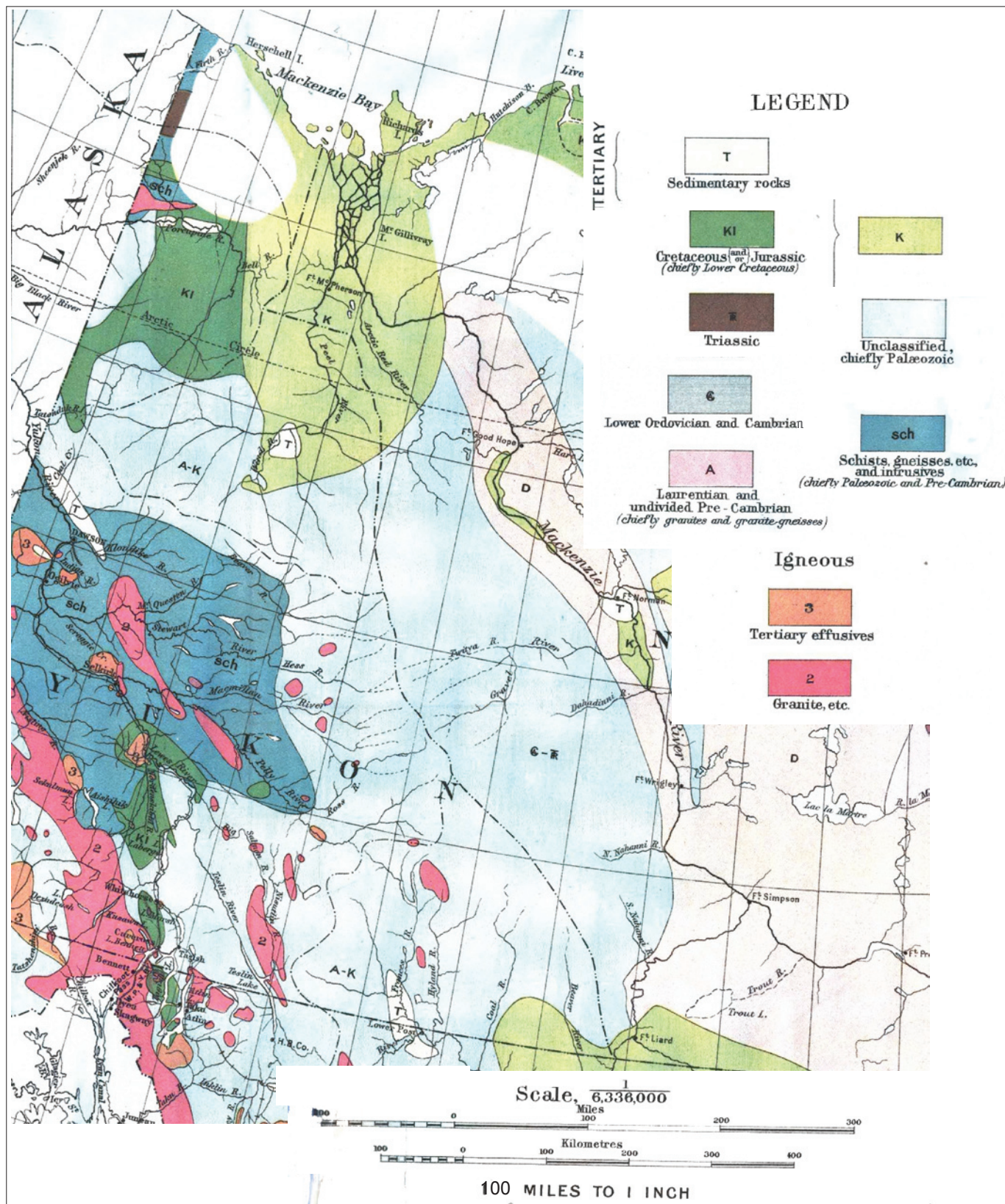


Figure 2. Image of the Yukon portion of the Geological Map of the Dominion of Canada (Young, 1913), showing the early knowledge of the distribution of rock units in Yukon.

(*cf.* Geological Survey of Canada 1945, 1955; Douglas, 1969; Wheeler *et al.*, 1991). These maps were distilled from the completion of systematic reconnaissance-scale (1:250 000) mapping operations. A significant step forward was the Tectonic Assemblage Map of the Canadian Cordillera (Wheeler and McFeely, 1991). On this map, metamorphosed rocks are organized according to their pre-metamorphic environment of origin (protolith). This advance continued with the Yukon bedrock geology map (Gordey and Makepeace, 1999), a digital database that enables construction of derivative maps combining other geographically referenced data, such as mineral claims and eco-regions; it is an essential tool of the YGS. The distribution of unconsolidated deposits is shown on the Glacial Limits map (Duk-Rodkin, 1999). A digitally based surficial geological map for the Yukon territory, a multi-year project, is in preparation.

The portrayal of tectonic assemblages is highly interpretive and has, in some ways, made the resulting geology map incomprehensible to persons without geological training. For example the bedrock legend of Gordey and Makepeace (1999) is a separate sheet listing about 185 map units; many of these descriptions do not represent what can be seen in an isolated outcrop. Furthermore, these maps are large sheets of paper (a 1:1 000 000 scale the map is 1.0 x 1.24 m in length) and cumbersome in the field. Unfamiliar users may find it difficult to orient themselves geographically because only major rivers, lakes and towns are shown on the base layer. For the non-specialist, a simpler and smaller map is needed. We call our new product a 'geological highway map', although it can also be used away from the road network. The map should highlight the major rock types, answer questions about local landmarks, and give useful information about the outcrop. Ideally such a map helps the user understand why geology is important (*e.g.* Donohoe *et al.*, 2003).

YUKON GEOLOGICAL HIGHWAY MAP PROJECT

A Yukon geological highway map has been a primary outreach objective in the five-year plan that resulted from the third Yukon Geoscience Planning Workshop (Abbott, 2005). Steps toward reaching this include: defining what the map will show (and not show), developing a legend, and preparing the map and derivative products. Furthermore, discussion of the terrane and glacial history requires additional explanation; we need to create schematic diagrams to supplement the map. To meet the

demands of a diverse audience, we are planning to create a series of brochures that address individual highway segments. As part of the work, we are noting every roadside exposure, and compiling a Geological Road Log for Yukon Highways. These components of the Yukon geological highway map project are illustrated in Figure 3, and described below.

DEFINING THE MAP

The making of a geological highway map requires decisions on the type and complexity of geological information to portray. Typically the starting point is existing geological maps. Such maps are based upon years of research and employ units that often have characteristics too subtle for non-geologists to distinguish in the field (such as age determined by microfossils).

Units of a geological highway map should reflect features that can actually be seen; these observations then need to be hooked into the larger, geo-interpretive picture. For example, many metasedimentary and volcanic rocks in the southwestern half of Yukon comprise rock assemblages now considered to be terranes (displaced assemblages of rocks related in origin or shared deformation history); these reflect their origin as oceanic seafloor or a former arc-volcano. The geological highway map should include both rock and unconsolidated deposits – whatever earth material the user finds 'underfoot'. Many people without geological training view them together and consider both as part of 'the landscape'. This contrasts with most standard geological maps in Canada which show either the distribution of bedrock or the distribution of surficial materials. Geological highway maps are likely to be used for other purposes (perhaps unfolded from the glove compartment in less-than-ideal conditions when there is a need for route directions), therefore, cultural features such as road junctions and landmarks must not be obscured by the geology.

We reviewed geological highway maps from many provinces and determined that maps designed for minimum 'geo-literacy' suited our primary audience best. We want to make a map that is relevant to residents of Yukon, most of whom have little or no education in earth sciences (*cf.* Clague *et al.*; 1997). If the map and literature is attractive and informative it will also appeal to tourists. An example of this approach is the Geological Landscapes Highway Map of northern British Columbia (Turner *et al.*, 2007). At first glance this publication resembles a familiar road map. Upon opening it however, the cartoon figures

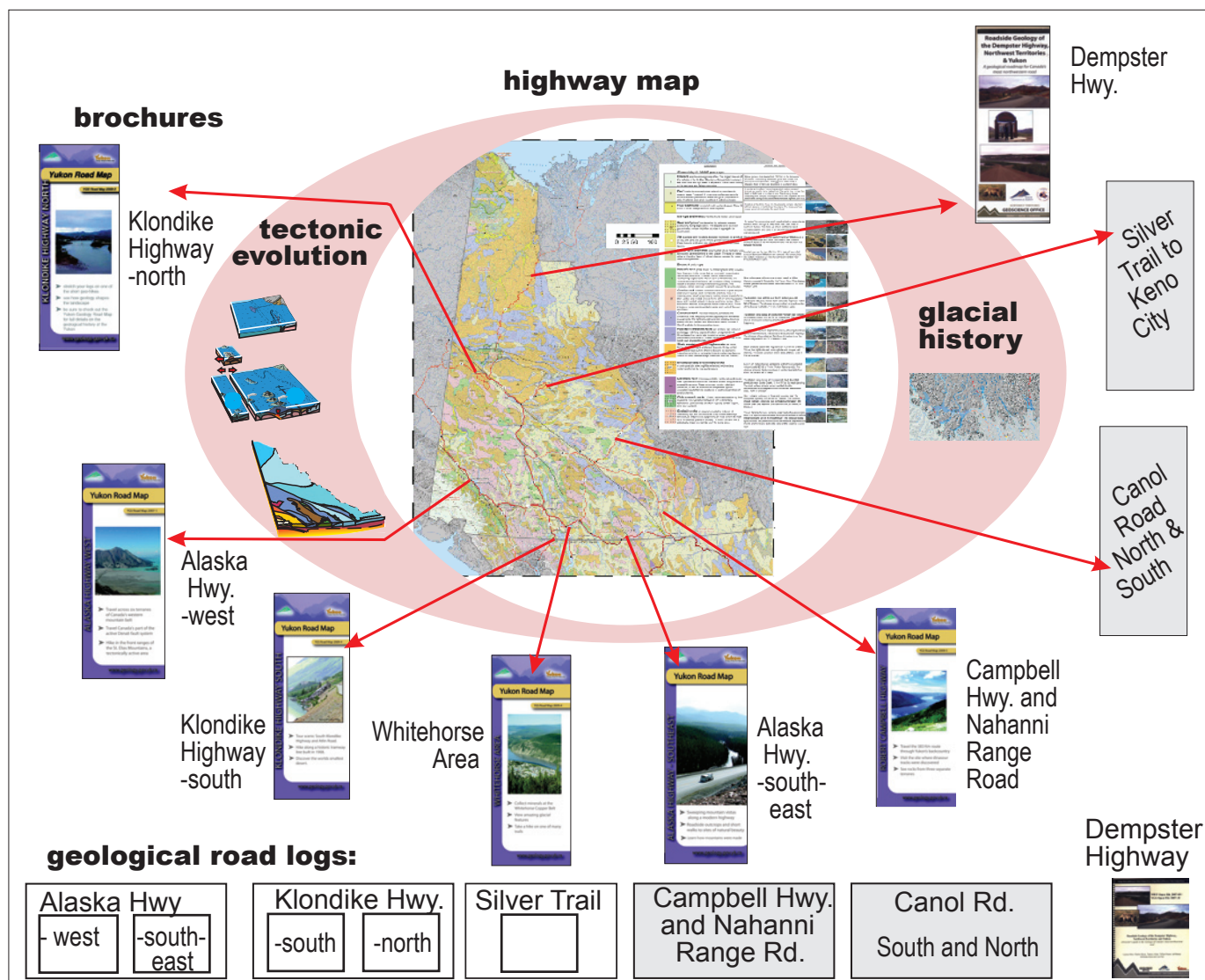


Figure 3. Components of the Yukon geological highway map project. Items shaded grey are under construction.

and photographs linked to the map draw the reader into a geological perspective. The subjects discussed include landscape features that people quickly recognize and earth resources that are relevant to their lives.

DEVELOPING A LEGEND

We began with the legend for the *Geoscape Canada* poster (Turner *et al.*, 2003), which depicts the earth materials at surface for all parts of the country. Map units on the poster are divided into three, broad age categories: modern sediments (up to 10 000 years old); ice-age sediments (10 000 to 2.5 million years old) and rocks (older than 2.5 million years). For each unit we emphasized broad composition first and used simple

words where possible. The unit description also made a short statement about origin or use of the material, to aid in its recognition or underscore its importance (Fig. 4). Two photographs – a distant view and a close-up – of each unit were included to help the user form a mental image of the rock type. The images had to convey salient features despite reduction to less than 2 x 3 cm.

By choosing these basic rock type units, we depart from the traditional geological map, which emphasizes their age through designation of formations. Some geologists disagree with our decision. However in the Cordillera, as map scale diminishes, disparate formations are shown as groups. For example, the Triassic Lewes River Group contains both limestone (the Hancock Formation) and


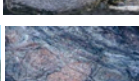
unit	description	landforms and deposits	distant view	close-up view
Present-day to 10,000 years ago:				
g	Glacier and ice patches exist where winter snowfall exceeds summer melting over millenia. Remnant ice on high peaks in the Mackenzie and Selwyn mountains is receding as the climate warms. Glaciers descend broad valleys from the ice fields of the St. Elias Mountains.	Alpine glaciers cloak Keele Peak (2972m), in the Mackenzie Mountains. The closeup shows the gravel and boulder-rich terminal moraine beneath a melting glacier at the head of Wheaton River in the Coast Mountains of southern Yukon.		
p	Peat (partly decomposed plant material) accumulates in swampy areas ('muskeg'). It thermally insulates underlying sediments, which in northern Yukon become permanently frozen (permafrost). Biological decomposition is very slow.	In central and northern Yukon, low-gradient valleys are poorly drained and peat is many metres thick. The aerial view is near the head of Wolf Creek in southern Yukon. The close-up shows collapsing peat overlying melting ground ice, the long-term result of disturbance during construction of the Dempster Highway (km 100).		
r	River sediments consist of mud, sand and gravel. These fill broad valleys and form deltas where the streams and rivers enter lakes.	The delta of the Slims River into Kluanne Lake contains abundant silt from glaciers in the St. Elias Mountains. The close-up shows coarse gravel of the braided Burwash Creek.		
Ice-Age sediments (10,000 to 2.5 million years ago):				
sg	Sand and gravel deposited by streams, particularly as large ice sheets and glaciers melted. These deposits contain abundant space between particles and are a good groundwater source. Deposits called 'aggregate' by the construction industry.	An 'esker' (sinuous ridge which was the bed of a sub-glacial stream) winds through a valley floor near Ibex River in southern Yukon. The close-up shows well sorted and rounded cobbles and sand in an ancient stream terrace (kame) deposit.		
t	Till , a general term for debris deposited by glaciers, is a mixture of clay, silt, sand and gravel. Clay content makes it poor for groundwater and construction. Some granite particles in the till release radioactive gas (radon); a hazard in confined spaces.	Viewed from above, the till plain east of downtown Whitehorse is a maze of gravel ridges and ponds. The closeup view shows an eroded till deposit in the Wheaton River valley with abundant mud between the stones.		
m	Glacial lake sediments are mostly silt and clay where a lake was dammed behind a melting glacial lobe. Visible as terraces on valley slopes and layers of silt and clay are eroded by down-cutting streams.	Locally known as 'the clay cliffs', the 120 m high silt layers that surround downtown Whitehorse are remnants of a former glacial lake bottom. The close-up view shows fine sand and silt near the outlet of Kusawa Lake.		
Bedrock outcroppings				
v	Volcanic rock (less than 10 million years old) includes lava flows and cinder cones still recognizable as volcanic landforms. The rock is black, brown and dark green, commonly with gas bubble holes and minute crystals. Basalt is excellent building material and can be a good groundwater reservoir. Lava flows are exposed at Miles Canyon and near Fort Selkirk.	Nine million-year-old columnar-jointed basalt at Miles Canyon, now partly flooded by the Yukon River. The closeup shows gas-bubble filled basalt near Rancheria, 62 km W of Watson Lake.		
gr	Granitic rock consists of interlocking crystals of white or pink feldspar, clear or grey quartz, black hornblende and shiny mica. Formed by magma cooling slowly underground, these large masses are exposed by uplift and erosion. Granite forms cliffs in formerly glaciated areas and rounded uplands elsewhere. When exposed to weather, some granite decomposes to 'grus'. Some intrusions north of Dawson and Mayo contain invisible gold.	The turreted crest and talus of the 92 million year-old Tombstone intrusion, visible from Dempster Highway, 75 km NE of Dawson. The closeup shows medium-grained granite of the Cassiar batholith, 110 km E of Watson Lake.		
c	Carbonate rock includes limestone, dolostone and calcareous shale. It typically forms rugged skylines and steep escarpments. Bare rock is light-coloured and steadily dissolves, leaving pits and cavities. Lichen cover is patchy and some plants grow poorly because the ground water is alkaline.	The distant view shows an overturned Permian reef complex at White Mountain, 100 km SE of Whitehorse. The close-up shows limestone containing brachiopods and coral fragments.		
cp	Paleozoic carbonate rocks are similarly light coloured and craggy with long slopes of broken, unvegetated rock. Groundwater from carbonate formations contain calcium that precipitates ('hard water'). Crushed limestone is used near old mines to neutralize acid, and can be heated to make cement.	Aerial view of northern Ogilvie Mountains, showing Cambrian to Devonian limestone, traversed by the Dempster Highway. The closeup shows strained Cambrian limestone near the Alaska Highway 80 km W of Watson Lake.		
ss	Shale, sandstone and conglomerate are compressed and hardened mud, sand, and gravel deposits. They may contain precipitated metal sulfides that constitute an economic mineral occurrence. Compacted organic matter may become coal or oil shale (beneath Eagle Plains and the Peel Plateau).	Black siltstone beside the Rogue River, 120 km W of Mayo, Yukon, has light coloured iron sulphate and orange rust staining. The close-up shows folded beds of black shale in the same area.		
sm	Metamorphosed sedimentary rocks include quartzite, slate, argillite and schist. They were sandstone, mudstone and siltstone, transformed by heat and pressure. The rock is durable with a preferred splitting direction, thus may be suitable as facing stone for buildings and constructing walls.	Layers of metasiltstone, sandstone and tuff (consolidated volcanic ash) 80 NE of Teslin (Yukon-Tanana unit). The closeup shows a fracture surface of banded quartzite from Keno Hill, 60 km NE of Mayo.		
um	Ultramafic rocks include peridotite, harzburgite and dunite: dark crystalline intrusive rocks that were uplifted along faults and exposed by erosion. These rocks may contain nickel and chromium, as well as asbestos and serpentine. Few plants live on soil from this rock because it lacks sodium and potassium.	The distant view shows an iron-stained, fault-bounded peridotite near Bocks Creek, 15 km SW of Burwash Landing. The rock surface shows veined and belt-buckle serpentinization of magnesium-rich minerals; Moosehide slide, north of Dawson.		
vm	Metamorphosed volcanic rocks: Green and brown crystalline rock, typically interlayered with sedimentary formations. Dark coloured lava flows typically contain copper, zinc, lead and gold. Often called 'Greenstone' in old geology.	Grey volcanic outcrops of flows and breccias near the Dempster Highway 120 km NE of Dawson. The closeup shows "pillows" (vesicular lava extruded underwater) 480 million years old, near the Blackstone River, 80 km NE of Dawson.		
gn	Gneissic rocks are coarsely crystalline in bands of contrasting light and dark minerals; they formed under high temperature and pressure. Depending on mica content the rock is as resistant as granite or crumbly. In many cases the rock is attractively striped and can be sawn for facing stone.	Yukon Tanana Terrane contains large tracts of gneissic rock. Here the layering approximates the original sediments before metamorphism; 25 km N of Swift River. The closeup shows light coloured recrystallized quartz and feldspar separated by sheets of chlorite and actinolite, a former meta-volcanic rock.		

Figure 4. Legend for the Yukon geological highway map project (draft version).

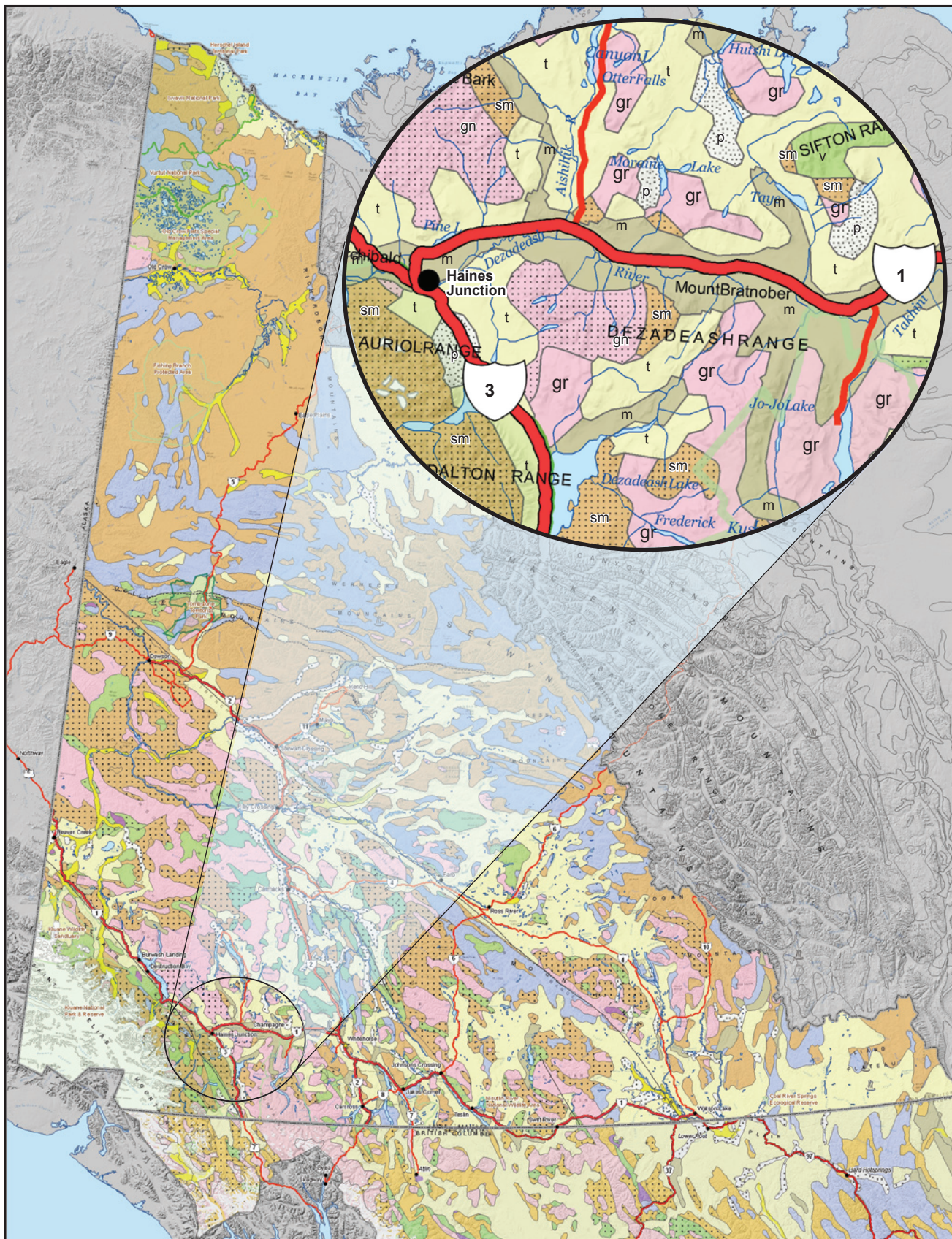


Figure 5. Yukon geological highway map (early draft; reduced size). The inset shows detail at final scale of 1: 2 000 000.

andesite (Povoas Formation). Both are integral to interpretation of the Lewes River Group as an island arc with volcanoes and reefs. On the geological highway map, we do not have space to explain the rationale for grouping such disparate rock types. As an alternative, we present a block-diagram sequence that portrays the larger tectonic evolution of Yukon (see later section). By having the legend focus on rock types rather than age of deposition, the map portrays the composition which is most observable to the general public.

PREPARING THE MAP

A clip-out of Yukon and northern British Columbia portions of the Geoscape Canada map (*cf.* Turner *et al.*, 2003) served as our starting point. Cartographers at the Geological Survey of Canada and the Yukon Geological Survey draped these polygons over a shaded relief base and added geography information, including selected Yukon communities, roads, rivers, lakes, glaciers and national and international borders. Other information prepared includes Yukon hot springs, protected areas, parks, wildlife areas and special management areas (Fig. 5). Finally, names for Yukon geographic features were added.

Symbology for the bedrock geology was standardized across the Yukon – British Columbia border to simplify the regional geology. The rocks are symbolized by generalized rock composition. We are currently adjusting colours, fonts and label placements to achieve the best cartographic product possible.

SUPPLEMENTARY IMAGES TO SURROUND THE MAP

We intend that the map and legend will be complemented by diagrams that place the geology in time and tectonic contexts. The goal is to answer the user's logical questions: "How do these rocks fit together?" and "Why are the rocks distributed as they are?". The solution is to portray current interpretations of deposition, deformation, terrane accretion and the glacial (and de-glacial) history through block diagrams. For the bedrock story, a series of block diagrams will have coloured elements that can be followed from one diagram to the next, ending with the present-day scenario. The cross-sectional fronts of the blocks show that "what's on the surface does not go all the way down", encouraging consideration of the third dimension (depth). An obvious application is that a valley filled with glacial deposits is underlain by bedrock, and

study of the nearby mountainside may be useful in predicting what rock type lies beneath the till.

Tectonic story

The block diagrams are at an early stage and diagrams for some time intervals are not yet constructed. We began with a simplified terrane map – the Yukon portion of the Canadian–Alaskan Cordilleran terranes map (Colpron *et al.*, 2007b; his Fig. 1) and first de-constructed it along major transcurrent faults to give a schematic impression of the mid-Cretaceous distribution of terrane elements (Fig. 6; space constraints preclude showing the cumulative displacement accurately). For earlier periods of time, depositional environments and terrane relationships (rifting, subduction, or far-travelled terranes) are shown schematically. For example, a recent interpretation for the source of Alexander terrane, which has zircon ages similar to the Baltic craton and may have drifted across the top of Northern America since Permian time (Colpron and Nelson, *in press*) is included. The objective is to give the user a visual impression that in the past some parts of Yukon lay under oceans, some were parts of active volcanoes, and some were parts of other continents.

As a source of general geological information, the Internet surpasses what is possible to achieve on a small paper map. The reader will find explanations there for classic geologic environments such as volcanic arcs or spreading oceanic ridges using any Internet search engine. Furthermore, the block diagrams show tectonic evolution as static; they cannot portray the fourth (time) dimension. Websites provide numerous animated plate reconstructions (e.g. ODSN, 1999; Scotese, 2003; Atwater, 2008).

Glacial story

Most of Yukon's road network occurs in valleys containing thick glacial deposits. These are cut through where the road right-of-way traverses steep slopes, exposing sediment deposited during past ice ages. Vistas from the highway include horizontal terraces left by lakes, cirques where glaciers formerly accumulated, and many other glacial features. We intend that the highway traveler will better appreciate the geological processes that sculpted the valley through pictures and diagrams.

The boundary between glaciated and unglaciated parts of Yukon is important for interpreting the geological landscape. For geologists, the 'ice limit' or 'edge of

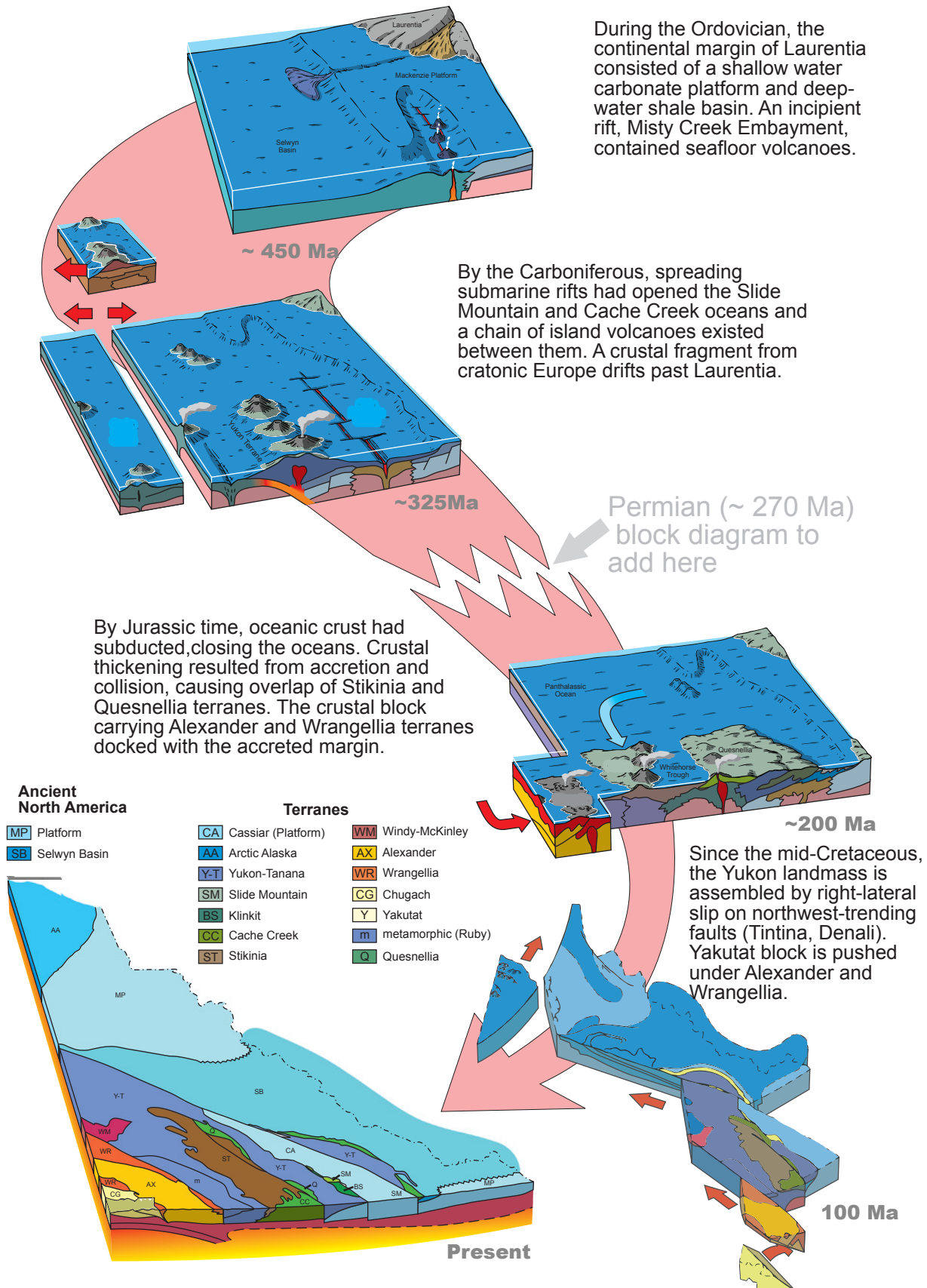


Figure 6. Block diagrams to illustrate some stages in the tectonic evolution of Yukon (early draft).

Beringia' changed with time: there is a maxima (generally about 2.3 million years ago), intermediate glaciations and the most recent (McConnell; which began to recede about 15 000 years ago) across central Yukon. In northern Yukon, the encroachment of the Laurentide Ice Sheet and interactions with local rivers led to interesting glacial drainage features. For the audience of outreach who are mostly traveling the roads of southern Yukon, we will illustrate the glacial lakes of southern Yukon (Fig. 7). Bond (2004) resolved the deglaciation sequence for the Whitehorse area and emphasized that many of the southern lakes such as Teslin, Tagish, Marsh, Kusawa lakes, and Lake Lebarge are shrunken remnants of these great ephemeral deglacial waterways.

BROCHURES FOR HIGHWAY SEGMENTS

Geological field guides have a long history in Yukon. Visiting geologists (and royalty; Bostock, 1958) were traditionally given tours of the mining districts and areas where regional geology mapping projects were nearing completion. During the International Geological Congress held in Montreal, field trips were made to all corners of Canada, including Yukon. When the Dempster Highway was completed from Dawson to Inuvik, it became a popular route for sedimentary and petroleum geologists (Norris *et al.*, 1992; Pyle *et al.*, 2007). New terrane

interpretations have encouraged geological tours of Yukon-Tanana and other terranes (Johnston *et al.*, 1993; Colpron and Reinecke, 2000, Appendix; Colpron *et al.*, 2007a). Although some of these earlier field trip records are difficult to locate, they provide abundant information for the roving geologist. Most require familiarity with current geological and tectonic terms, and these passages are like a foreign language to most Yukon residents.

Previous public outreach initiatives completed by the YGS reveal several types of audiences among Yukon residents. Some people enjoy scientific investigation and wish to know how scientists see the world. Those who find geology interesting will likely choose the geological highway map for its depiction of the entire territory. Others, including tourists passing through en route to Alaska or the Beaufort Sea, will only care for the geological highlights along their route. We anticipate a significant population of the latter. For them, we are preparing fold-out pamphlets of segments of the Yukon highway system. For each segment, a self-titled brochure will contain an enlarged and annotated clip-out of the Yukon highway map, surrounded by photographs and short descriptions of selected points of geological interest (Fig. 8). The brochure will provide a quick synopsis of the geology along the route, encouraging the traveller to make two or three stops and thus experiencing Yukon

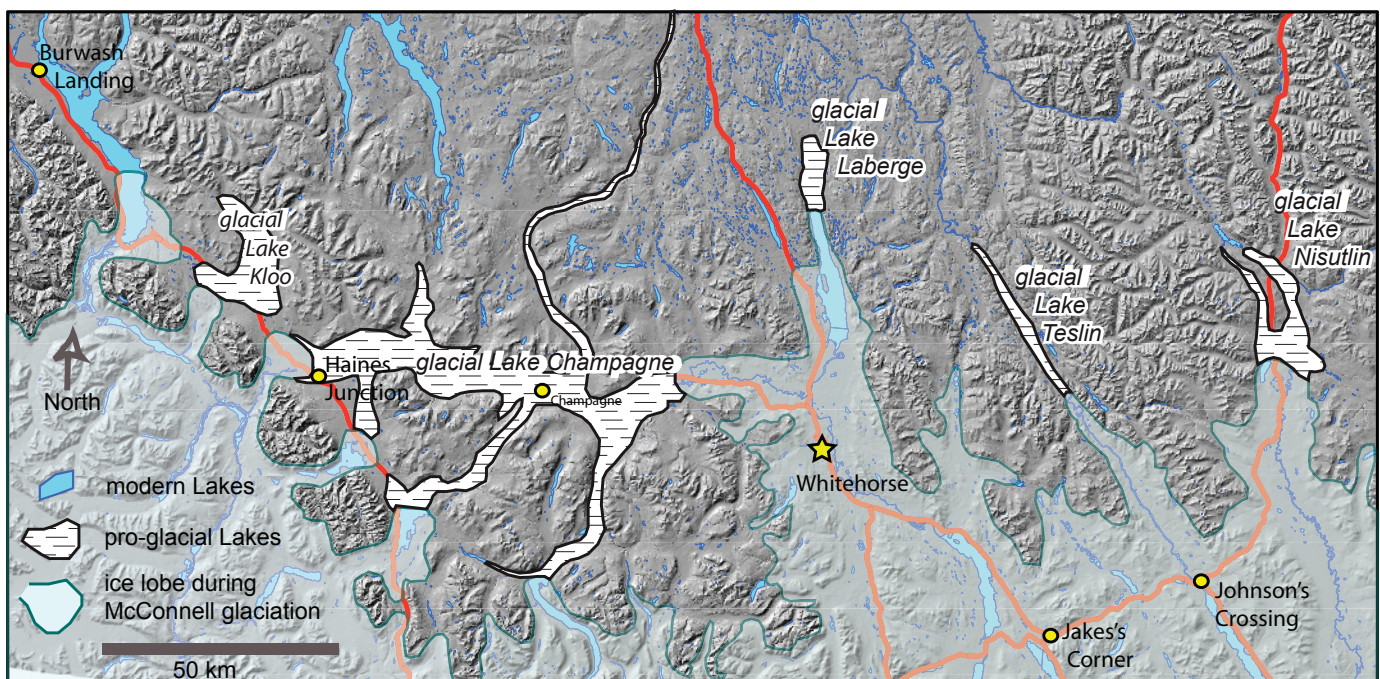


Figure 7. Extent of glacial lakes in southern Yukon, 12 000 to 16 000 years ago. These lakes were created when receding ice lobes blocked valley drainages.

away from the population centres. They will also provide a low-cost souvenir of their trip. In time, up to eight pamphlets will be available and will complement the geological highway road map.

Care and consideration of non-geological features is involved in selecting a few suitable stopping sites to feature in each brochure (Fig. 9). Most importantly, the site must be safe to visit. Although the Alaska and Klondike highways have wide shoulders along much of their lengths, stopping is not recommended because traffic continues to pass at highway speed. Crossing the traveled portion of the roadway with a group, or if accompanied by younger people, is very unsafe on these

highways during the summer season. We therefore choose pullouts and parking areas away from the highway and favor those which have reasons in addition to geology, to interest other members of a traveling group.

Furthermore, we assess the inherent hazards of the geology. Un-guarded precipices, steep riverbanks and unstable slopes make some sites unsuitable. A good spot has an interesting outcrop near a pullout and a view that (with a geologist's eye) reveals an aspect of the geological history. Bonuses might include a maintained latrine, interpretive signage and a well designed trail. Interpretive signage is increasing along Yukon highways through the efforts of the Historic Sites Branch of the Department of

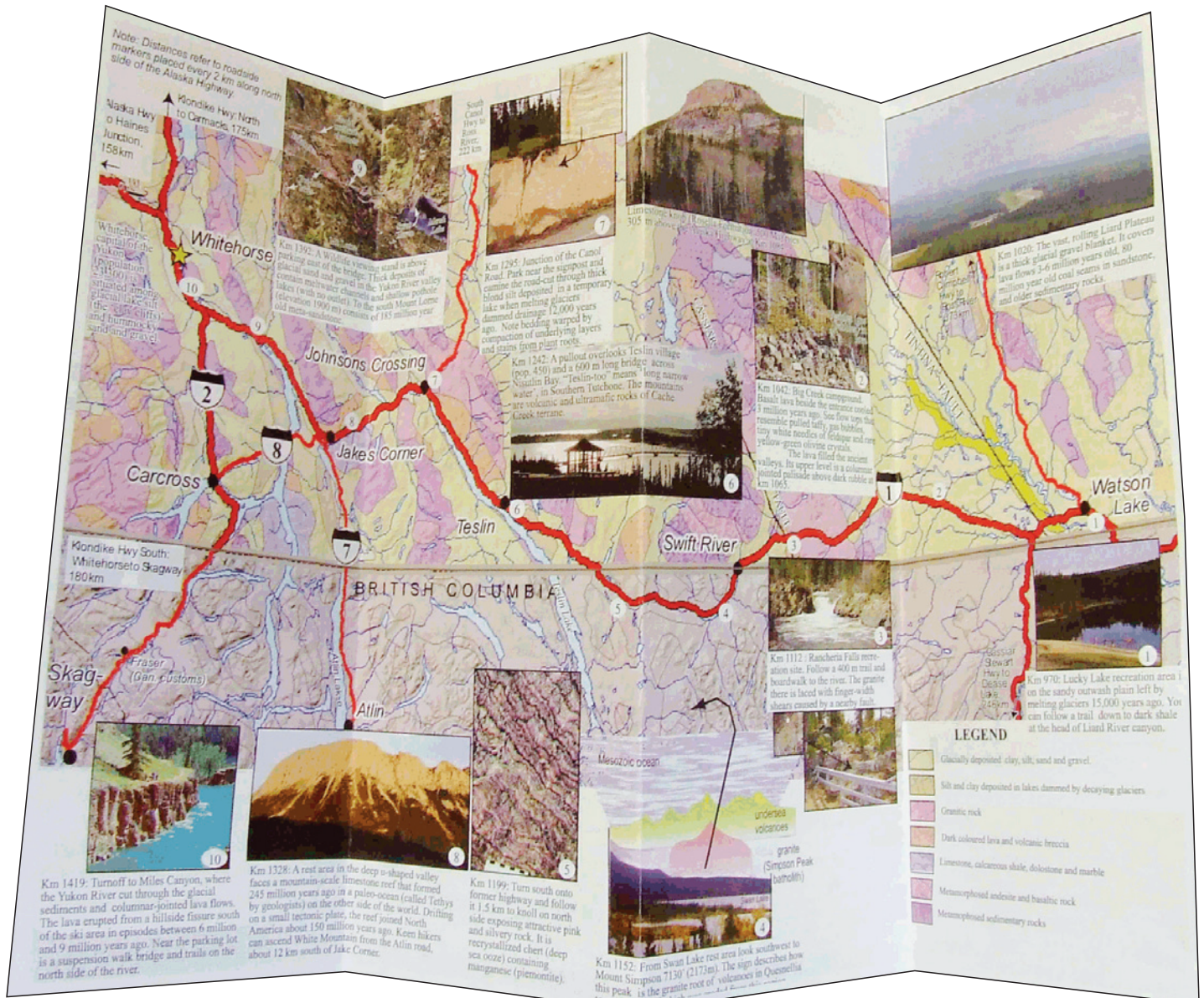
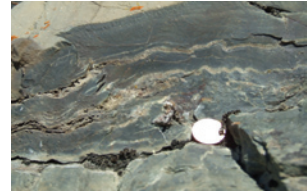


Figure 8. Example: Alaska Highway-southeast brochure (map side, 2007 draft).

ALSEK HIKING TRAIL (5)



5a. The first outcrop along the trail is phyllitic black shale and thin bedded sandstone of the Dezadeash Formation. The sediments have been deformed – look at the tiny folds (crenulations). High strain is also indicated by abundant pods and veinlets of white quartz. Approximately 2 km further along the trail are outcrops of black to green weathering meta-basalt of the Nikolai Formation. The point where the trail first intersects a rock outcrop (on the left) is a bend in the trail with a panoramic view of the Alsek River valley. From here you can leave the trail towards the right to see glacier-scratched ('striated') outcrops of meta-basalt. The original lava has been altered and now contains quartz and epidote, which makes the yellow-green patches. Pillow textures, which form when lava cools underwater, and folded quartz veins are present.



5b. Just after the long phyllite outcrop, a right branch in the trail leads to loose cliffs of glacial sand and gravel. At the base of the cliff are rare golfball-to basketball-sized spheres of sand cemented by lime. These are 'concretions' and form where an impurity (such as a pyrite crystal, or decayed plant debris) in the sand acts as a nucleus for the precipitation of mineral-rich groundwater.

Note: although the concretions have no monetary value, the terrace has been staked under the Yukon Placer Mining Act. It is not legal to collect from this site without permission of the owner.



SOLDIERS SUMMIT HIKING TRAIL (6)



The first outcrop is black siliceous shale with minor sandstone and limestone of the Skolai Formation (upper right photo). Although there are no outcrops along the rest of the trail, there is an excellent view of the mountain to the north showing a small granitic intrusion and a prominent thrust fault (reddish zone and arrows on photo to left).

Back at the beginning of the trail, a 2nd path that veers off to the right leads past thickly bedded basalt flows, locally with calcite-filled amydules, of the Nikolai Formation. There is an age difference of 100 million years between the Nikolai and Skolai formations, and the contact between them is an unconformity (signaling a period of non-deposition or erosion in the rock record). Upslope from the basalt is blocky rock rubble from a geologically young land-slide, carbon isotopic dating from tree trunks killed by the slide indicate that it happened between 1200 and 490 years before present (lower right photo).

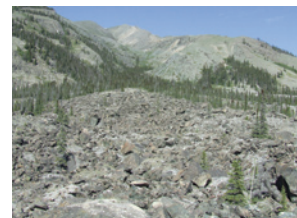


Figure 9. Example: Excerpt from the Alaska Highway-west brochure, description of geology hikes (draft).

Tourism and Culture in cooperation with the Department of Highways and Public Works (See <http://www.yukonheritage.com/Sign>).

To date we have prepared four brochures, which draw attention to the following sites:

Alaska Highway East (Watson Lake to Whitehorse)

- Km 1042: Big Creek – Rancheria basalt flows
- Km 1112: Rancheria Falls (Cassiar Fault mylonite)
- Km 1199: Andrew Creek (purple metamorphosed chert and phyllite)
- Km 1295: Canol Road terminus (glaciolacustrine silt)

Alaska Highway West

- Km 1443: Mailbox stop, (Lewes River Group sediments)
- Km 1476: Takhini Deformation zone, (Stikinia)
- Km 1487: Takhini Burn outcrop (Yukon-Tanana terrane)
- Km 1547: Canyon Creek, (Kluane Schist)
- Km 1589: Alsek hiking trail (Wrangellia terrane)
- Km 1707: Soldiers Summit hiking trail (Wrangellia terrane, see Figure 9)
- Km 1864: Pickhandle Lake (Windy-McKinley terrane)
- Km 1936: Gravel Pit (Windy-McKinley terrane)

Klondike Highway South (and the Atlin Road)

- Km 36: Fraser (Coast Plutonic Complex)
- Km 64: Tutshi Lake (Lewellyn fault zone)
- Km 82: Montana Mountain (Carmacks volcanics and historic mill site)
- Km 95: Bove Island rest stop (Cache Creek Group limestone)
- Km 107.7: Carcross Desert rest stop (glacial lake sediments)
- Km 117.6: Emerald Lake rest stop (Laberge Group sandstone/conglomerate)

Klondike Highway North

- Km 202: Vista Road (Laberge Group volcanic rocks)
- Km 225: Lake Laberge campground (Laberge Group siltstone and sandstone)
- Km 298: Whitehorse trough rest stop (Laberge Group conglomerate)
- Km 365: Cliffside Agate Road (Carmacks Group volcanic rocks)
- Km 380: Five Finger Rapids (Laberge group conglomerate)

Km 535: Stewart Crossing – Roadcut north of bridge (biotite schist)

Km 713: Midnight Dome (ultramafic klippe)

We are also planning brochures for: Whitehorse area, the Silver Trail, the Robert Campbell Highway and the Canol and Nahanni Range roads. Literature for the Dempster Highway is completed (see next section).

GEOLOGICAL ROAD LOGS

Since 2006, we have been conducting field work to record most outcrops along the highway right-of-way. This is on-going: Yukon highways are constantly upgraded which creates new exposures in some places, and closes others. Our objective is to provide a roll-call of outcrops with GPS location points and photographs for those worthy of visiting. Descriptions will emphasize rock features, leaving interpretation to the leaders of future field trips and consultation of the digital Yukon Geology map site (www.geology.gov.yk.ca).

The road logs employ geological terminology (Fig. 10). It is baseline information for use within government science departments. Selected sections, possibly with links to photographs, may be made available on the YGS website as pdf files.

COMPLETED: DEMPSTER HIGHWAY – TRAVELER’S GUIDE AND GEOLOGICAL ROADMAP

The geology of Canada’s most northwestern road, which extends from near Dawson northeastward, across the Arctic Circle to Inuvik, Northwest Territories (717 km) is published as a booklet (Pyle *et al.*, 2007) and folded brochure (Jones and Pyle, 2007). The book was co-produced by the YGS and the NTGO (Northwest Territories Geoscience Office) with assistance of Geological Survey of Canada geologists in 2005 and 2006. The guidebook uses geological language with nine page-size maps, a stratigraphic table, photographs and sidebars that highlight features along the route. The brochure, a simplified geological map (1:600 000 scale), is surrounded by photographs and short descriptions of 18 sites of geological interest and will suit non-geological travelers.

SUMMARY

“What’s that rock I saw back there?” spoken by a traveler, belies natural curiosity, but also a missed opportunity – the opportunity to tell a geological story, or perhaps an outdoor moment between Yukon communities. The Yukon Geological Survey Outreach initiative seeks to create products that will use that opportunity: attractive, informative literature and a knowledge bank of the most accessible geology exposures in the territory. These products include a map which shows the extent of surficial materials and rock types across Yukon, companion brochures for segments of the highway network, and a sequential road log. We will have succeeded if more residents and tourists take the time to appreciate our geological landscape by getting out of their cars to experience the rocks in their natural setting and lingering a while in their journey, enjoying the Yukon’s geological heritage.

ACKNOWLEDGEMENTS

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In documenting roadside exposures, we enjoyed the company of Diane Emond, Amber Church, Catherine Vander Lay, Kristie Long, Jessica Doyle, Sarah Shoniker and Lauren Blackburn. The Geoscience Canada map was clipped and manipulated to form a Yukon image by Marianne Ceh of the Geological Survey of Canada, Vancouver office. The block diagrams (shown in first-draft form) are the skilled work of Richard Franklin of Sidney, British Columbia. We are grateful to reviewers Lee Pigage and Steve Irwin, and Lauren Blackburn, editor, for improvements to this manuscript. This article is Natural Resources Canada, Earth Science Sector, Geological Survey of Canada Contribution #2008550.

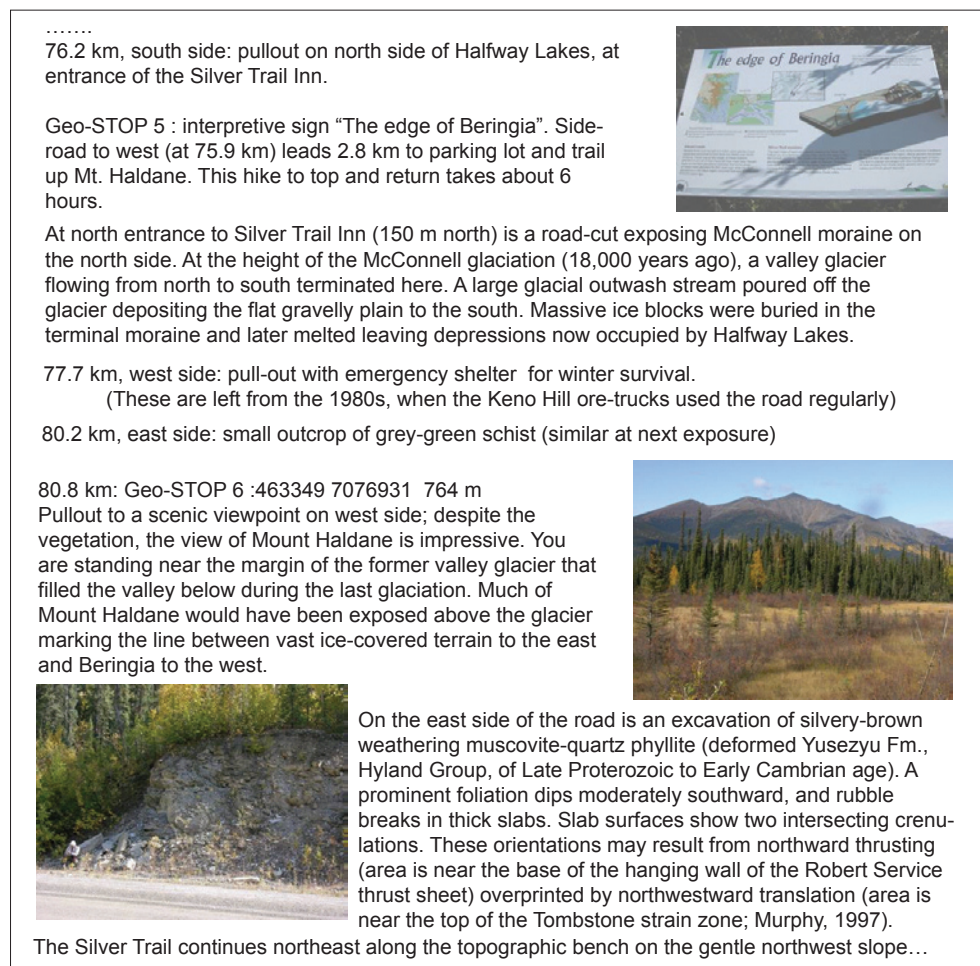


Figure 10. An excerpt from the Geological road log (Silver Trail, about 20 km north of Mayo).

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Bedrock geology of western 'Mendocina Creek' (NTS 105F/5) and eastern Livingstone Creek (NTS 105E/8) areas, south-central Yukon

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ABSTRACT

Metasedimentary and meta-igneous rocks in 'Mendocina Creek' (NTS 105F/5) and eastern Livingstone Creek (NTS 105E/8) areas are part of three distinct stratigraphic sequences: from east to west, the Sheep Creek, Scurvy Creek and Dycer Creek successions. The Sheep Creek succession contains extensive carbonate horizons and is likely part of the Cassiar terrane. To the west, metaclastic rocks of the Scurvy Creek succession are extensively intruded by sills and dykes composed of augen meta-granite of Early Mississippian age; they are correlated with the Snowcap assemblage of Yukon-Tanana terrane. The overlying Dycer Creek succession in the southwest comprises marble, carbonaceous rocks, greenstone and quartzite of Lower Mississippian (and younger?) age that probably correlate with the Finlayson assemblage of Yukon-Tanana terrane. The 'Mendocina Creek' area experienced at least four phases of deformation and greenschist- to amphibolite-facies metamorphism. An east-verging thrust locally imbricates the Scurvy Creek succession and the boundary between the Yukon-Tanana and Cassiar terranes corresponds with a west-verging, brittle-ductile thrust fault in the eastern part of the area. Re-interpretation of the geology in western Quiet Lake map-area indicates that this boundary is located 20 km east of the d'Abbadie fault, the previously inferred terrane boundary.

RÉSUMÉ

Les roches métasédimentaires et méta-ignées des régions cartographiques de 'Mendocina Creek' et Livingstone Creek forment trois séquences stratigraphiques distinctes: d'est en ouest, les successions de Sheep Creek, Scurvy Creek et Dycer Creek. La succession de Sheep Creek comprend d'importants horizons de carbonate et forme probablement une partie du terrane de Cassiar. À l'ouest, les roches métaclastiques de la succession de Scurvy Creek sont recoupées par de nombreux dikes et sills de méta-granite "oeillé" d'âge Mississippien précoce; ces roches sont corrélées avec l'assemblage de Snowcap du terrane de Yukon-Tanana. La succession susjacente de Dycer Creek, dans le sud-ouest, se compose de marbre, de roches carbonées, de roches vertes et de quartzite d'âge Mississippien inférieur (ou plus jeune?) qui correspondent probablement à l'assemblage de Finlayson du terrane de Yukon-Tanana. La région de 'Mendocina Creek' fut affectée par au moins quatre phases de déformation et un métamorphisme des faciès des schistes verts et des amphibolites. Un chevauchement vers l'est répète localement la succession de Scurvy Creek, et la limite entre les terranes de Yukon-Tanana et de Cassiar correspond à un chevauchement vers l'ouest dans la partie est de notre étude. Cette nouvelle interprétation de la géologie de la partie ouest de la région de Quiet Lake suggère que la limite entre les terranes de Yukon-Tanana et de Cassiar se situe environ 20 kilomètres plus à l'est de la faille de d'Abbadie, qui fut préalablement interprétée comme la limite entre ces terranes.

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INTRODUCTION

Bedrock mapping of a 625 km² area straddling the 'Mendocina Creek' (NTS 105F/5) and Livingstone Creek (NTS 105E/8) 1:50 000-scale map sheets in south-central Yukon was completed during the 2008 summer field season. The area is located approximately 80 km northeast of Whitehorse and 25 km east of the Livingstone town site (Fig. 1). The map area straddles the boundary between the Quiet Lake (NTS 105F) and Laberge (NTS 105E) 1:250 000-scale quadrangles. It is primarily underlain by Paleozoic (and possibly older) polydeformed, amphibolite-facies metasedimentary, meta-plutonic and metavolcanic rocks that are intruded by post-tectonic Cretaceous plutons (Fig. 2). Previous knowledge of the bedrock geology of the 'Mendocina Creek' area was based on reconnaissance mapping from the 1970s at a 1:250 000 scale (Tempelman-Kluit, 1977a). At the time, most of the rocks in the 'Mendocina Creek' area were assigned to the Pelly-Cassiar platform (Cassiar terrane) and included minor occurrences of the Yukon

Cataclastic Complex (Nisutlin assemblage¹) which was interpreted to occupy a klippe in the southern part of the area. The boundary between the Yukon Cataclastic Complex and Cassiar terrane was considered to be the d'Abbadie fault, the western limit of the present study area. Tempelman-Kluit (1979) interpreted the Yukon Cataclastic Complex west of the d'Abbadie fault as a subduction complex (his Teslin Suture zone¹) that formed during the Jurassic accretion of Stikinia to the western margin of North America.

The rocks that were included within the Yukon Cataclastic Complex are now assigned to the Yukon-Tanana terrane, a pericratonic terrane that occurs mainly within the central portion of the northern Canadian Cordillera (Colpron *et al.*, 2006, 2007). Detailed studies of the terrane have progressively established a coherent regional stratigraphic framework that records the evolution of a system of rifted continental fragments, island arcs and back-arc basins that evolved off the western Laurentian margin between mid-Paleozoic and early Mesozoic time (Mortensen,

1992; Colpron *et al.*, 2006, 2007; Nelson *et al.*, 2006). The Yukon-Tanana terrane consists of a pre-Upper Devonian metasedimentary basement complex (Snowcap assemblage) overlain by up to three unconformity-bounded Upper Devonian to Permian volcanic arc sequences (Finlayson, Klinkit and Klondike assemblages; Colpron *et al.*, 2006). These rocks are coeval with oceanic chert, argillite and basalt of the Slide Mountain terrane, an upper Paleozoic back-arc ocean that separated the Yukon-Tanana arcs from the western Laurentian margin (Nelson *et al.*, 2006; Colpron *et al.*, 2007).

The boundary between the Yukon-Tanana and Cassiar terranes remains cryptic in the western Quiet Lake and eastern Laberge map areas (*cf.* Colpron, 2006a; Colpron *et al.*, 2006, p. 9). Recent studies in the eastern Laberge map area demonstrated that the 'Teslin Suture zone' represents a zone of complex, superposed deformation of late Paleozoic to Cretaceous age, bounded by the Big Salmon and d'Abbadie faults, and is therefore not the product of deformation in a

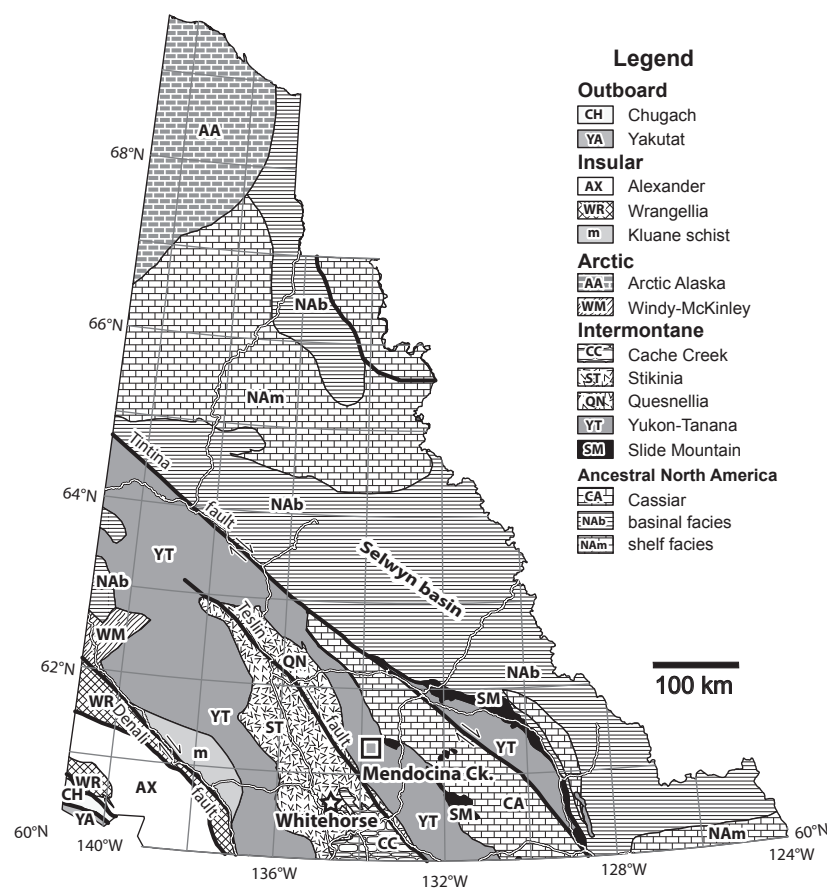


Figure 1. Terrane map of Yukon illustrating the location of the 'Mendocina Creek' area in south-central Yukon.

¹Note that use of the terms Yukon Cataclastic Complex, Nisutlin assemblage, and Teslin Suture zone are obsolete (see Colpron *et al.*, 2006, p. 14).

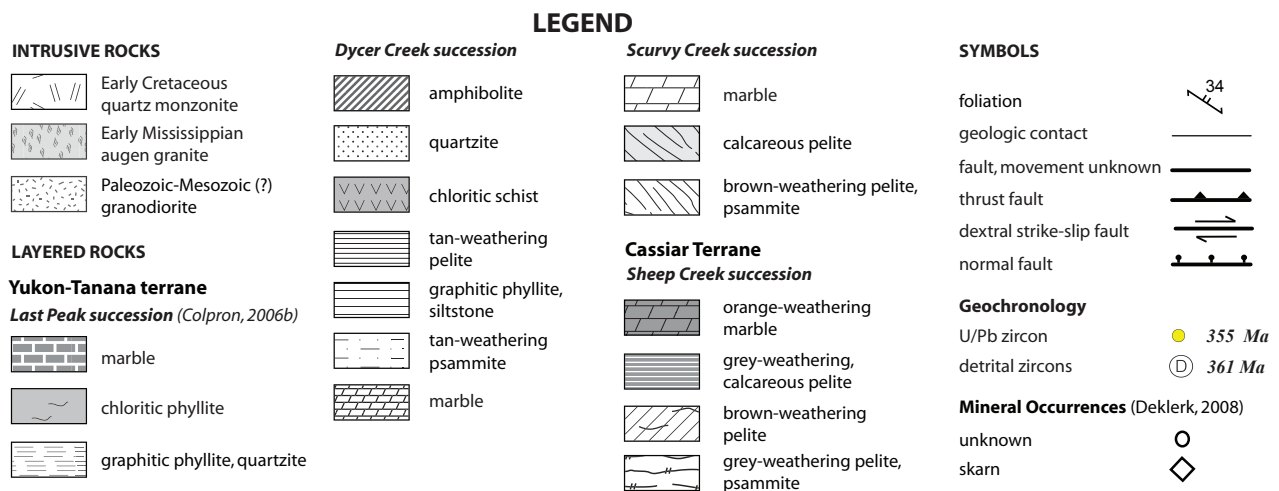
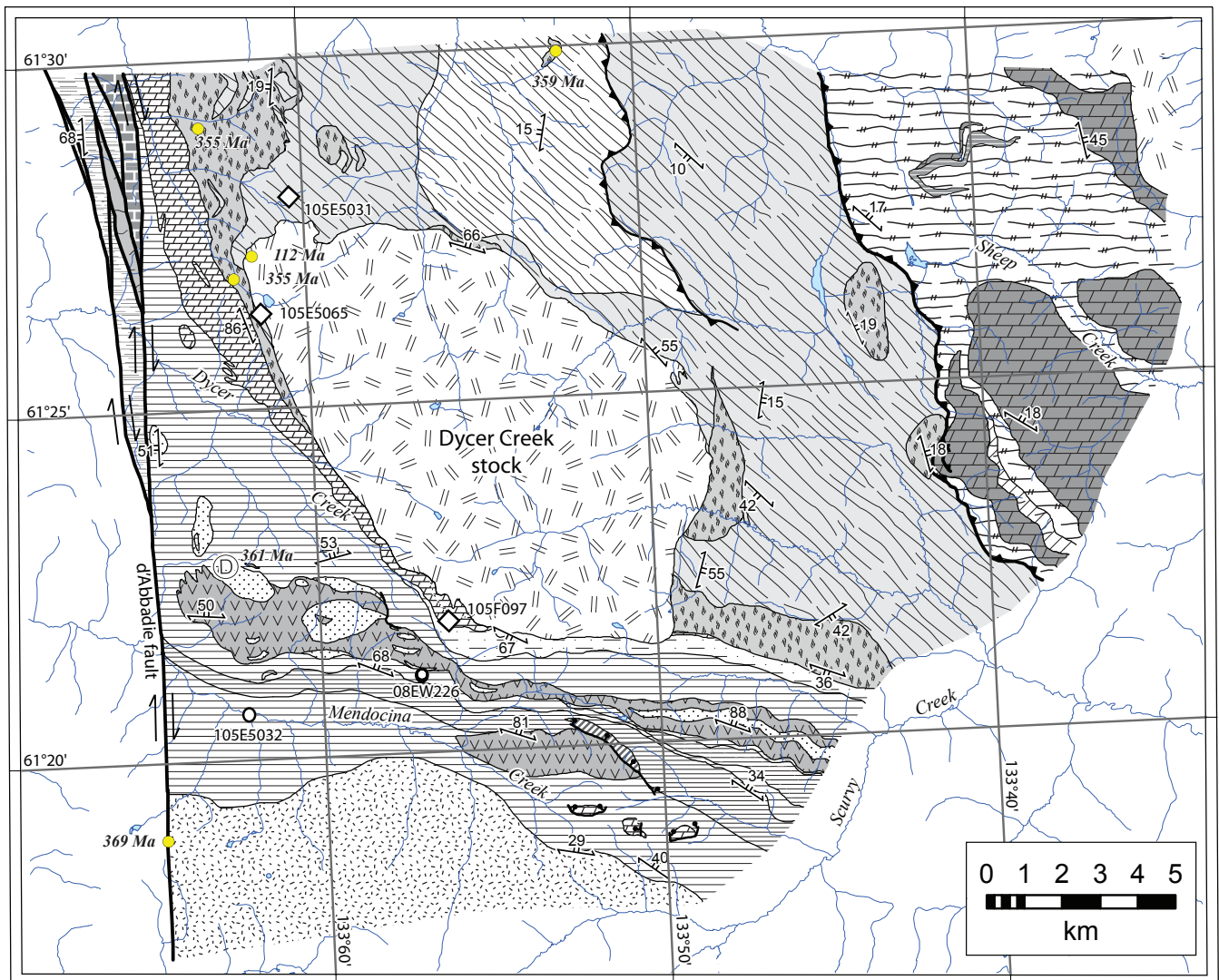


Figure 2. Simplified bedrock geology of the 'Mendocina Creek' (NTS 105F/5) and eastern Livingstone Creek (NTS 105E/8) areas. Geology near the d'Abbadie fault modified from Colpron (2005b). U-Pb zircon dates in eastern part of the area are from Hansen et al. (1989) and Gallagher (1999); location of our preliminary U-Pb zircon date of ca. 359 Ma (B. Kamber, pers. comm., 2008) is shown along northern edge of the study area.

subduction zone environment (de Keijzer *et al.*, 1999). More recent mapping in the Livingstone Creek area has suggested that rocks of the Yukon-Tanana terrane probably extend to the east of the d'Abbadie fault zone into the 'Mendocina Creek' area, and consequently the d'Abbadie fault does not mark the boundary between Yukon-Tanana and Cassiar terranes (Colpron, 2005a, b; 2006b). Our mapping in the 'Mendocina Creek' area supports this interpretation and proposes a revised location for this terrane boundary, approximately 20 km to the east of the d'Abbadie fault zone.

Regional studies indicate that the Yukon-Tanana terrane was subjected to four, and locally five, episodes of deformation and associated metamorphic events (Colpron *et al.*, 2006; Berman *et al.*, 2007). These events range in age from Late Devonian to Cretaceous, and detailed thermobarometric studies in western Yukon suggest that the terrane experienced at least two significant crustal thickening events (Berman *et al.*, 2007). However, the regional extent of these various deformation and metamorphic events in the Yukon-Tanana terrane remains unclear. In western Quiet Lake area, occurrences of amphibolite-facies metamorphic rocks and locally abundant Cretaceous intrusions, although well known, have yet to be properly documented. De Keijzer (2000) speculated that a late, regional metasomatic event overprints amphibolite-facies metamorphic assemblages and was probably related to regional Cretaceous extension. Proper documentation of metamorphic and structural relationships supporting this interpretation is still lacking.

The present study was initiated to address the lack of knowledge regarding the stratigraphy, structure and metamorphic evolution of the western Quiet Lake map-area, and to further constrain the nature and location of the boundary between Yukon-Tanana and Cassiar terranes in the area. The study area was mapped at a 1:20 000 scale during the summers of 2007 and 2008 and a suite of rock samples was collected for future microstructural, metamorphic, geochemical and geochronological analyses. A 1:50 000-scale geological map of the area is in preparation (a simplified version of this map is presented in Fig. 2). Herein we summarize some of the geological relationships represented on this map of the 'Mendocina Creek' area. Our study builds upon previous observations made by Colpron (2005a,b; 2006b) to the west in the Livingstone Creek area.

STRATIGRAPHY

Metasedimentary and related metavolcanic rocks in the 'Mendocina Creek' area are divided into three successions: the Sheep Creek, Scurvy Creek and Dycer Creek successions.

SHEEP CREEK SUCCESSION

Metasedimentary rocks of the Sheep Creek succession occupy the northeastern portion of the map area (Fig. 2) and comprise intercalated light grey and orange-buff-weathering dolomitic marble (Fig. 3); silvery-grey-weathering, variably siliceous, biotite-quartz-muscovite phyllite/schist; and tan-weathering, calcareous, quartz-



Figure 3. Looking northeast at interfingered grey and orange-buff-weathering marble, Sheep Creek succession.

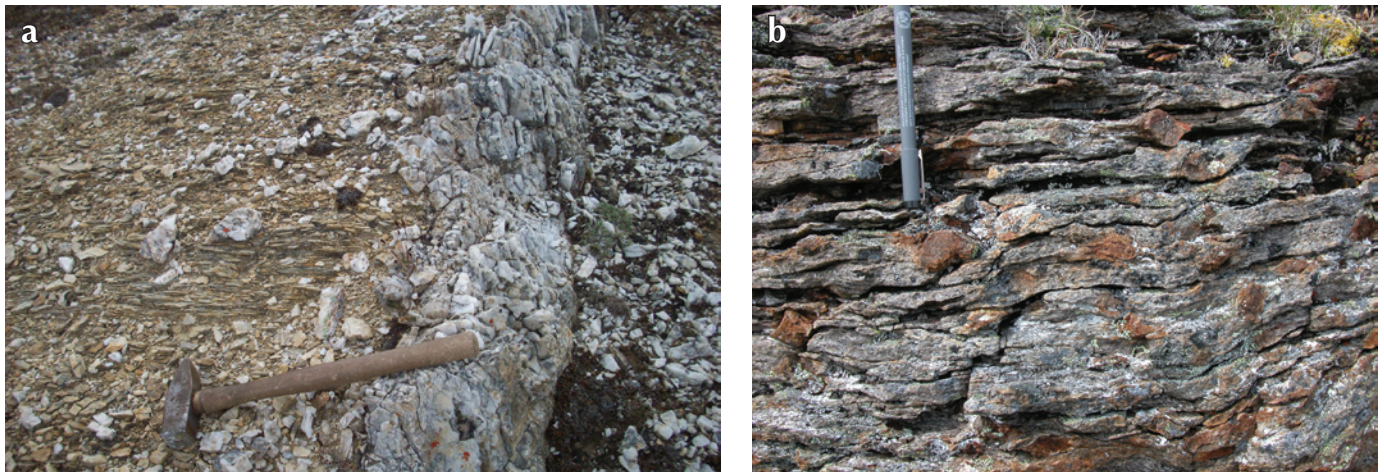


Figure 4. (a) Quartz-muscovite schist of the Sheep Creek succession cut by sheared quartz vein. View is to the southeast. Slickenlines on the shear plane are oriented with a trend of N120° and plunge 20° to the southeast; (b) garnet-quartz-plagioclase-biotite-muscovite schist, Scurvy Creek succession.

muscovite ± garnet schist (Fig. 4a). Millimetre-wide partings in the quartz-muscovite schist and centimetre to decimetre-wide laminations in the biotite-quartz-muscovite schist parallel the dominant foliation. Aligned biotite books form a faint mineral lineation on the foliation plane, suggesting a component of syn-tectonic growth. A medium green, locally dolomitic, chloritic schist and fine-grained, tan-weathering, variably micaceous quartzite are locally contained within the Sheep Creek succession.

SCURVY CREEK SUCCESSION

Metasedimentary and meta-igneous rocks of the Scurvy Creek succession occupy the north-central portion of the map area and are divided into two units (Fig. 2). The lower unit of the Scurvy Creek succession is exposed at the favour of a west-dipping thrust panel north of the Dycer Creek stock (Fig. 2). It consists of decimetre to metre-wide intercalations of grey and brown-weathering, medium to coarse-grained quartz-plagioclase-biotite-muscovite schist (psammite); biotite-muscovite-plagioclase-quartz schist; micaceous quartzite; quartzite; and calc-silicate schist. The quartzite and psammite weather in blocky, decimetre-wide layers while the pelitic schist parts along millimetre to centimetre-wide planes. Retrograded garnet (replaced by new quartz grains and plagioclase) is variably present in both, and varies in size from 1 mm to 3-4 cm in diameter (Fig. 4b). At one location, a zebra-striped, garnet-diopside calc-silicate forms a marker horizon within the psammitic schist. Notably, marble is absent from this unit.

The upper unit of the Scurvy Creek succession comprises rusty-brown-weathering, garnet-quartz-plagioclase-biotite-muscovite schist (Fig. 4b) intercalated with decimetre to 20 m-scale horizons of coarse-grained, grey and brown-weathering marble. Locally, decimetre-long marble lenses occur within the pelitic schist, suggesting a gradational intercalation of these lithologies. Garnet-diopside-epidote skarn occurs locally within marble horizons in close proximity to the Cretaceous Dycer Creek stock. Occasionally, a medium to fine-grained, white and grey-banded quartzite is structurally above the marble and forms a prominent 1 to 5 m-wide marker bed. Radiating crystals of tremolite are randomly oriented along the foliation near the contact between the marble and banded quartzite. Coarse-grained amphibolite occurs throughout the Scurvy Creek succession. When not concealed by the Dycer Creek stock, the top of the Scurvy Creek succession is defined by a large sheet(?) of augen granite (see descriptions of ‘Intrusive Rocks’ on the following page).

DYCER CREEK SUCCESSION

The base of the Dycer Creek succession is defined by an ~1 km-thick, southeast-striking, light grey to white, medium to coarse-grained marble unit (Fig. 5). Garnet-diopside-epidote skarn is locally developed in the marble. In the south, the marble interfingers with, and grades into, a biotite-quartz-muscovite schist. The marble is structurally overlain by fine to medium-grained, black graphitic schist (Fig. 6a) and quartzite; medium to light grey, carbonaceous, quartz-muscovite schist; and fine-grained,

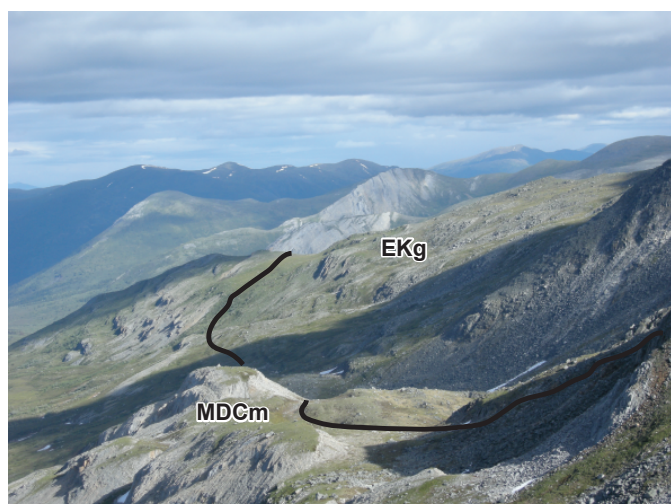
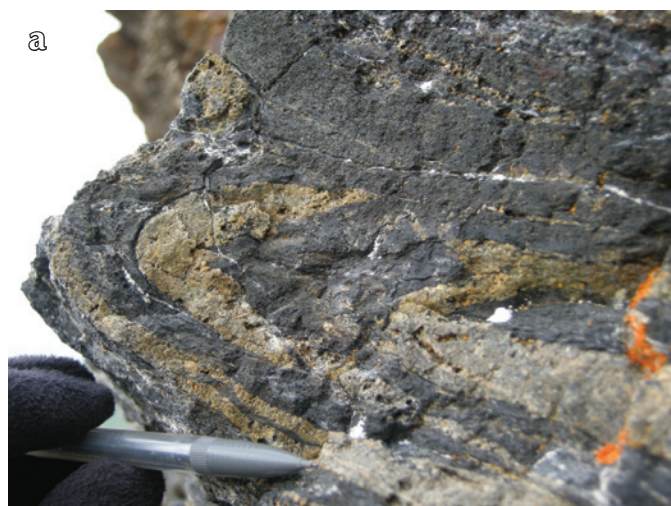


Figure 5. Looking north towards marble (MDCm) of the Dycer Creek succession intruded by quartz monzonite of the Dycer Creek stock (EKg).

black, calcareous metasiltstone and marble. A grey and buff-weathering, variably calcareous, quartz-biotite-muscovite \pm garnet schist locally interfingers with centimetre to decimetre-wide horizons of graphitic phyllite, suggesting a gradational contact between these lithologies. In the southeastern part of the study area, decimetre-wide lenses of medium-grained, brown-buff-weathering dolomitic marble occur in the graphitic schist. A fine-grained, light to dark green, locally dolomitic, chloritic schist (greenstone) structurally overlies the graphitic unit. Large (0.5 cm) biotite booklets and hornblende crystals are randomly oriented along the dominant foliation in the greenstone; their growth is interpreted to be related to contact metamorphism



around the Cretaceous Dycer Creek stock. The chloritic schist is gradationally intercalated with white to light green, fine to medium-grained quartzite and micaceous quartzite (Fig. 6b).

LAST PEAK SUCCESSION

In the Mendocina Creek area, metasedimentary and metavolcanic rocks of the Last Peak succession lie in the northwestern portion of the map area and are entirely contained within the 1 km-wide d'Abbadie fault zone (Fig. 2). Rocks belonging to the Last Peak succession comprise buff-weathering, dolomitic marble, chloritic phyllite, variably siliceous graphitic phyllite and quartzite (Colpron, 2005b). Colpron (2006b) suggested that rocks of the Last Peak and Dycer Creek successions were probably correlatives separated by the d'Abbadie fault.

INTRUSIVE ROCKS

The 'Mendocina Creek' area contains three distinct plutonic suites. The oldest suite is composed of moderately to strongly foliated, K-feldspar augen, two-mica granite. This meta-granite occurs as sheets that are concordant with the dominant foliation and intercalated with metasedimentary rocks of the Scurvy Creek succession. Prior to this study, augen granite had only been reported from the northwestern part of the 'Mendocina Creek' area, between Dycer Creek stock and d'Abbadie fault (Gallagher, 1999; Hansen *et al.*, 1989). This suite of meta-granite occurs throughout the Scurvy Creek succession (Fig. 2). It forms a large, continuous sheet that is only disrupted by intrusion of the Cretaceous



Figure 6. Photos of (a) folded, calcareous, graphitic schist, Dycer Creek succession; and (b) gradational boundary between the chloritic schist (MDCv) and white quartzite (MDCq) of the Dycer Creek succession.

Dycer Creek stock, at the top of the Scurvy Creek succession. The nature of the contact between the augen granite and the Dycer Creek succession is not yet fully resolved; this contact could represent an unconformity or alternatively a fault. Augen granite is not observed in either the Sheep Creek or Dycer Creek successions (Fig. 2). An Early Mississippian age is assigned to this older meta-plutonic suite based on two U-Pb zircon dates from the northwestern part of the area (ca. 355; Hansen *et al.*, 1989; Gallagher, 1999); preliminary results from one of our samples collected in the north-central part of the study area confirm this age (ca. 359 Ma; B. Kamber, pers. comm., 2008). This intrusive suite corresponds in age and composition with the Grass Lakes plutonic suite, part of the first cycle of widespread arc magmatism in the Yukon-Tanana terrane (Finlayson cycle; Piercey *et al.*, 2006).

The age of the large body of granodiorite south of Mendocina Creek is uncertain. Near its northern contact with the Dycer Creek succession, the granodiorite is strongly foliated parallel to the regional transposition foliation. Further south into the pluton, the granodiorite is only weakly foliated. This variably foliated granodiorite has generally been considered to be of Paleozoic age on the basis of the localized high strain in the granodiorite and due to a poorly resolved, discordant U-Pb zircon age (Tempelman-Kluit, 1984; Hansen *et al.*, 1989; Fig. 2). Along its western edge, the granodiorite body is strongly altered and truncated by the vertical d'Abbadie fault zone (Colpron, 2005a,b). Colpron (2005a) raised the question whether this large intrusion could be a northern extension of the Quiet Lake batholith. Although it is locally highly strained, the granodiorite has a similar composition to the Early Cretaceous Quiet Lake batholith to the south, which is locally foliated (Tempelman-Kluit, 1977a), and for which preliminary geochronological analyses indicate a complex zoning pattern of zircons with Proterozoic, Paleozoic and Cretaceous age domains (C.J.R. Hart, pers. comm., 2004). Further field and geochronological studies of this granodiorite body are required to precisely determine its age and ascertain its possible relationship to the adjacent Quiet Lake batholith.

The youngest plutonic suite in the area comprises the Dycer Creek stock and an unnamed pluton at the northeastern edge of our study area (Fig. 2). The Dycer Creek stock is a medium to coarse-grained, biotite-quartz monzonite that has been dated by U-Pb zircon at 112 ± 1 Ma (Gallagher, 1999). The quartz monzonite is locally foliated and contains a moderately developed mineral lineation along its outer margin. Euhedral, millimetre-wide garnets are variably present within the

stock, suggesting a component of crustal melt in the genesis of this pluton.

Two small, 1 to 10 m-wide, unfoliated, coarse-grained mafic pods intrude calcareous pelites of the upper unit of the Scurvy Creek succession. These pods intruded post-D₃ and may be related to Cretaceous magmatism. In one locality, a coarse-grained, unfoliated, talc-carbonate rock intrudes near the eastern contact of the lower and upper units of the Scurvy Creek succession (see section on 'Structure' below).

STRUCTURE

The 'Mendocina Creek' area has undergone at least four phases of deformation. The first observable phase of deformation is a cryptic transposition foliation locally preserved within competent, quartz-rich metasedimentary rocks (Fig. 7a). A second phase of deformation refolds the earlier fabric into rootless, intrafolial, tight to isoclinal folds whose axial planes define the regional transposition foliation. In the northern portion of the map area, the folds are overturned to recumbent, and the second phase axial planes strike south-southeast and dip shallowly to the southwest (Fig. 7b). In the south, these folds plunge gently to the northwest and the transposition foliation defines a structural fan that varies from moderate to steep southwest dips in the north to moderate northeast dips in the south (Fig. 2). A third phase of deformation refolds the stratigraphy and the transposition foliation into broad, upright, northwest-verging open folds (Fig. 7c). Southwest-verging thrust faults (Fig. 7d) and fault propagation folds are associated with this phase of deformation, locally, a crenulation cleavage and mineral lineation developed as a result of open folding. Brittle deformation related to a later period of extension resulted in normal faulting and is expressed on the map by abrupt unit truncations (Figs. 2, 7e,f). Throughout the study area, extension gashes, pull-apart features and boudinage occur at the macroscopic and microscopic scale and suggest extension towards the north-northeast.

In the north-central part of our study area, the lower Scurvy Creek succession defines a west-dipping panel that is interpreted to be thrust over the upper unit of the Scurvy Creek succession along an east-verging thrust fault (Fig. 2). A relative increase in strain, the occurrence of talc-carbonate in the lower unit near its eastern contact, and the sharp transition into the structurally underlying, carbonate-rich upper unit to the east support this interpretation.

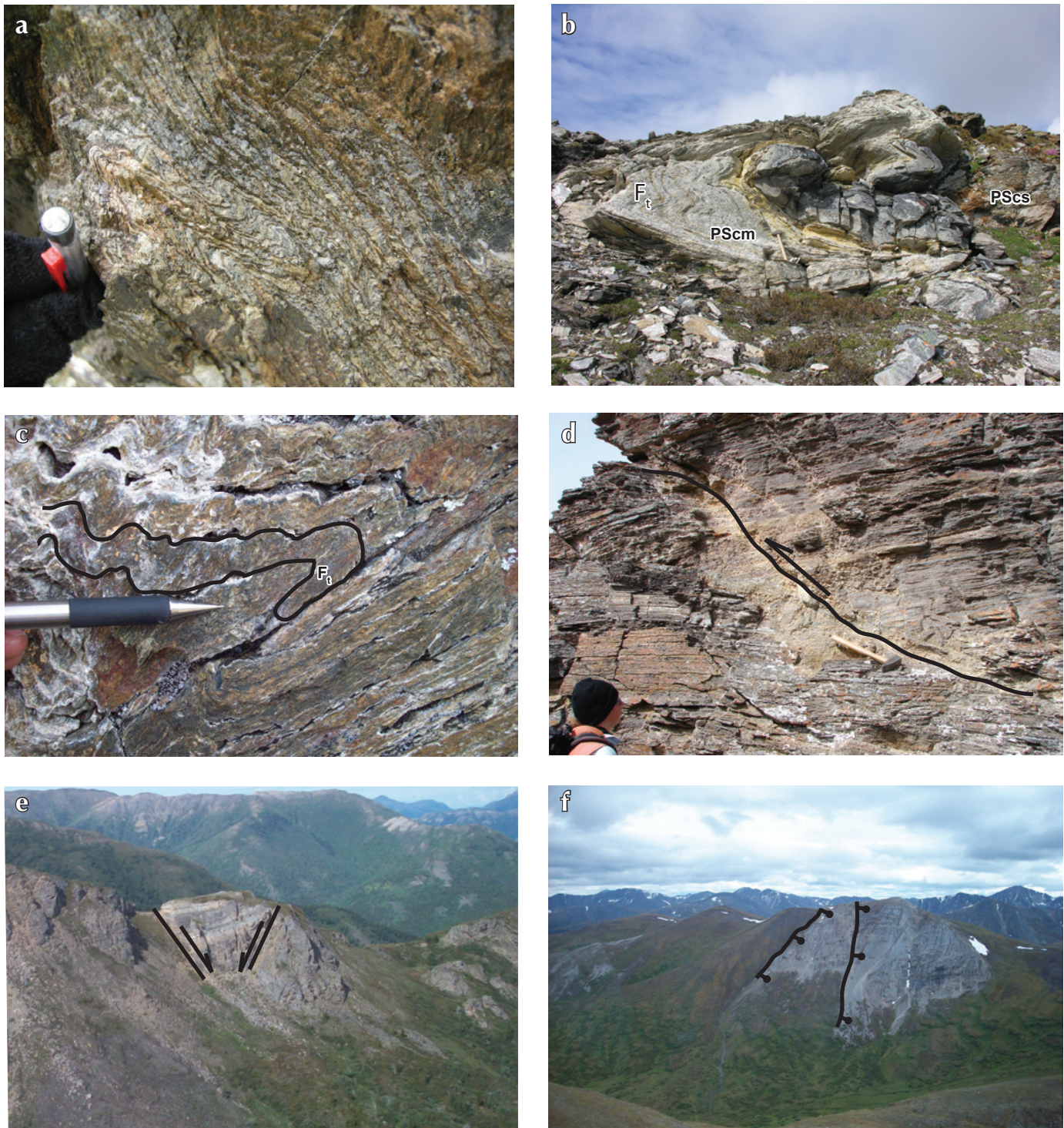


Figure 7. (a) Relic foliation preserved in microlithons between crenulation cleavage planes of the dominant foliation in white quartzite, Dycer Creek succession (pencil end on the left for scale); (b) isoclinal folds (F_t) in marble (PScm) and pelitic schist (PScs), Scurvy Creek succession; (c) re-folded isoclinal fold (F_t) in grey phyllite, Sheep Creek succession; (d) looking west towards a southwest-verging thrust fault in a calcareous pelite, Scurvy Creek succession; (e) looking northeast at a down-dropped fault block in intercalated marble and calcareous pelite, upper unit of the Scurvy Creek succession; (f) looking southeast at normal faulting within marble of the Dycer Creek succession.

Figure 8. C-S fabric illustrating top-to-the-west kinematics in the hangingwall of a west-verging thrust fault in marble, Sheep Creek succession.



In the eastern part of the study area, the Sheep Creek succession structurally overlies the Scurvy Creek succession along a west-verging thrust fault (Fig. 2). Evidence for thrust faulting along this contact includes shallow, northeast-plunging stretching lineations and C-S fabrics (Fig. 8) suggesting transport towards the west-southwest. Locally, the Sheep Creek succession contains small, southwest-verging, 1 to 10 m-scale thrust faults that are interpreted to explain abrupt lithological changes along strike in localities where there is a paucity of kinematic information. Late, brittle structures, such as development of cataclastic rocks (Fig. 9a) and foliated

quartz veins that crosscut the regional transposition foliation and contain slickenlines plunging gently towards the southeast (Fig. 4a), are only developed in rocks of the Sheep Creek succession in the hangingwall of this thrust fault.

The ‘Mendocina Creek’ area is bounded on the west by the north-trending d’Abbadie fault zone, a Late Cretaceous system of brittle-ductile, dextral strike-slip faults that cut across the dominant foliation and regional structural trends (Gallagher, 1999; Colpron, 2005b). The d’Abbadie fault zone is characterized by multiple generations of ductile fabrics associated with dextral shear

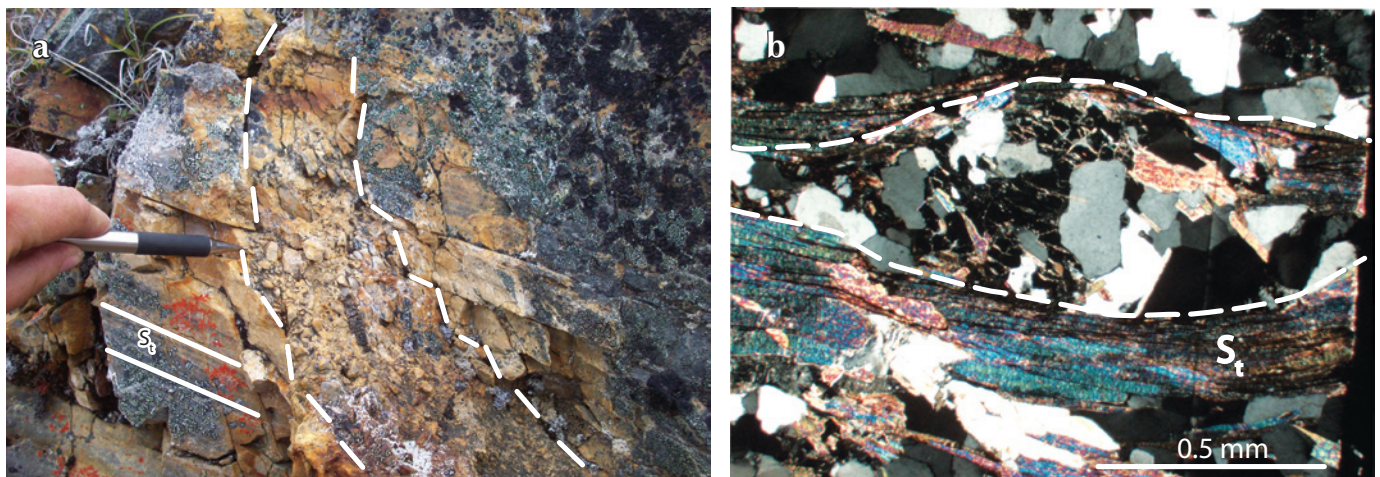


Figure 9. (a) Cataclastic rock within white and black banded quartzite, Sheep Creek succession. Dashed lines represent the limit of the cataclastic zone, the transposition fabric is represented by S_t ; (b) photomicrograph of a recrystallized, sigmoidal garnet porphyroblast within a quartz-biotite-muscovite-garnet schist, Scurvy Creek succession. S_t defines the regional transposition foliation, and recrystallized tails suggest syn- S_t garnet growth.

that are overprinted by younger brittle structures associated with shallow, north-plunging lineations and stepped fibers; these features also support dextral movement (Colpron, 2005b). Part of the ductile strain recorded along the d'Abbadie fault zone has been dated at ca. 96 Ma based on a U-Pb zircon age of a syntectonic granite emplaced along the fault (Gallagher, 1999).

METAMORPHISM

Rocks of the 'Mendocina Creek' area are characterized by upper greenschist to amphibolite facies metamorphism. In the north, metasedimentary and meta-igneous rocks are generally coarse-grained and have garnet-grade assemblages. Pelites and psammites typically contain biotite, garnet and locally andalusite, whereas calc-silicates contain garnet-diopside-epidote assemblages, and metabasites contain hornblende-biotite-epidote assemblages and locally garnet. Garnet porphyroblasts developed prior to, or during, development of the regional transposition foliation (Fig. 9b). In the south, metasedimentary and metavolcanic rocks are generally finer grained and have biotite-grade assemblages consisting of chlorite and biotite. Garnet is locally found in pelites that are in close proximity to the southern granodiorite. Calc-silicates in the south contain garnet, epidote and rarely diopside.

MINERAL POTENTIAL

Mineralization within the 'Mendocina Creek' area is limited and generally occurs within skarn that developed near the Cretaceous Dycer Creek stock. Tungsten mineralization occurs along the southern margin of the Dycer Creek stock (Yukon MINFILE 105F097) and a small skarn occurrence was reported along the eastern margin of the stock by Colpron (2006b; Yukon MINFILE 105E065). A new showing of malachite was discovered during regional mapping in 2008 (UTM Zone 8, 556040E, 6802342N). Malachite is randomly distributed in a 1 m-wide quartz vein that crosscuts the graphitic schist of the Dycer Creek succession. Assay results from one sample yielded 5737.9 ppm in copper. This mineralization is probably related to circulating hydrothermal fluids from a nearby granite.

Regionally, small amounts of disseminated pyrite and pyrrhotite are locally contained within the graphitic phyllite of the Dycer Creek succession. Correlation of these carbonaceous rocks and their associated

metavolcanic rocks with the Yukon-Tanana terrane (see below) suggests that these rocks may be prospective for syngenetic SEDEX or VMS-style sulphide mineralization.

DISCUSSION

Detailed mapping of the 'Mendocina Creek' area indicates that the region is underlain by three distinct stratigraphic sequences. The centre region of the study area is underlain by the Scurvy Creek succession, a sequence of predominantly metaclastic rocks containing amphibolite and minor marble that is intruded by numerous bodies of Early Mississippian granitoids. These combined characteristics resemble those of the Snowcap assemblage, the oldest unit in the Yukon-Tanana terrane (Colpron *et al.*, 2006). Occurrences of abundant Early Mississippian granitoids intruding siliciclastic rocks are more characteristic of the Yukon-Tanana terrane in the northern Cordillera than of the nearby Cassiar terrane. Cassiar terrane and correlative rocks of Selwyn basin northeast of the Tintina fault (Fig. 1) contain only local occurrences of Paleozoic magmatism, most of which is Late Devonian in age, which is somewhat older than granitoids in the 'Mendocina Creek' area. For these reasons, we propose that the Scurvy Creek succession correlates with the Snowcap assemblage and therefore represents part of the Yukon-Tanana terrane. However, it should be noted that Late Devonian to Early Mississippian granitoids (>356 Ma) are widespread in the western Kootenay terrane of southeastern British Columbia, a distal portion of the Laurentian continental margin (*cf.*, Paradis *et al.*, 2006 and references therein), and therefore their occurrence in the Scurvy Creek succession is not in itself uniquely diagnostic of the Yukon-Tanana terrane.

The Scurvy Creek succession is overlain to the southwest by marble, graphitic phyllite, greenstone and quartzite of the Dycer Creek succession (Fig. 2). Colpron (2006b) assigned these rocks to the Yukon-Tanana terrane based on the occurrence of Late Devonian detrital zircons in quartzite in the upper part of the Dycer Creek succession. The predominance of fine-grained carbonaceous rocks in the Dycer Creek succession suggests a possible correlation with the Finlayson assemblage of the Yukon-Tanana terrane (Colpron, 2006a; Colpron *et al.*, 2006). Colpron *et al.* (*ibid*) suggested that carbonaceous rocks in western Quiet Lake map area may represent a southern extension of the back-arc environment documented in the Finlayson assemblage northeast of Tintina fault (Murphy

et al., 2006; Piercey *et al.*, 2006). Quartzite and greenstone in the upper part of the Dycer Creek succession may alternatively correlate with the Klinkit assemblage of Yukon-Tanana terrane (e.g. Colpron, 2006a), an interpretation that would imply the presence of an unconformity within this succession (see Colpron *et al.*, 2006 for discussion of the sub-Klinkit unconformity). It should be noted that metaclastic rocks north of the Dycer Creek stock were formerly considered to be part of the Dycer Creek succession (Gallagher, 1999; Colpron, 2006b); they are herein reassigned to the upper part of the Scurvy Creek succession. The contact between the Scurvy Creek and Dycer Creek successions is marked by a large (<1 km-thick) sheet of augen granite (where not concealed by the Cretaceous Dycer Creek stock; Fig. 2). The nature of this contact remains enigmatic – it may be either an unconformity or a fault. The absence of Paleozoic intrusions in the Dycer Creek succession is notable, with the possible exception of the large granodiorite pluton at the south end of our study area. Both its age and contact relationship with the Dycer Creek succession remain uncertain.

In the eastern part of the ‘Mendocina Creek’ area, the Sheep Creek succession is in contrast with both the Scurvy Creek and Dycer Creek successions. It is composed predominantly of massive horizons of dolomitic marble and variably siliceous metaclastic rocks with rare, thin, decimetre-thick horizons of chloritic schist. Notably, the Sheep Creek succession does not contain amphibolite or metaplutonic rocks, which are defining characteristics of the Scurvy Creek succession to the west. The occurrence of thick marble units and the absence of metaplutonic rocks suggest that the Sheep Creek succession may correlate with the Cassiar terrane of eastern Quiet Lake map area, where it is predominantly composed of Cambrian-Mississippian platformal carbonate and coeval metasedimentary rocks (Tempelman-Kluit, 1977a,b). The boundary between the Sheep Creek and Scurvy Creek successions is interpreted to be a west-verging thrust fault, thus this fault places the parautochthonous Cassiar terrane on top of the allochthonous Yukon-Tanana terrane.

The boundary between Yukon-Tanana and Cassiar terranes is typically delineated by the presence of fault-imblicated, basalt, chert and argillite of the Slide Mountain terrane (e.g. Colpron *et al.*, 2005). Rocks of the combined Yukon-Tanana and Slide Mountain terranes are generally interpreted to have been emplaced on top of distal North America (Cassiar terrane, Selwyn basin) along

east-verging thrust faults (e.g. the Inconnu thrust northeast of Tintina fault; Murphy *et al.*, 2006; Devine *et al.*, 2006; Tempelman-Kluit, 1979; Nelson and Friedman, 2004; Colpron *et al.*, 2005). Our interpretation of a west-verging structure along the terrane boundary in western Quiet Lake map area represents a departure from this regional pattern. It is however in agreement with the series of imbricated, west-verging thrust panels marked by carbonate rocks of Cassiar terrane to the east of ‘Mendocina Creek’ area (Tempelman-Kluit, 1977a).

In the southeastern Canadian Cordillera, allochthonous terranes were first emplaced over distal North America along east-verging structures in Early Jurassic time (Murphy *et al.*, 1995). They were subsequently deformed in west-verging structures during development of a regional fan structure of Middle Jurassic age (Colpron *et al.*, 1998; Gibson *et al.*, 2008), a structural style that presumably extended the length of the Canadian Cordillera (Price, 1986). West-verging structures in western Quiet Lake map area may be part of this Middle Jurassic regional structural style. The development of west-verging thrust faults has likely modified the original terrane boundary and may explain the apparent absence of the Slide Mountain terrane in the area (*cf.* Colpron, 2006a). Further studies of west-verging structures in western Quiet Lake map area are required in order to fully resolve the regional extent and significance of these structures.

Mapping of the ‘Mendocina Creek’ area and the correlations discussed above suggest that the Yukon-Tanana terrane is much more extensive in western Quiet Lake map area than previously interpreted by Tempelman-Kluit (1977a, 1979). Tempelman-Kluit (1977a) identified only limited occurrences of the Nisutlin assemblage (*i.e.* Yukon-Tanana terrane) in a klippe structurally overlying the Cassiar terrane immediately north of Mendocina Creek. These rocks – the quartzite and greenstone units in the upper part of the Dycer Creek succession on our map (Fig. 2) – represent only a portion of the rocks we now assign to the Yukon-Tanana terrane. In our interpretation of the geology (Fig. 2), the boundary between the Yukon-Tanana and Cassiar terranes is located approximately 20 km to the east of the previously inferred boundary, the d’Abbadie fault.

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List of Publications and Maps

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YGS released 29 new publications in 2008: two annual reports, two Geoscience Maps, 21 Open Files and four MPERG reports.

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