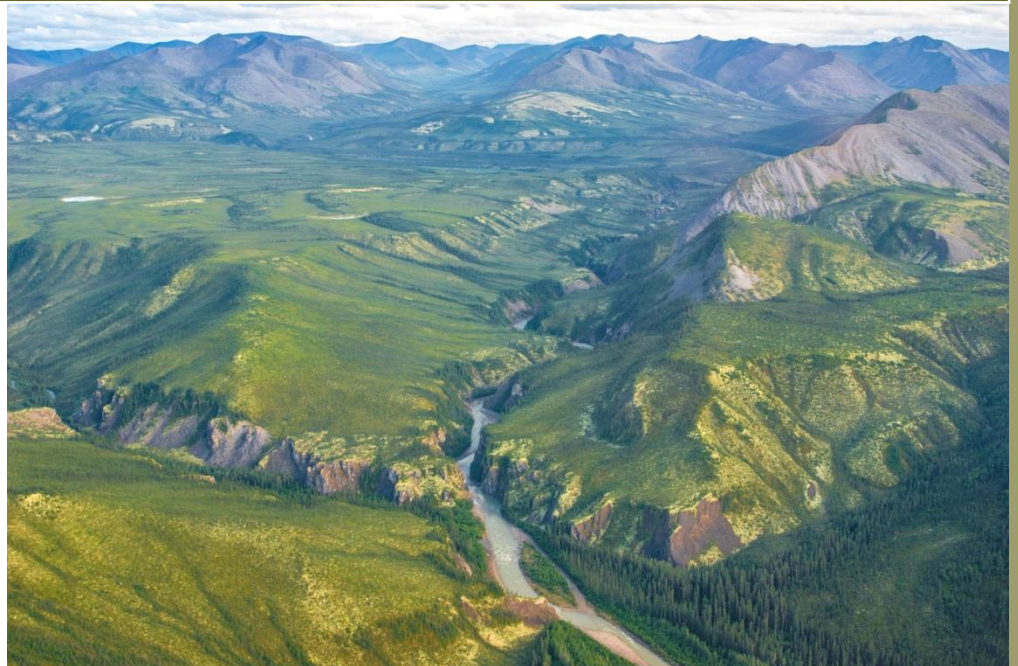


2016

# Yellowknife Geoscience Forum



Abstract and Summary  
Volume

### **Cover photograph**

Mackenzie Mountains foothills, NWT;  
Viktor Terlaky, Senior Petroleum Geologist at the Northwest Territories Geological Survey

The picture was taken near the Arctic Red River and shows river cuts and thaw slumps in the Peel Plateau area. Old meets new: the river cuts expose Devonian and Cretaceous strata, some of which are the target of investigation as potential unconventional hydrocarbon plays; thaw slumps are caused by permafrost melting and are interpreted to be the consequence of climate change.

**Compiled by D. Irwin, S.D. Gervais, and V. Terlaky**

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# Abstracts - Oral Presentations

Presenting Author denoted by \*

## **QILALUGAQ DIAMOND PROJECT, NUNAVUT – A UNIQUE LOCALITY FOR RARE 'CANARY' YELLOW DIAMONDS**

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The Qilalugaq diamond project is located near the community of Naujaat (Repulse Bay), Nunavut. A total of eight kimberlite pipes (Q1-4, A34, A42, A59, A76, A94, A97 and A152) have been identified within the project as well as a number of laterally extensive kimberlite dyke systems. The Q1-4 kimberlite, at 12.5 hectares and containing a May 15, 2013 Inferred Mineral Resource\* estimate of 26.1 million carats from 48.8 million tonnes total content of kimberlite with an average +1 DTC (>1mm) total diamond content of 53.6 carats per hundred tonnes (cpht), is the most significant discovery on the property. (\*Mineral resources that are not mineral reserves do not have demonstrated economic viability. For information on the data verification, exploration information and the resource and related target for further exploration estimation procedures please see the technical report dated May 13, 2013 which is available under North Arrow Minerals' profile at [www.sedar.com](http://www.sedar.com)).

Q1-4 also represents a unique situation in Nunavut, being located within the municipality of Naujaat, only 9 km from the community. Evaluation of the deposit is

conducted directly from Naujaat and local employees are able to live at home while working at the project. During the summer of 2014, North Arrow collected, by surface trenching, an approximate 1,350 dry tonne sample from Q1-4. Final diamond recoveries from the sample included 11,083 diamonds greater than +1 DTC weighing approximately 384 carats. Yellow diamonds, representing a range of hues and tones, comprise approximately 9.0% by stone count (21.5% by carat weight) of the +1 DTC diamonds. The diamond parcel was valued by WWW International Diamond Consultants (WWW) with a modeled range of possible values from a possible low of \$43 per carat and a possible high of \$92 per carat. The primary conclusion reached by WWW was that the valuation results and modeled values should be treated with considerable caution when assessing the Qilalugaq project due to the very small size of the diamond parcel.

Subsequent evaluation of the diamond parcel has focused on the yellow diamond population in order to better understand its potential value contribution to the deposit. The yellow diamonds have been confirmed as rare Type Ib – IaA 'Canary' yellow diamonds, representing a distinct population from the non-coloured diamonds. A diamond polishing exercise has confirmed the canary yellow diamonds could command a premium price and a review of possible size frequency distribution models suggests the canary yellow diamonds could have a significant positive impact on the potential viability of the Q1-4 diamond deposit. Additional sampling is required to confirm the appropriate size frequency distribution

and valuation models for these rare and beautiful diamonds.

## **INSIGHTS INTO GOLD MINERALIZATION AT THE YELLOWKNIFE CITY GOLD PROJECT USING SYNCHROTRON X-RAY SPECTROSCOPY**

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The Yellowknife City Gold Project (YCGP) encompasses 129 sq. km of contiguous land immediately north and south of Yellowknife, in one of the six major high-grade gold districts in Canada. The project lies in the prolific Yellowknife greenstone belt, covering 23 km of strike length on the northern (15 km) and southern (8 km) extensions of the shear system that hosts the past producing high-grade Con (6.1 Moz @ 16.1 g/t Au) and Giant (8.1 Moz @ 16.0 g/t Au) gold mines. Samples of high-grade mineralization were collected from the Crestaurum, Barney Shear, Hébert Brent, and Homer Lake targets as well as historical samples from the Geological Survey of Canada Yellowknife EXTECH collection. Gold occurs as either visible or so-called “invisible gold”; either lattice-bound in sulphides or as nanoparticle inclusions. Gold in these deposits is also commonly intimately associated with pyrite and/or arsenopyrite in arsenic-rich mineralization

and sphalerite and/or galena in arsenic-poor mineralization.

Sulphide ore minerals efficiently incorporate many key metals during precipitation and progressive growth that effectively records the chemical evolution of mineralizing fluids. Trace elements like Ni and Cu can substitute for Fe in the sulphide lattice whereas As can exchange with S. Sulphide ore minerals crystallized from hydrothermal fluids with different trace-element contents will contain variable concentrations of these elements that manifest themselves as zones like growth rings in a tree. Gold commonly displays similar geochemical characteristics to many trace elements during pyrite precipitation but may behave differently during hydrothermal fluid evolution. Synchrotron radiation micro X-ray fluorescence (SR- $\mu$ XRF) provides rapid and cost-effective micron to cm-scale trace element analysis and mapping of ore minerals with ppm detection limits. In addition, speciation of gold and trace elements important for understanding element mobility can be probed using synchrotron X-ray absorption near-edge structure (XANES) spectroscopy.

We have developed new SR- $\mu$ XRF techniques that can be performed directly on half core samples and produce trace element maps >10 cm long by full core width. The technique is totally non-destructive and provides critical trace-element associations in gold bearing sulphide minerals that provide integral information regarding the nature of mineralizing fluids. By using synchrotron-based  $\mu$ XRF mapping, micron scale growth halos and correlations between gold and other trace metals can be resolved. In addition, XANES analysis provides critical information about the oxidation state of these elements, providing evidence for fluid redox states as well as the nature of

invisible gold. Ultimately, this project will help develop an understanding of the metallurgical characteristics of the ores as well as the nature of refractory and free-milling gold and its association with potentially deleterious elements such as arsenic. Synchrotron X-ray spectroscopy is a novel niche presently under-utilized in our field. Harnessing synchrotron light for micron-scale analysis provides a powerful tool that addresses industry relevant problems using a rapid, high-resolution analytical technique.

## **SOCIO-ECONOMIC AGREEMENTS IN THE NORTHWEST TERRITORIES**

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Socio-Economic Agreements formalizes socio-economic commitments made between resource developers and the Government of the Northwest Territories (GNWT). These agreements focus on maximizing benefits to communities in the Northwest Territories.

The Government of the Northwest Territories (GNWT) currently has three SEAs in place with three active mines:

- Dominion Diamond Corporation (DDC), Ekati Diamond Mine (Ekati), signed October 1996;
- Diavik Diamond Mines (2012) Inc. (Diavik), signed October 1999 and amended January 2015; and
- De Beers, Gahcho Kué Project, signed June 2013.

This presentation provides an overview of these agreements and how the GNWT monitors their implementation.

## **NORTHERN MODELS OF CONSULTATION AND ACCOMMODATION PRACTICE**

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In partnership with Indigenous and Northern Affairs Canada (INAC), NPMO has developed northern Models of Consultation and Accommodation Practice each composed of an integrated suite of tools, procedures and broadened resources. These Models integrate the duty within officials' normal course of business, streamline (for all parties) how the duty is discharged and improve the protection of asserted or established Aboriginal and/or Treaty rights.

## **PRELIMINARY GEOLOGY OF THE KELVIN-FARADAY KIMBERLITE CLUSTER**

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The Kelvin-Faraday kimberlite cluster is located in the southeastern Archean Slave Craton of northern Canada and consists of at least four irregular pipe-like bodies (Kelvin, Faraday 2, Faraday 1 - 3, Hobbes) and numerous kimberlite sheets. Hosted in metaturbidites of the Yellowknife Supergroup, the cluster occurs along a regional northeast structural trend, eight kilometres from the Gahcho Kué diamond

mine. The kimberlite bodies are significantly diamondiferous and characterized by multiple emplacement events and characterized by non-traditional inclined pipe shapes. Detailed core logging, petrography, microdiamond investigations and preliminary 3-D modeling over the past three years have been completed to establish the pipe morphology and the internal geology of the Kelvin, Faraday 2 and Faraday 1 - 3 pipes.

The Kelvin pipe is primarily infilled by volcanoclastic kimberlite (VK). Hypabyssal kimberlite (HK) and a spectrum of kimberlite displaying textures transitional between VK and HK textures have been identified. Seven kimberlite phases have been established and grouped into three geologic zones (A, B and C) based on textural characteristics, country rock dilution, diamond grade and interpreted emplacement relationships. Internally the Kelvin pipe displays sub-horizontal layering of the different kimberlite phases over the length of the pipe. External to the Kelvin pipe are a number of hypabyssal kimberlite sheets and a volcanoclastic blow (Hobbes), which together make up an extensive associated sheet complex that extends for one kilometre to the south of Kelvin.

The Faraday 2 pipe is infilled by volcanoclastic kimberlite, with minor amounts of hypabyssal and transitional kimberlite. Four kimberlite phases have been identified. The internal geology of Faraday 2 also shows sub-horizontally layered kimberlite phases trending the length of the pipe similar to the Kelvin kimberlite.

The Faraday 1 and Faraday 3 kimberlite bodies are also characterized by volcanoclastic kimberlite, extensive kimberlite rich marginal breccia features,

and several hypabyssal kimberlite sheets. Work is currently underway to establish preliminary 3-D geology models for Faraday 1 - 3.

The geology of the Kelvin-Faraday kimberlite cluster is similar and yet unique compared to kimberlites that have been previously discovered and mined globally. Our understanding of emplacement processes of these kimberlites, specifically with respect to Kimberly-type pyroclastic bodies, will continue to evolve. This evolution will have an impact on the exploration and recognition of non-typical volcanoclastic kimberlite bodies, particularly in the southeastern Slave province.

## **MARIAN WATERSHED COMMUNITY-BASED AQUATIC EFFECTS MONITORING PROGRAM**

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The Tłıchọ Government is working together with Wek'èezhii Land and Water Board (WLWB) and other partners to develop the Marian Watershed Community-Based Aquatic Effects Monitoring Program. This is a community-based monitoring program that is being developed based on the questions and needs of the Tłıchọ people.

Tłıchọ Lands have been under Moratorium since the signing of the Tłıchọ Agreement in 2005 and on June 1, 2013, the Moratorium was lifted as the Tłıchọ Wenek'e or Land Use Plan came into force. With the potential for future development of Tłıchọ Lands, the Tłıchọ people have expressed concern about impacts on the water and wildlife they are so dependent upon. The objective of the

Marian Watershed Monitoring Program is to begin collecting baseline information about the water and fish on Tłıchǫ lands and in locations the Tłıchǫ feel are the most important, prior to any major development pressure (such as the NICO mine by Fortune), and to continue collecting this data over time. Community members are being trained to collect samples, analyze the samples, and report findings back to the rest of the community members.

A pilot project was conducted at Hislop Lake, upstream of the planned NICO Mine site, in the fall of 2013. This project included the training of eight community members and a field program where the newly trained Environmental Monitors worked with scientists to investigate the concerns of the elders and community members.

A workshop was organized by the Department of Culture and Lands Protection (DCLP) in the spring of 2015 to bring back the results from the Marian Lake camp and to develop a long term monitoring plan that truly addresses the concerns of the elders. We identified five important field sites along the Marian River from Hislop Lake to Marian Lake, which will be visited on a four-year cycle. The DCLP organized the forth field program this fall on Marian River near La Martre River. Where the Environmental Monitors worked with the scientist to investigate the concerns from the elders and communities.

The ongoing program will facilitate enhanced understanding of fish health and water chemistry each year, ensure active monitoring of Tłıchǫ waters by Tłıchǫ people, and prioritize meaningful communication back to community members.

## **EKATI AUTOMATED UG DEWATERING**

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As the Ekati underground mine approaches its end of life it was recognized that the single line pumping system was unable to deal with major inflows from freshet or a significant rain event (>500 gallons per minute). This risk resulted in the design and construction of a fully automated dual eight inch dewatering system capable of pumping a combined 2000 gallons per minute with a maximum particle size of three quarter inch and four percent solids. The lines run independently of one another, are fully automated without human input for up to 72 hours and were constructed utilizing existing infrastructure. Construction took place without interrupting operations, unnecessary sumps were eliminated, the life of mechanical seals was extended, pumps are protected from cavitation, and the system is fully operable from the Human Machine Interface (HMI) at the underground dispatch. A dual system allows for on-going maintenance to take place without compromising daily pumping requirements.



## **DEVELOPING A HYDROTHERMAL MODEL FOR POLYMETALLIC NI-CO-BI-AG- SB-AS-U VEINS AT BLANCHET ISLAND AND COPPER PASS, EAST ARM BASIN AND SOUTHERN SLAVE PROVINCE**

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Polymetallic veins (Ni-Co-As-Bi-Ag-Sb-U), traditionally defined as “five-metals association” veins, occur in the southern Slave Province and East Arm basin of Great Slave Lake, Northwest Territories. This style of mineralization was historically mined at Blanchet Island and Copper Pass, and is being investigated in this study using a variety of bulk and microanalytical (geochemical and geochronological) techniques. Blanchet Island occurs in the East Arm basin of Great Slave Lake where vein hosted-styles of cobalt-nickel mineralization occur within skarnified carbonate sedimentary rocks of the Paleoproterozoic Great Slave Supergroup (ca. 1.88 Ga), and adjacent to (and locally within) monzonitic sills (ca. 1.87 Ga). Copper Pass occurs within the southern the Slave Province and mineralization occurs as massive nickeline veins that cross-cut Archean metavolcanic rocks and pegmatite dykes. Nickeline mineralization also occurs as breccia-cements in altered country rock; this has only been observed in float, not outcrop. Ore mineralization consists of nickel-cobalt-arsenides, galena, native bismuth, molybdenum and minor sulfides.

Blanchet Island contains cobalt-ores skutterudite, safflorite, cobaltite and Ni-minerals rammelsbergite and minor amount of nickeline. Copper Pass is dominated by nickeline and minor gersdorffite, with native bismuth, molybdenum, antimony, and galena, and a late uranium phase. Microthermometry of fluid inclusions hosted in quartz and carbonate indicate a narrow range in fluid salinity and wide range of homogenization temperatures for the paleo hydrothermal fluids. Analysis of fluid inclusions in Blanchet Island vein-carbonate minerals indicate a range of entrapment temperatures between 124.8 to 244.3°C, with fluid salinities between 18.5 to 23.7 wt.% CaCl<sub>2</sub>. Fluid inclusions in Copper Pass vein-quartz and carbonate return entrapment temperatures between 123.5 to 359.5 °C and 125.9 to 244.3 °C, respectively, with a bulk salinity range from 20.1 to 22.6 wt.% CaCl<sub>2</sub>. Ongoing Raman spectroscopy and LA-ICP-MS on fluid inclusions will complement the micro-thermometry to help constrain the chemical composition and evolution of hydrothermal fluids as they relate to ore formation.

## **2016 NWT MINERAL EXPLORATION AND MINING OVERVIEW**

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This year marks a 25-year commemorative milestone for the diamond industry of the Northwest Territories (NWT). In 1991, on the shores of Lac de Gras, geologists Chuck Fipke and Stewart Blusson found evidence of the territory's first diamond-bearing kimberlite pipe that resulted in the largest staking rush in Canadian history. Their

discovery resulted in the construction and opening of Canada's first diamond mine, Ekati, and ignited a \$28-billion-dollar industry which established Canada as the world's third largest diamond producer by value and fifth by volume.

Despite tough financial market conditions, NWT mineral producers continue to advance their projects. In mining news, after moth-balling the Snap Lake Mine late last year, in September DeBeers Canada and Mountain Province Diamonds opened the Gahcho Kué Mine, the NWT's fourth diamond mine. Both Diavik and Ekati mines are proceeding with major expansions that will increase the longevity and profitability of these projects. The total estimated value of minerals produced in the NWT during 2015 was \$1.79 billion, of which diamonds account for 97 percent of this value.

Explorers have become cautiously optimistic about being able to raise money for exploration activities. The Slave Geological Province saw several diamond, gold and base metal exploration projects. Kennady Diamonds received promising new results on their Kennady North property based on drilling of the MZ, Doyle, Kelvin, Hobbes and Faraday kimberlites. Closer to Yellowknife, TerraX continued drilling gold and base metal targets on their expanded Yellowknife Gold Project. Good intersections continue to come back from the lab from TerraX's ca. 27,000 metre, 2016 summer drilling program. Nighthawk Gold completed almost 8,400 metres of drilling on the Colomac 1.5 Zone, Goldcrest and other prospects in the Indin Lake Volcanic Belt. Favourable results from the Nighthawk drill program have attracted the interest of Kinross Gold, prompting a buy-in. Outside of the Slave Geological Province, exploration for gold, lithium and other

metals continued in the NWT Cordillera and other areas.

This year the NWT Mining Incentive Program supported six corporate and five prospector programs exploring for gold and diamonds in the Slave Geological Province and the NWT Cordillera. The program invested \$400,000 in assistance to NWT mineral exploration.

## **NORTHWEST TERRITORIES GEOLOGICAL SURVEY – MINERAL DEPOSITS AND BEDROCK MAPPING 2016 ACTIVITIES**

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The Northwest Territories Geological Survey (NTGS) carries out geological survey activities for the Government of the Northwest Territories. Within the NTGS, the Minerals Deposits and Bedrock Mapping section (MDBM) carries out geological, geochemical, and geophysical research to enhance our knowledge of NWT geology.

MDBM is enhancing mapping of Slave Geological Province volcanic belts, targeting areas of bedrock exposure that have been recently cleaned by forest fires. The detailed mapping will assist the mineral exploration industry to test the potential for undiscovered gold, volcanogenic massive sulphide, and other deposits. Surficial geochemistry research is being conducted in conjunction with the bedrock mapping in order to understand how drift prospecting techniques might be better used to find a variety of Slave mineral deposits.

Several studies in the East Arm area of

Great Slave Lake continued during 2016. These are aimed at improving our understanding of the geological history and mineral potential of one of the more accessible regions of the NWT.

In the NWT Cordillera, NTGS stream sediment data is being statistically analyzed to better understand its potential for finding new mineral deposits. In the Howards Pass area, systematic sampling for conodonts and graptolites is being used to aid our understanding of the structure and stratigraphy of these rocks. MDBM also completed detailed mapping to help understand the structural and stratigraphic complexities affecting the Mactung tungsten deposit. Several graduate student research projects were supported in the Cordillera.

MDBM is conducting several diamond related research initiatives. These activities include projects to explain occurrences of, and characterize the potential for, diamonds in frontier areas such as Banks Island and the central Dehcho Region. Additional diamond related projects aim to characterize the mantle beneath, and physiochemical conditions of, known diamondiferous kimberlites.

In 2015, CanNor funds allowed the completion of a research program studying the surficial geology of the central Slave Province diamond fields. The program utilized drilling, surficial mapping, geophysics, and a host of innovative tools to model indicator mineral entrainment, develop new 3D surficial material maps, and contribute to glacial transport models for use by industry diamond explorers. This year saw the publication of a large amount of research from this program.

## **INTO THE UNKNOWN PART 2: SURFICIAL GEOLOGICAL INVESTIGATIONS IN THE SOUTH RAE, NORTHWEST TERRITORIES**

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The Geological Survey of Canada, as part of its Geo-Mapping for Energy and Minerals Program (GEM2), in partnership with the Northwest Territories Geological Survey, is in the second year of a project to upgrade the bedrock and Quaternary geoscience knowledge for the underexplored and predominantly drift-covered South Rae Craton in southeastern Northwest Territories. During the 2016 field season, surficial geological mapping and till sampling was conducted in NTS map sheets 75G and H. Targeted reconnaissance sampling (~15 km spacing) resulted in 109 till samples collected at 103 sites for provenance, geochemistry, indicator minerals and gold grains. Multiple small and meso-scale erosional ice-flow indicators (e.g. striations, grooves, roche moutonnée) were measured at 109 locations. To help establish a minimum age for deglaciation in this area, samples were collected for age dating from 3 beach or delta sites (optically stimulated luminescence) and 5 boulder sites (terrestrial cosmogenic nuclides).

Preliminary mapping has identified at least 4 phases of ice flow with 2 main flowsets

variably affecting the entire study area. An old flow of unknown sense (SSE/NNW) and temporal relationship was recorded at a few sites. An old regional southward flow is overprinted by the main regional southwest flowset (Late Wisconsin deglaciation). A late (youngest) west flow overprints this southwest flow.

Distinctive erratics, such as Dubawnt Supergroup lithologies derived from sources located to the north-northeast are more prevalent than in the 2015 map area to the south. This is consistent with sustained transport and dispersal of glacial debris by the older southward flow.

Drift cover of variable thickness is extensive, with bedrock exposure ranging from 0 to 30%. The dominant surficial material is till of varying composition, thickness and genesis. The till becomes sandier northward likely reflecting an increased Thelon sandstone component in the till. The landscape, particularly in northeastern 75G and much of 75H is dominated by streamlined landforms with organic terrain in the lows. Numerous parallel NE – SW trending eskers systems and subglacial meltwater corridors cross the map area with two types of signature landform/deposits assemblages: 1) eskers, parallel trains of either ice-contact glaciofluvial (hummocks and ridges) deposits or terraced glaciofluvial deposits, and 2) trains of hummocky till, boulder lags, exposed bedrock with small discontinuous eskers and related deposits. New mapping has continued to delineate the extent of glacial lakes in this region. The reworking of the existing glacial and glaciofluvial deposits below 410-420 m elevation has resulted in a widespread veneer of sands and sandy diamictos over the low relief terrain.

The 1:100 000 scale surficial geological

mapping, together with reconnaissance-scale till sampling, will provide new data and improved understanding of the glacial history in support of mineral exploration, sustainable resource development and land-use management for the South Rae region.

## **DIRECT DETECTION OF DRIFT-CONCEALED KIMBERLITES USING SURFACE GEOCHEMISTRY AND LANDSCAPE EVOLUTION MODELS IN THE NWT, CANADA**

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Many diamondiferous kimberlites in the Lac de Gras region of the Northwest Territories are concealed by glacial drift, rendering them challenging to detect by traditional exploration techniques that exploit residual surface chemistry. Much research has been aimed at the development of deep penetrating geochemical exploration technologies to increase the rate of discovery whilst reducing risk and exploration cost. However, results from a detailed study of soil geochemistry above the DO-18 kimberlite (Peregrine Diamonds) demonstrate the potential to apply conventional surface geochemical techniques coupled with surface material mapping and landscape evolution models to the evaluation of discrete targets.

150 soil samples from the oxidized upper B-horizon in a detailed grid crossing the concealed kimberlite were collected.

Samples, screened to -180 microns, were analysed by multi-element ICP-MS following 4-acid, aqua-regia and deionized water extractions. Fp-XRF was utilised as an equivalent total method to evaluate its applicability. Sequential leach on selected samples was undertaken to understand the deportment of the elements of interest within the soils. Surficial mapping included soil type, topographic variation, landforms, environment and vegetation. This allows an assessment of surface controls on the geochemistry, in particular the generation of false anomalies from chemical traps such as swamps; and allows the generation of a landscape development model. Hydrocarbons, analysed using the SGH and Goresorber techniques, were evaluated to characterize the type and abundance of complex hydrocarbons above the kimberlite relative to above the host granitic gneiss.

Geochemical data is subject to landform generation processes. The northern half of the grid comprises till with numerous frost boils. The southern half, at lower topography below a distinct break, is dominated by sand-rich material and fine clay. Results from the 4-acid and aqua regia extraction show a dispersion of Nb, Ni, Mg, Ce, Cr and Cs from directly above the northern part of the kimberlite to the edge of the sampling grid, approximately 500 metres to the northwest, following glacial dispersion. SGH-hydrocarbon results exhibit a similar pattern in light-alkyl benzenes. Fp-XRF data repeats the pattern in all elements except Mg, where the concentrations are too low for reliable detection. In the southern half of the grid, at a lower topographic level, geochemical responses are considerably more subtle.

It is hypothesised that anomaly formation in the till followed standard glacial dispersion in the down ice trend. Material was

entrained to the surface from deeper in the till, locally above the kimberlite, by frost boil action. The southern part of the area is considered to have been inundated with water, the remains of which comprise the current lake over the DO-27 kimberlite approximately 400m to the south. Sediments in this area are clay rich – comprising material deposited by the lake, or re-worked sandy material along the palaeo-lake margin and subsequent erosional channels. These later processes acted to further disperse, conceal and dilute the signal of the underlying body.

## **THE YELLOWKNIFE BAY AQUATIC ECOSYSTEM 75 YEARS AFTER GOLD PRODUCTION BEGAN: ARSENIC, ANTIMONY AND METALS IN WATER, SEDIMENT AND FISH**

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Yellowknife Bay on Great Slave Lake is a water body of cultural, subsistence and recreational importance for the Yellowknives Dene First Nation and residents of Yellowknife. The bay has been impacted by releases of pollution from gold

mining since the start of ore production in the late 1930s. Arsenic, antimony and metals were deposited in the bay through effluent and tailings releases, and air emissions from ore roasting. Local concerns remain over the long-term fate of legacy mining pollution. A study from 2013 to 2015 investigated processes controlling the movement and environmental fate of metal(loid)s released into Yellowknife Bay, with a focus on water and sediment quality, and bioaccumulation in the food web.

Dated sediment cores showed significant enrichment of antimony, arsenic, copper, lead, mercury, silver and zinc in sediments corresponding with the timing of historical mining operations in the region. Atmospheric deposition of pollution from ore roasting extended approximately 20-25 km south of Giant Mine and into the main body of Great Slave Lake. The most intensive enrichment of metal(loid)s in sediments occurred in Yellowknife Bay within 5 km of the Giant Mine roaster and during the early years of operation. In Yellowknife Bay nearest to Giant Mine, levels of antimony and metals have declined near the sediment surface but remain above pre-mining levels. At farther sites, concentrations of elements in surface sediments have declined to background.

While sediments in Yellowknife Bay indicate some recovery from legacy pollution of less mobile metals (e.g. copper, lead), arsenic remains highly concentrated in younger surface sediment with solid-phase peaks of 800-4500 ppm in the top 5 cm. Levels and speciation of dissolved arsenic in sediment porewaters were related to oxygen conditions, with elevated concentrations found below the oxic-anoxic boundary. The arsenic peaks in near-surface sediment likely resulted from dissolution and upward

migration of dissolved arsenic from arsenic-rich sediments below.

Summer concentrations of arsenic in surface waters were relatively low (<4 ppb) in Yellowknife Bay, although levels were several-fold higher close to Giant Mine compared to the mouth of Yellowknife Bay and main body of Great Slave Lake. Surface water arsenic was predominantly in the dissolved fraction as arsenate ( $\text{As}^{+5}$ ) although arsenite ( $\text{As}^{+3}$ ) was also present. Recent total arsenic concentrations in Yellowknife Bay surface waters near Giant Mine were about half the levels measured in the 1980s and 1990s.

Over 200 fishes, representing seven species, were collected in Yellowknife Bay and near Wool Bay on Great Slave Lake for arsenic and metals analysis of tissues. Arsenic concentrations in fish muscle were well below the Canadian Food Inspection Agency guideline of 3.5 ppm wet weight. The low arsenic in fish muscle can be explained by low arsenic in surface waters and the physiological behaviour of this element in fish.

Yellowknife Bay is showing positive signs of recovery with long-term declines of arsenic in water and metals in surface sediment. However, further study is recommended to better understand the potential for arsenic release from sediment, which remains a large and potentially leaky reservoir of legacy arsenic.

## **AREAS OF OPERATION: IMPROVING CLARITY AND CONSISTENCY IN LAND AND WATER BOARD PRACTICES AND PROCEDURES**

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In early 2008, the Mackenzie Valley Land and Water Board (MVLWB) formed the Standard Procedures and Consistency Working Groups to focus on specific regulatory improvements to improve clarity and consistency among the Land and Water Boards (LWBs). Though the Working Group initiative was successful, lessons have been learned and improvements are necessary to ensure continued success in areas of collective LWB product development. The LWBs have identified areas where improved clarity and consistency in our common practices and procedures should be achieved. These Areas of Operation include: Corporate Excellence, Regulatory Improvement, Information and Communications Technology, and Outreach and Engagement. This talk will provide an overview of these Areas of Operation and the exciting initiatives and products that are underway.

## **TECHNICAL SESSIONS ON CULTURAL IMPACTS - A NEW ENVIRONMENTAL ASSESSMENT TOOL**

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The Mackenzie Valley Review Board (the Board), when conducting environmental assessments, is required to consider the protection of the environment from the significant adverse impacts of proposed developments, as well as the protection of the social, cultural and economic well-being of residents and communities of the Mackenzie Valley. In addition, the Board is required to consider both scientific and traditional knowledge. The Board has found that a disproportionate amount of information provided to the Board to consider in past environmental assessments has focused on scientific evidence related to the biophysical environment, and less so on the human environment and traditional knowledge. To help address this imbalance, the Board has recently held as part of an ongoing environmental assessment process community technical sessions that have focused on cultural impacts and the collection of traditional knowledge. This talk will focus on how these sessions were conducted and how the information provided will assist the Board to better fulfill its broader mandate.

## **INNOVATIVE APPROACHES TO COMMUNITY ENGAGEMENT IN AN INDIGENOUS AND URBAN ENVIRONMENT**

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Earning social licence is critical for successful natural resource projects. Experience in Canadian territories has focused on remote fly-in fly out projects. While northern stakeholders, regulators and industry have made significant improvements in meaningful community engagement over the last 25 years it has been almost that long since the last community hosted project shut down. The concerns, opportunities, impacts and benefits of a project on the outskirts of N'dilo, Dettah and Yellowknife are different than remote projects. Here employees would drive home every day, indigenous employees and suppliers are 20 minutes from site, infrastructure will be impacted, residents and tourist would see the project from where they ski, snowmobile, hike and have their cabins and the environment legacy of mining is close by. TerraX's Yellowknife City Gold Project is developing the last major greenstone belt in Canada on 129 sq. km bordering the north and south of the City. The talk will provide an update since last year's community engagement presentation and discuss TerraX's pioneering approach to co-usage and partnering with urban stakeholders for a project within sight of the YKDFN Band Office and City Hall.

## **COORDINATION AND COMPLETION OF MULTI-YEAR GEOTECHNICAL INVESTIGATION IN THE CANADIAN ARCTIC: CHALLENGES AND LESSONS LEARNED**

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The Northwest Territories Department of Transportation is entering the final winter season of construction of an all-season highway connecting Tuktoyaktuk with Inuvik which is currently the terminus of the Dempster highway. This development will comprise over 140 km of two-lane, gravel surfaced highway. It will require roughly 7 million cubic meters of granular material for construction and operation and thus required the completion of a borrow source investigation program along the proposed corridor.

The execution of the program required the development of risk management strategies with an emphasis on team roles focusing on the logistical aspects and associated challenges while maintaining technical oversight and quality. As such, significant effort was spent on planning, including identifying areas deemed most probable to contain suitable borrow. This included cooperation between geotechnical staff and terrain staff using new technologies to complete an initial desktop study of the proposed alignment area to identify and prioritize investigative areas of interest. Overall, approximately 700 boreholes were drilled successfully in under 80 days, spread over three winter seasons in a remote location.

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## **EFFECTS OF FIRE AND DEVELOPMENT ON BATHURST CARIBOU WINTER RANGE HABITAT SELECTION**

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Barren-ground caribou are a migratory species and their ability to locate suitable resources on different seasonal ranges is important to their survival and reproductive success and coping with environmental variability. The winter range is important because it immediately precedes the calving period and represents a time when energetic costs of thermoregulation and foraging are high and body reserves required to maintain cow pregnancy are typically decreasing. For Bathurst caribou, the winter range has historically included a large area of boreal forest, which is subject to spatial and temporal variation of wild fire and human development disturbance. A new resource selection model for the Bathurst caribou winter range was developed with collared cow data from 1996 to 2015 to assess factors important to caribou distribution on their winter range. These data were used to determine the relative importance of different vegetation communities, and the size, age and frequency of fire, different types of development, density dependence (herd size) and the segment of the Bathurst herd that remains on the barren-grounds during winter. This was accomplished by comparing locations used by caribou with a random sample of locations describing available habitat. Available habitat was

defined as the area outside of individual home ranges but within the cumulative area used by all other collared caribou cows. We used a hierarchical approach of information theory to identify the most supported resource selection models representing different ecological hypotheses with variables supported by Traditional Knowledge in mixed-model logistic regression. Our study builds on work from two previous Bathurst caribou winter habitat selection studies and uses more recent techniques to determine indirect effects (zones of influence) to habitat quality associated with different development including active mines, exploration camps, power transmission lines, winter roads and communities. Our results indicate that Bathurst caribou prefer areas above the treeline during winter suggesting they may be less sensitive to forest fire than previously believed. The results of this study will be informative to land use plans, caribou management and future environmental assessments.

## **KENNADY NORTH PROPERTY: 2015 FIELD SEASON UPDATE**

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The Kennady North Property, wholly owned by Kennady Diamonds Inc. (KDI) is located 300 km northeast of Yellowknife adjacent to the DeBeers/Mountain Province Gahcho Kué mine site. Exploration on the property dates back to the early 90's, during which time several kimberlites were discovered. Since 2012, KDI has completed a number of geophysical, hand and RC till sampling, diamond drill, and large diameter bulk sampling programs.

In 2016, KDI completed a large diameter reverse circulation drill program to bulk sample the Northern lobe of the Kelvin kimberlite and to collect a mini bulk sample from the Faraday 2 kimberlite. Following the RC program, diamond drilling and ground geophysical surveys continued in the Kelvin-Faraday Corridor (KFC) and at the MZ Sill. Operations were split between summer and winter field efforts.

The RC drill pad and a seasonal spur road off the Gahcho Kué seasonal road were completed in January to coincide with the opening of the Tibbit-Contwoyto winter road and facilitated the mobilization of two large diameter RC rigs operated by Midnight Sun Drilling Inc. to the property.

A total of 612 tonnes of the Kelvin kimberlite and 21.1 tonnes of the Faraday 2 kimberlite were obtained via RC drilling between February 18 and April 24. The bulk sample was processed via DMS at the Saskatchewan Research Council in Saskatoon.

One diamond drill commenced drilling prior to the RC program and two other drills commenced during the final stages of RC drilling. A total of 20,260 meters of NQ and HQ core were drilled during 2016. Diamond drilling focused on delineating the Faraday 1, Faraday 2 and Faraday 3 kimberlites. These pipe-like bodies are similar to the Kelvin Kimberlite in geometry and internal geology.

Aurora Geosciences Ltd. conducted geophysical surveys in the KFC and at the MZ Sill. These comprised 20,346 stations of ground gravity, 763.3 line-km of walk mag and 587.36 line-kilometers of Ohm Mapper™ capacitively coupled resistivity. Additionally, 143.3 line-km of bathymetry were conducted at 24 lakes.

Exploration results have been very encouraging and Kennady Diamond Inc. anticipates the continuation of this success in 2017.

## **ENVIRONMENT AND CLIMATE CHANGE CANADA'S ENVIRONMENTAL EMERGENCY REGULATIONS – A SUMMARY OF IMPORTANT CHARACTERISTICS AND CURRENT REGULATORY REQUIREMENTS**

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Environment and Climate Change Canada's (ECCC) Environmental Emergencies Program aims to protect Canadians and their environment from the effects of environmental emergencies through the provision of science-based expert advice and regulations. ECCC's main environmental emergencies responsibilities are defined in the Canadian Environmental Protection Act, 1999 (CEPA) and the Fisheries Act.

This talk will focus on the federal Environmental Emergency Regulations under CEPA. In 2003, the Environmental Emergency (E2) Regulations came into force under the authorities of section 200 of CEPA. The current E2 Regulations are focused on land-based, fixed facilities, and aim to enhance the protection of human life and health and the environment, by minimizing the frequency and consequences of environmental emergencies involving the unplanned, uncontrolled or accidental release of hazardous substances. The E2 Regulations require the development and implementation of environmental

emergency plans for substances with associated thresholds that, if released to the environment as a result of an environmental emergency, may harm human health or environmental quality.

This talk will summarize key aspects of the current regulations, including the substances regulated, associated reporting requirements, and important timelines. Examples of common facilities that are subject to the E2 regulations within the Prairie and Northern Region of Canada will be provided.

## **DIAMOND BREAKAGE AND GRADE PREDICTION**

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The size-frequency distribution of diamonds in natural samples follow a log-normal distribution which can readily be modelled. The modelled distribution is used for grade prediction and hence can have significant impact on target prioritization in exploration. The predicted occurrence of large diamonds (deca- and hecto-carat sizes) also has implications for recovery process design in operating mines.

Combining diamond data from diamond recovery from drill core exploration samples (using caustic fusion) and bulk samples (using dense medium separation; DMS) produces a smooth log-normal data distribution. The data modelling is complicated by two major factors: 1) inefficient recovery of microdiamonds <100 µm and a recovery gap between smallest grain size of DMS and caustic fusion; and 2) broken diamonds artificially deflating the frequency of macrodiamonds. The first factor is eliminated by rigorous quality

control and security monitoring of all processes involved in diamond recovery. Diamond breakage is more complex and involves expert evaluation of each broken diamond to assess whether breakage occurred prior to emplacement or from exploration or mining activities. The general paucity of macrodiamonds in exploration samples makes identifying breakages and reporting the affected diamond to their correct size fractions essential for forward modeling of diamond distributions. The reconstructed size-frequency distribution often has a significant increase in the 10kT diamond size (largest single diamond predicted for a 10,000 tonne sample). Some samples recovered at SRC have increased 5 to 25 carats 10kT when the breakage is corrected.

## **TALMORA DIAMOND INC. - HORTON RIVER PROJECT UPDATE**

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The Slave “Diamond Corridor” is a north-northwest trend that appears to have controlled the emplacement of significantly diamondiferous kimberlites of the Slave craton. Darnley Bay and Dharma diamondiferous kimberlites on the east side of the Lena West diamond region of the Northwest Territories are on a northern extension of this corridor that has been subject to major left-lateral displacement (~350km) in the region of the Great Bear Fault Zone. Talmora's Horton River project is located on the corridor extension about 100 kilometers south of the Darnley Bay kimberlites near Paulatuk.

Regional sampling programs across Lena

West have recovered widespread kimberlite indicator minerals (KIMs) with good diamond association chemistry including 18 diamonds. There is evidence that many of the KIMs recovered on the western side of Lena West are derived from secondary concentrations at the base of the Cretaceous sedimentary basin with a likely primary source to the east, probably outside the basin along the diamond corridor. KIMs both within and outside the Cretaceous basin were redistributed by glaciation.

The regional KIMs across Lena West differ from those of the Darnley Bay kimberlites but are similar to those of the Dharma kimberlites. The latter kimberlites are small and have a limited range of KIM compositions so cannot be the source of all the Lena West KIMs. Cluster analysis confirms that KIMs in the Horton River area have compositions that cover the full range of those found across Lena West and differ from those at Darnley Bay and Dharma.

Ferricrete ("laterite") cobbles occur in tills in Talmora's project area especially down-ice of magnetic anomalies and appear to be of local origin. Together with diagenetic alteration of KIMs and apparent destruction of silicate KIMs they are evidence of a humid and tropical climate that probably coincides with the Eocene Thermal Maximum (55Ma). Located on the flanks of the unglaciated Melville Hills glaciation has not removed the weathered zone.

Numerous magnetic anomalies on the Talmora property show characteristics of weathered kimberlite pipes. Over forty of them have associated KIMs down-ice (mostly chromite and ilmenite). The magnetic anomalies have relatively low amplitude and as expected in deeply weathered kimberlites, in which magnetite

alters to hematite and iron-hydroxides, show little evidence of early remnant magnetism. The tops of two magnetic anomalies were successfully investigated with a small Packsack drill. The holes penetrated through about 10 vertical meters of glacial overburden and ended 1 to 2 meters in compact rusty coloured clay. A 25mm section of clay was recovered with a composition similar to weathered kimberlite from Sierra Leone. Drill cuttings from one hole contained thirteen chromites, one picroilmenite, fourteen altered Mn-ilmenites and five fresh Mn-ilmenites with diamond inclusion chemistry. Chromite compositions lie on a relatively narrow Fe/Mg crystallization trend line indicating a single population and nearby source.

There is evidence that Talmora could hold the source area of the Lena West KIMs and diamonds. A larger drill is required to obtain fresh kimberlite and sufficient core for microdiamond analysis.

## **INTERRELATIONSHIPS BETWEEN PERMAFROST AND SUBSURFACE WATER: 3 CASE STUDIES ALONG A LATITUDINAL GRADIENT IN THE CANADIAN NORTH**

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For a few decades, Northern Canada has been experiencing noticeable climate change (e.g. increase of air temperature, change in precipitation). These changes affect the water balance and the thermal regime of permafrost through the development of new flow paths, and may trigger thermokarst processes, drainage of lakes, mass movements such as active layer detachment slides and thaw slumps, and the formation of gullies.

Groundwater-permafrost dynamics are complex and the processes involved highly depend on the permafrost properties and climate conditions. To understand and compare the variety of interactions between subsurface water and permafrost, we present three case studies along a large latitudinal gradient: 1. Beaver Creek, Yukon (ice-rich discontinuous permafrost); 2. Bylot Island, Nunavut (inland continuous ice-rich permafrost); and 3. Ward Hunt Island, Nunavut (polar desert continuous permafrost).

The results show substantial variability between sites in the response of permafrost to groundwater flow. At the Beaver Creek site, groundwater flowing through water tracks (preferential flow paths) have the effect of lowering the permafrost table by 30-50 cm, while stagnant water within the surrounding wetland contributed to decrease the ground surface mean temperature by 1°C (in comparison with proximal mesic terrain units). Under the road infrastructure at the same site, the groundwater flow is an effective heat transfer vector and the permafrost degrades about 10 times faster where groundwater flow is present.

On Bylot Island, ice wedge polygons in organic rich silty sediments are ubiquitous at the valley floor level. Recurring and localized water flow from snowmelt at the

surface and in the active layer acts as a thermo-erosion agent for the ice wedges, inhibiting infiltration and leading to the formation of tunnels in the permafrost, preferentially in ice-wedges. Ultimately these tunnels collapse and form a network of gullies. This process occurs in a short time scale: for example, one gully had a linear erosion rate averaging  $90 \text{ m y}^{-1}$  between 1999 and 2007, several orders of magnitude faster than permafrost thawing due to higher air temperatures.

Ward Hunt Island possesses very cold and arid climatic conditions where permafrost contains almost no unfrozen water. During the short summer season, runoff from melting snow flows rapidly underground through water tracks, mobilizing fine sediments along the way. This near-0°C water has a different effect on permafrost compared to the two other study sites, as groundwater flow is slowing down the thawing of the active layer by preventing effective radiation heating of the ground.

While this research identified variable permafrost response to groundwater flow along a latitudinal gradient, more work is necessary to clearly identify the conditions that cause this variability. With the current global warming trend, issues associated with increased groundwater erosion and permafrost degradation will continue to present challenges for the long term stability of infrastructure. Understanding the interrelationship between groundwater and permafrost is a key for the advancement of fundamental periglacial geomorphology and for the construction and maintenance of sustainable and adaptable infrastructure.

## WHAT DOES THE MINISTER DO WITH THE BOARD'S REPORT?

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Mining is a highly regulated business, from cradle to grave. Many of the most important project approvals processes in the NWT and Nunavut are the responsibility of co-management tribunals which report to Ministers who make final decisions. This is the case for environmental impact assessment and water licensing (regulatory processes) proceedings which result in two of the most important decisions in the mining approvals process. These regulatory processes require significant investment of time and resources by all parties, none more so than project proponents. On occasion, however, the outcomes of these processes are not satisfactory to one or more of the participants. The tribunals' reports nevertheless go to a Minister(s) for final decision.

What does the law say about the Minister's options at that point? What role can the participants play in influencing that decision? What are the legal constraints on the Minister and the participants and how can we ensure the integrity of the decision-making process?

This presentation will explore these questions in the context of several recent examples from the mining approvals process in the NWT and Nunavut. The results of this investigation should help project proponents and other parties to better understand their options in the final approvals process.

## THE GRAYS BAY ROAD AND PORT PROJECT – ARCTIC GATEWAY CONNECTING NUNAVUT TO THE WORLD

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The Grays Bay Road and Port Project (GBRP Project) is a proposed transportation system that will connect the rich mineral resources of the Slave Geological Province to arctic shipping routes. The GBRP Project consists of a 227 km all-season road linking the northern terminus of the Tibbitt-Contwoyto Winter Road to a deep-water port at Grays Bay on the Northwest Passage. The GBRP Project would stimulate the regional economy, yielding a wide range of significant benefits to Nunavut residents and to other Canadians. The Government of Nunavut and the Kitikmeot Inuit Association jointly champion the project and are seeking to advance it by: 1) securing Federal Government infrastructure program funding to cover the majority of capital costs; and 2) acquiring all necessary environmental approvals to allow construction to proceed. Details on this project, including its multiple benefits, will be provided in this presentation.

**SLAVE PROVINCE SURFICIAL  
MATERIALS AND  
PERMAFROST STUDY  
PRELIMINARY RESULTS -  
REVITALIZING MULTI-  
COMMODITY MINERAL  
EXPLORATION AND  
FACILITATING SUSTAINABLE  
DEVELOPMENT IN A KEY  
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In 2014 and 2015 the Northwest Territories Geological Survey (NTGS) carried out the Slave Province Surficial Materials and Permafrost Study (SPSMPS), a two year collaborative government–industry–academic research program in NTS sheets 76C and 76D. The overall goals of this project were to advance our understanding of glacial history, develop innovative exploration techniques, update surficial maps in targeted areas and study permafrost and terrain sensitivity to climate change. This project was funded through the Strategic Investments in Northern Economic Development (SINED) program of the Canadian Northern Economic Development Agency (CanNor). Highlights include: A database of indicator mineral counts, indicator mineral chemistry and till geochemistry showing previously unknown anomalies and new unsourced indicator trains;

- 3D models of the DO-27 / DO-18, Monument and Coppermine indicator trains with implications for mineral exploration;
- Studies on esker transport distance, glacial dynamics and geochemical

sampling with implication for mineral exploration;

- Updated surficial maps highlighting landforms associated with glacial outwash corridors;
- Installation of a large thermistor network to study the impact of climate change on permafrost and terrain sensitivity to inform potential infrastructure development;
- The application of ground penetrating radar and Ohm Mapper to determine depth to bedrock in permafrost rich areas.

In order to accomplish these objectives, 1131 glacial sediment samples were collected from 235 boreholes and 363 thermistors were installed at 41 LIDAR surveyed permafrost monitoring sites. In addition, over 1500 km<sup>2</sup> of field mapping and approximately 150 line km of ground geophysics were carried out. Large proprietary indicator mineral and remote sensing datasets and logistical support were generously provided by our industry partners.

Our industry partners included Dominion Diamond Ekati Corp, Diavik Diamonds Mines Inc., North Arrow Minerals Inc., Peregrine Exploration Ltd., Artic Star Exploration Corp., New Nadina Explorations Limited, and TNT Mineral Science. Our research partners included the Canadian Mining Institute Research Organization (CAMIRO), Palmer Environmental Consulting Group Inc., DCGeo Applied Sedimentary Geology, the University of Waterloo, Simon Fraser University, Carleton University and the University of British Columbia. This work was carried out with Aurora Geosciences Ltd as the operator.

This presentation will highlight the new

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datasets and geological models generated over the course of this study while providing an update on forthcoming scientific publications from the NTGS and our project partners.

## **MACTUNG: AN INTRODUCTION TO THE TUNGSTEN DEPOSIT AND ITS GEOLOGICAL SETTING**

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The Mactung deposit is a W- (Au-Cu-Bi) skarn that straddles the NWT/Yukon border just north of the historic Canol Trail. In 2009, North American Tungsten (NATCL) reported it to contain mineral reserves of 8.5 Mt, at an average grade of 1.082% WO<sub>3</sub> within an Indicated Mineral Resource of 33.0 Mt grading 0.88% WO<sub>3</sub>. This compares favourably with the reported Measured and Indicated Mineral resources of the recently opened Hemerdon Mine, UK (56.9 Mt grading 0.17% WO<sub>3</sub> and 0.02% Sn) and the Los Santos Mine, Spain (2.2 Mt grading 0.29% WO<sub>3</sub>). NATCL's mining plan envisaged the project as an underground mine utilizing long-hole blast and mechanized cut-and-fill mining methods with long-hole stoping for the majority of the ore at a high production rate and mechanized cut-and-fill stoping for thinner and steeper ore zones. An open pit option to reduce costs and increase the production rate could also be considered.

The Mactung mineralization occurs within a sequence of altered limestones, shales and siltstones of Cambrian to Silurian age, up to

230 m in thickness. The deposit consists of two scheelite-bearing skarn zones separated by 100 m of hornfelsed pelite, along the southern contact of the granitic Cirque Lake stock. The main exposure occurs along a steep northerly-sloping cliff on the side of Mount Allan, which marks the border between the Yukon and the NWT. Both zones dip to the south, but the sequence has been folded to the north, producing a recumbent isoclinal "z" fold in the lower zone with an amplitude of about 90 m and an axis that plunges at about 16° to the west in the west, and at a shallow angle to the east at the eastern end of the deposit.

Scheelite is the economic mineral of interest occurring predominantly with pyrrhotite in the pyroxene-pyrrhotite skarn facies, such that scheelite content increases while its grain size decreases with pyrrhotite content. Ore-grade mineralization, including minor amounts of coarser-grained scheelite, also occurs in garnet facies skarn. Wolframite has been reported occasionally.

Nine stratigraphic units were distinguished and were designated from oldest to youngest numerically 1, 2B, 3C, 3D, 3E, 3F, 3G, 3H, and 4. The sediments were deposited in the late Precambrian to Early Devonian Selwyn Basin. Thin-bedded dark siltstone to fine-grained quartzite of the Proterozoic –Early Cambrian Vampire Formation (1) grade to the northeast into the thick-bedded carbonate sediments of the variably subsiding Mackenzie Platform. The mineralized stratigraphy includes the Early Cambrian Sekwi Formation (2) (calcareous siltstone, limestone slump breccia and conglomerate) and Rabbitkettle Formation (3D, 3E, 3F) (silty limestone, phosphatic limestone conglomerate, and mudstone). These are separated by Hess River Formation (3C) mudstone and overlain by the Ordovician to Lower Devonian Road



River Group including the Duo Lake Formation (3H, 4) (black shale, laminated chert, and minor limestone) and the Steel Formation (pyritic, siliceous, bioturbated mudstone to siltstone). In the Mid-Devonian, the sequence was superseded by turbiditic, chert-rich clastic rocks of the Earn Group that were sourced from the north and west in contrast to the previous eastern sources.

## **NORTHWEST TERRITORIES GEOLOGICAL SURVEY: PETROLEUM GEOSCIENCES 2016-17 ACTIVITY OVERVIEW**

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The Petroleum Geosciences Group of the Northwest Territories Geological Survey (NTGS) had five primary research objectives during 2016. These were to eliminate the current backlog of NTGS Petroleum Geosciences publications by fiscal year end, review the results of the 2015-16 Northwest Territories (NWT) Petroleum Atlas Scoping Project, review the recent drilling results for the Canol oil play in the Central Mackenzie Valley, advance the knowledge of the hydrocarbon potential of Devonian age shales of the Peel Plateau and Mackenzie Plain areas of the NWT, and promote research collaborations with universities, surveys and other government agencies.

The Petroleum Geosciences Group has identified a need to deliver NWT petroleum geoscience information to the public via a single encompassing web application. Abundant published NWT petroleum technical information is available but it is

distributed over many different sources and requires keyword and subject expertise. A web-based NWT petroleum geological atlas would simplify petroleum-related data searches by providing industry, government and private sector clients with downloadable data from one resource.

Scoping research, in addition to industry and Geological Survey of Canada consultations, was conducted by the Petroleum Geosciences Group in the fiscal year 2015-16 to evaluate the feasibility of initiating a NWT petroleum geological atlas project. During the remaining fiscal year (2016-17), the Petroleum Geosciences Group will review the research and formulate recommendations regarding a web-based NWT petroleum geological atlas project. Such recommendations will include project scope, participants, design, product delivery, timing and budget.

Advancing the knowledge of the petroleum potential of Devonian age shales of the Mackenzie Plain area of the NWT has been a Petroleum Geosciences Group primary research objective since 2009. The 2014 “Shale Basin Evolution in the Central Northwest Territories Mainland” project was initiated to extend the knowledge of the petroleum potential of these shales beyond the boundaries of the Mackenzie Plain. Field work in 2016 was conducted in the Peel Plateau to characterize the petroleum potential of the Bluefish and Canol shales at two outcrop localities. The analytical results of this field work will be published in Open Report format during the spring of 2017.

Data from seven new exploration wells drilled in the Central Mackenzie Valley to test the Canol shale oil play have been recently released to the public requiring further work in the Mackenzie Plain area. The data will be reviewed to further the

understanding of the Horn River Group stratigraphy, geochemistry and hydrocarbon distribution. Existing mapping will also be updated.

The Petroleum Geosciences Group strives to ensure the delivery of high-quality petroleum geoscience to the public. Collaborating with universities and other government surveys assists in ensuring excellence. A contribution agreement has been entered with the University of Alberta in which a Ph.D. and M.Sc. student will be working on the Canol and Bluefish shales, respectively.

## **GEOLOGICAL DRILLING RESULTS FOR THE CENTRAL MACKENZIE VALLEY CANOL SHALE PLAY**

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The organic and silica rich mudstone and shale of the Upper Devonian age Canol Formation (Canol) has recently been the focus of significant industry activity in the Northwest Territories (NWT). The Canol sourced the oil trapped in the Kee Scarp carbonate member of the Horn River Group of the Norman Wells oil pool and is the exploration target of an unconventional hydrocarbon resource play in the Central Mackenzie Valley (CMV). Land sale activity commenced on this unconventional resource play with a 2010 to 2011 call for bids. By November of 2013, 14 exploration licenses totaling approximately one million hectares were acquired for a total gross bid of 627.5 million dollars.

A flurry of drilling activity followed the

land sales and by the spring of 2014, a total of seven new explorations wells (five vertical and two horizontal) were drilled to test the Canol unconventional hydrocarbon play. Drilling operations were conducted by ConocoPhillips Canada Limited, Husky Oil Operations Limited and MGM Energy Corp.

All of the new wells penetrated a hydrocarbon bearing Canol interval characterized by thicknesses that ranged from 93 to 141 m thick. This range of isopach values falls within the regional expectations. Five of the seven recently drilled wells were cored in the Canol Formation and the cores were sampled for various and abundant analyses. Each company analyzed the mineralogy of the Canol Shale by X-Ray Diffraction (XRD) of core chip samples. The new XRD mineralogy results show moderate to high quartz (average range 50.4 to 61.4 Wt. %) and low clay (average range 21.3 to 30.9 Wt. %) content, which agree well with the trends previously observed for the Canol in the CMV. Operators also analyzed for kerogen type, thermal maturity (e.g.  $T_{max}$  and reflectance data (%  $R_0$ )) and total organic carbon (TOC) content. The recent well data shows that the Canol is dominated by Types II and III kerogen,  $T_{max}$  variations that range from 439 to 471 °C, calculated %  $R_0$  values of 1.07 to 1.32 and an average TOC value of 4.2 Wt. %.

The new well data may have significant implications with respect to the understanding of the hydrocarbon phases likely present in the Canol Formation in the CMV. The resource assessment completed in 2015 by the National Energy Board (NEB) and the NTGS prior to the release of confidential data assumed only oil would be present in the reservoir. The results of the Canol production tests and thermal maturity studies suggest that the Canol contains oil,

gas, and condensate hydrocarbon phases that may be inter-layered within the mudstone and shale reservoir. During the remainder of fiscal 2016 the NTGS Petroleum Group will review all of the recent well data and reassess the NTGS current geological mapping for the Canol and Bluefish Formations. Once remapping is complete, the Canol and Bluefish shale resource assessment should be updated to account for the presence of oil, gas and condensate resource volumes in the Canol Formation reservoir.

## **2015 NWT ENVIRONMENTAL AUDIT: REVIEW OF RESULTS RELEVANT TO MINING AND OIL AND GAS DEVELOPMENT**

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In the Northwest Territories, an independent environmental audit guided by a committee of Aboriginal, Federal and Territorial governments is required every five years by the Mackenzie Valley Resource Management Act (MVRMA). A key objective of the audit is to review the effectiveness of the MVRMA regulatory regime. In 2015, industry, government and Aboriginal representatives were among a broad group of participants in the regulatory regime that were surveyed for their views. The 2015 NWT Environmental Audit was released in May 2016. The purpose of this presentation is to highlight audit recommendations that are of relevance to the mining and oil and gas industries.

Generally the Auditor found that the environmental regulatory system in the

NWT has continued to improve since the last audit in 2010. The integrated system of land and water management is generally effective in protecting the environment. However, they concluded that some foundational challenges continue to affect the ability of the system to fully function. Recommended actions included completing unsettled land claims, completing land use plans, providing clarity on federal Crown consultation, increasing funding for Aboriginal governments and organizations and others to participate in the system, and improving integration of socio-economics (especially community wellness) into decision-making. The Auditor found that these challenges create uncertainty for proponents, co-management boards, Aboriginal governments and regulators, and recommended that closing these gaps be a priority.

## **UPDATE ON RECENT AND PLANNED ACTIVITIES OF THE NWT OFFICE OF THE REGULATOR OF OIL AND GAS OPERATIONS (OROGO)**

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OROGO holds regulatory responsibility for oil and gas operations in the onshore Northwest Territories outside of the Inuvialuit Settlement Region and federal areas. Despite the current decline in oil and gas activity, OROGO has remained busy. This presentation will provide a brief update on OROGO's activities over the past year and our plans for the coming year. Areas of focus will include OROGO's efforts to further its strategic objectives of enhancing

certainty and predictability in regulatory decision-making and promoting accessibility and transparency in its work as OROGO maintains its readiness for a return of oil and gas activity to the NWT. The presentation will update conference attendees on new and proposed guidelines under the Oil and Gas Operations Act, the recently-launched Well Watch program, and OROGO's Information Office, regulatory compliance and inspection functions.

**PROJECT SUMMARY OF  
“GEOSCIENCE TOOLS FOR  
SUPPORTING  
ENVIRONMENTAL RISK  
ASSESSMENT OF METAL  
MINING” WITH A FOCUS ON  
THE DISTRIBUTION OF  
ARSENIC IN SEDIMENTS OF  
LAKES OF THE YELLOWKNIFE  
REGION**

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We will present an update on an on-going research project Geoscience Tools for Supporting Environmental Risk Assessment of Metal Mining to apply an innovative, multidisciplinary research methodology to reconstruct variations in climate, geochemistry, permafrost, and ecology over the past ~1000 years along a north-south transect from Yellowknife, NWT, to the Courageous Lake area in the central Slave Geological Province. Our objective is to assess the cumulative effects of natural and human-driven changes, particularly climate

change, on the transport and fate of metal(oids), with a focus on arsenic (As), and on the health of regional ecosystems in areas of high resource potential in the Canadian North.

We have initiated geochemical, sedimentological, and paleoecological analyses of sediment cores from lakes and permafrost peatlands with a focus on the Yellowknife and Courageous Lake regions. Data emerging from this research may be used to inform the establishment of geochemical background and baseline in environmental media and assess and predict the potential impact of climate change and land disturbance on environmental metal fluxes.

Project team work on near-surface sediments from 211 lakes in the Yellowknife area (et al., 2015) suggest that pre-mining geochemical background for arsenic is substantially lower than current values. We also show that the concentration of As in near-surface sediments is highest in lakes within a ~20 km radius of the historical Giant Mine roaster stack, a spatial pattern consistent with point source emission. Analysis of the type and amount of organic matter in the sediments, likely to be affected by current and forecasted climate change, show that highly reactive, readily degradable and labile organic matter (S1) is an important determinant of sedimentary As concentration. Sedimentary As is highly correlated with both dissolved and total As in overlying surface waters (Palmer et al., 2015), suggesting that As is present in a reactive and mobile forms in lakes throughout the study area.

Our research will support and improve decision making, environmental stewardship, and Canada's regulatory

processes to ensure sustainable development of Canada's North.

**GEOCHRONOLOGIC  
CONSTRAINTS AND  
GEOCHEMICAL  
CHARACTERISTICS OF  
GRANITOIDS AND  
ASSOCIATED  
MINERALIZATION AT THE  
MACTUNG TUNGSTEN SKARN  
DEPOSIT, YUKON-NWT**

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The skarn W-(Au-Cu-Bi) deposit at Mactung, Yukon, Canada is situated within the eastern flank of the NW-SE striking poly-deformed Paleozoic Selwyn metasedimentary basin. Two biotite granite stocks occur south and north of the deposit. The northern stock is dominantly porphyritic, cut and rimmed by a more leucocratic medium- to coarse-grained granite. Prominent aplitic dykes outcrop south of the mineralization. Major- and trace-elements strongly discriminate between the various phases of biotite granite and the leucogranite. The biotite granite has an arc-like affinity. The leucogranite is sourced from anatexis of a supracrustal sequence at depth. Tracer Sm-Nd and Rb-Sr isotope systems further indicate both these granitoids were sourced from the partial melting of old continental crust. The  $\delta^{18}\text{O}$  values of Mactung granitoids indicate a dominantly metasedimentary source region or extensive contamination during magma ascent. The less-evolved biotite granite is directly associated with the W-(Cu-Bi-Au) mineralization, based on field relationships,

metalogenic aspects of the intrusion, associated alteration-mineralization effects, and new geochronological data combined with previously published Re-Os dating of molybdenite.

Multiple dating techniques were used to characterize the various rocks of Mactung. U-Pb age data for zircon grains were obtained by ID-TIMS analytical techniques for five samples from three rock types of Mactung granitoids: an aplitic dyke south of the Mactung skarn tungsten deposit yields an igneous crystallization age of  $97.1 \pm 0.2$  Ma; porphyritic biotite granite from the main phase of the Mactung pluton yielded a crystallization age of  $97.6 \pm 0.2$  and  $97.0 \pm 0.1$  Ma. A leucocratic granite dyke, a marginal phase in the southeast of the pluton, yielded an age of  $97.0 \pm 0.3$  Ma. A titanite age from the lower skarn orebody was obtained using laser ablation inductively coupled plasma-mass spectrometry that yielded a less precise  $^{206}\text{Pb}/^{238}\text{U}$  concordia intercept age of  $97.1 \pm 4.1$  Ma that agrees very well with the U-Pb zircon dates (this work) of the biotite granite. Ar-Ar dating reveals the following best ages:  $95.6 \pm 0.3$  to  $98.1 \pm 2.0$  Ma from muscovite separates and  $91.8 \pm 0.4$  to  $95.1 \pm 0.8$  Ma from biotite separates from porphyritic biotite granite;  $93.3 \pm 1.2$  Ma from biotite of coarse-grained leucogranite;  $92.9 \pm 0.4$  and  $95.3 \pm 0.4$  Ma from muscovite of medium- to coarse-grained leucocratic granite dyke;  $94.0 \pm 0.5$  Ma from biotite of an aplitic dyke;  $97.1 \pm 1.9$  and  $96.9 \pm 0.6$  Ma from biotite grains of biotite hornfels. Re-Os molybdenite dating of quartz veins, cutting all granitoids and the lower metasedimentary unit, adjacent the Mactung tungsten skarn yields ages of  $97.3$  to  $106.3 \pm 0.4$  Ma; these Mo-W veins are the latest visible magmatic hydrothermal activity linked to the biotite granite at Mactung. They provide a direct lower

timing constraint for granite intrusion and sulphide mineralization events of the area, if the older ages are disqualified.

## **AN EARLY CAMBRIAN RADIATION INTO CHARACTERISTIC ETHOLOGICAL NICHES**

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The Cambrian represents an important time in Earth's history when complex metazoans first colonized the shallow marine realm. The Mount Clark Formation within the Colville Hills and Central Mackenzie Valley in the NWT is interpreted to record deposition within a storm-influenced shoreface succession, with storm-bed tops substantially reworked by an assemblage of post-storm opportunists. These shoreface sandstones comprise the major hydrocarbon reservoirs within the Colville Hills. Prominent hydrocarbon staining observed within piperock intervals show that reservoir quality is locally improved by bioturbation. The unit contains the *Bonnia-Olenellus* trilobite zone indicating early Cambrian deposition. We report diverse and robust ichnofossils in shoreface-associated environments that demonstrate that the broadest strategies of resource exploitation in different food-availability niches evolved before the Cambrian explosion. The observed ichnofacies are so well developed that they are directly comparable to well understood Mesozoic and Cenozoic shorefaces. We contend that the radiation of animals into these ethological landscapes was a necessary precondition for the Cambrian Explosion to occur. In addition, well-constructed facies models for the Mount Clark Formation will aid in the

exploration of subtle stratigraphic hydrocarbon traps within the Colville Hills and Central Mackenzie Valley.

## **FORTUNE MINERALS' NICO COBALT-GOLD-BISMUTH- COPPER PROJECT, NWT, CANADA**

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The NICO Cobalt-Gold-Bismuth-Copper Project is a proposed mine and concentrator in Tlicho Territory, 160 km northwest of Yellowknife Northwest Territories, and a hydrometallurgical refinery near Saskatoon, Saskatchewan. With expenditures exceeding \$116 million, NICO has Mineral Reserves with more than 33 million tonnes proven by drilling and test mining, and pilot plant validation of the process metallurgy to support a positive Feasibility Study and FEED engineering. Environmental Assessment approvals have been completed in both jurisdictions and the major mine permits received making NICO essentially shovel-ready upon receipt of project financing and public road construction schedule certainty.

NICO will be a vertically integrated producer of cobalt sulphate to the rapidly expanding Lithium-Ion rechargeable battery industry to support the transformative evolution of automotive electrification and use of stationary storage cells to enable renewable energy options for base load and off-peak charging from the electrical grid. With 12% of global bismuth reserves, NICO will produce ingots and chemicals used in the automotive and pharmaceutical industries and support growth in the consumption of bismuth as a non-toxic and

environmentally safe replacement for lead in plumbing and electronic industry alloys, paint pigments and cosmetics. As a reliable vertically integrated Canadian producer of cobalt and bismuth, development of NICO will alleviate geographic concentration of supply and other concerns with supply chain transparency and custody control from ore through to the production of value added metals and chemicals. More than 1.11 million reserve ounces of gold is a highly liquid co-product that is also typically countercyclical to cobalt and bismuth price volatility.

## **INTEGRATED ITRAX-XRF AND FREEZE CORING AS A METHOD FOR HIGH QUALITY, RAPID, AND COST EFFECTIVE (QRC) DETERMINATION OF BACKGROUND LEVELS OF ELEMENTS OF CONCERN: TESTING LINEAR AND MULTIVARIATE CALIBRATION METHODS**

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Historical issues related to mining practices led the Northwest Territorial government to establish the “Mine Site Reclamation Policy”, which stipulates that companies must present a detailed plan as to how they

will rehabilitate areas potentially impacted by mining operations to their original. Differentiating the relative environmental impacts from natural versus anthropogenic sources is paramount to developing reasonable baseline levels as required by sound remediation plans. The primary goal of this research is to develop new methodologies that provide high quality, rapid and cost effective (QRC) techniques to better inform mining companies and regulators as to potential liabilities for development and evaluation of remediation plans.

The continuous sedimentary records found in lake basins archive important records of both natural and anthropogenically sourced elements of concern (EOC), primarily arsenic (As) in the Yellowknife region. The nature of deposition and mobilization of EOC is linked to hydrologic conditions that can be directly linked to climate variability. Investigating the geochemical variability within lake sediments permits recognition of baseline levels of As, how As responds to hydrologic (climate) change, and the identification of possible overprinting anthropogenic contamination. Obtaining the required temporal resolution is difficult to achieve using conventional methods due to high per-sample cost of analyses and low sedimentation rates typical of Subarctic lakes where 1 cm of deposition may represent several hundred years. To overcome these issues, we have combined freeze coring, a method that reliably captures the sediment-water interface in soupy Subarctic lakes, with ITRAX high-resolution core scanning X-ray fluorescence (ITRAX-XRF).

ITRAX-XRF is relatively new technology designed to measure geochemical variations in split sediment cores at high resolution (<0.2 mm), rapidly (5 hours/1 m of core)

and inexpensively (\$100/hour) using XRF. The substantially increased resolution associated with ITRAX-XRF, however, comes with the drawback of semi-quantitative results. Traditional XRF requires a large volume of dry, homogenous sediment to ensure accurate calculation of absolute chemical concentrations. Because ITRAX-XRF analysis is conducted on split cores, matrix effects caused by sediment heterogeneity, variations in moisture content and topography-induced artefacts inherent to the material analyzed may interfere with the calculation of absolute elemental concentrations. Recent research has shown that it is possible to create calibration equations for ITRAX-XRF data by comparing quantitative geochemical results (e.g. ICP-MS data) from a subset of samples to ITRAX-XRF data. To test methods of ITRAX-XRF calibration, one freeze core was recovered from Milner Lake ~15 km north of Yellowknife in June 2015 with the support of TerraX Minerals Inc. The core was sub-sectioned into smaller segments and transported to McMaster University for analysis using an ITRAX-XRF core-scanner. The remaining core material was sub-samples at 1 cm resolution for ICP-MS analysis carried out at Bureau Veritas Labs, Vancouver. To calibrate ITRAX-XRF data, linear and multivariate log-ratio equations were derived. Here we present preliminary results, and comment on the relative merits from carrying out both linear and multivariate methods to calibrate ITRAX-XRF data in Subarctic lake sediments.

## **A FIRST YEAR OF GROUND TEMPERATURE MEASUREMENTS RESULTING FROM THE SLAVE PROVINCE SURFICIAL MATERIALS AND PERMAFROST STUDY**

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The Slave Geological Province is a key region for mining in the Canadian North. Its tundra areas form a large and resource-rich landscape in which comparably few systematic permafrost observations exist. Because the region contains layers of ice-rich till, the ground is susceptible to subsidence during thaw. The possibility for severe consequences of permafrost thawing on infrastructure and the natural environment motivate baseline investigations.

In July 2015, an observation network, of more than 40 study sites, was installed to monitor ground thermal regimes and to detect surface subsidence. Each site represents a distinct combination of surficial geology, vegetation, drainage conditions, and snow cover. At each study site, temperature measurements are recorded continuously down a borehole as well as at four near-surface ground locations. The aim of the measurement approach is to more fully resolve spatial variation in ground temperature and thus to support better analysis and prediction of ground thermal regimes.



In September 2016, the sites were re-visited. During this visit, data was downloaded from the data loggers and site conditions as well as damage to the installations were described. This contribution presents the first results of the temperature measurements as well as an assessment of the strengths and challenges of the techniques used for instrumentation.

## **ACTIVITIES OF THE CANADA-NUNAVUT GEOSCIENCE OFFICE**

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The Canada-Nunavut Geoscience Office (CNGO) opened in September 1999, following on Nunavut's own creation in April 1999. The CNGO is a unique government entity within Canada, being co-funded and co-managed by three partners – Natural Resources Canada, Indigenous and Northern Affairs Canada and the Government of Nunavut's Department of Economic Development and Transportation. The CNGO is considered Nunavut's de-facto' Geological Survey, with Nunavut being the only jurisdiction within Canada without a formal 'geological survey'.

The mandate of the CNGO is to provide accessible geoscience information and expertise in Nunavut to support sustainable development of mineral and energy resources, geoscience education, training, and capacity building.

This work over the years has collectively concentrated on 1) regional and detailed mapping, including aeromagnetic surveys,

bedrock and surficial geology mapping, and geochemical surveys, and recently carving stone deposit mapping; 2) thematic studies, including detailed research of specific subjects (e.g., Paleozoic stratigraphy) and select mineral deposits (i.e., Meadowbank gold mine, lead-zinc potential of Borden Basin); 3) energy-related research (uranium, petroleum); 4) research for infrastructure needs (permafrost studies, aggregate studies), and 5) data dissemination (publication of maps, reports and datasets, as well as publicly-accessible websites, and outreach efforts).

Some of the work that has been conducted to date include: 1) the CNGO-led Hall Peninsula project (2010-2014) that involved bedrock and surficial mapping and many thematic studies. Aeromagnetic surveys of Hall Peninsula were flown and interpreted in 2010 and published as Open Files Maps. The success of the Hall Peninsula project leveraged a new GSC-led mapping project initiated in 2012 under Geo-Mapping for Energy and Minerals (GEM) programming to conduct regional-scale bedrock mapping of southern Baffin Island; 2) Surficial (glacial) mapping being completed through the Western Hudson Bay project (a joint GSC-GEM and CNGO initiative) includes the determination of ecosystem classifications and delineation of surficial deposits (such as construction aggregate resources) that are used by the mineral exploration sector. The results of this project may influence decision-making in the territory, especially in regards to permafrost stability, climate change effects, and infrastructure development and maintenance; 3) the Frobisher Bay seabed mapping project is a collaborative effort between the CNGO, GSC and Government of Nunavut. Originally planned as a small-scale program by the Geological Survey of Canada-Atlantic, this initiative has since

grown and supports another project conducted by ArcticNet, a consortium of many collaborators, which conducts detailed case studies in Frobisher Bay to help with port and infrastructure development; 4) Quicklime from high-calcium limestone is of particular interest to the mining sector and has many uses within mines or advanced exploration projects. Since 2009, the CNGO has delineated the resource potential for industrial limestone on Southampton Island; 5) CNGO and GN have evaluated and defined carving stone resources, of particular importance to Nunavut and the arts and crafts sector, and 6) disseminated geoscience data through many avenues, including the annual Summary of Activities initiated in 2012.

## **FATE AND TRANSPORT OF CONTAMINANTS AT A CLOSED LEAD ZINC MINE IN YUKON, CANADA**

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As part of the closure process for a lead-zinc mine in the Yukon an assessment of the fate and transport of environmental contaminants at the surface and within the subsurface was conducted in order to assess the potential impacts to human health and ecological receptors. The results of this assessment was used to facilitate permanent closure of the mine. A sediment, soil, waste rock and groundwater sampling and chemical analysis program was completed in order to delineate the spatial extent of contaminants at each area of environmental concern. Areas of environmental concern associated with core (waste rock piles, mine portals, sediment ponds, concentrator complex, truck load-out area, tailings and reclaim ponds, haul roads

and ore stockpiles) and non-core (landfill, maintenance Shop, fuel tanks, and power house) mine activities were assessed. Both surface and sub-surface contaminant transport mechanisms were evaluated. For heavy metals and petroleum hydrocarbons, surface water fate and transport of particulate and dissolved phase organic and inorganic solids, as well as wind-induced contaminant transport of near surface soil, was assessed. For subsurface contaminant movement, environment factors and groundwater geochemistry were taken into consideration. Results of the work concluded that both wind-induced and surface water particulate transport were the primary mechanism for the spread of heavy metals (arsenic, lead, molybdenum, nickel, selenium, vanadium, and zinc) at the surface and groundwater flow was the primary transport mechanism for in-organics in the sub-surface. Surface contaminants were transported a significant distances from the source zone with wind-induced transport of up to 150 m and surface water particulate transport up to 400 m. Natural attenuation processes in the subsurface limited the transport of organics and most in-organic contaminates, except a localized area of cadmium, to the unsaturated zone within the source areas.

## **OUTCROP TO SUBSURFACE SEQUENCE STRATIGRAPHIC RELATIONSHIPS OF THE CANOL AND HARE INDIAN SHALES IN RELATION TO THE KEE SCARP REEF COMPLEX; NEW TECHNIQUES FOR AN OLD PROBLEM**

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The late Devonian Canol, Hare Indian, and Ramparts/Kee Scarp Formations record distal basin fill to shallow-water carbonate platform sedimentation within the Central Mackenzie Valley of the Northwest Territories, Canada. The sequence stratigraphic relationship between the Kee Scarp Reef and the basinal Canol Formation has been a topic of debate over the last 70 years. Various workers have argued for a Pre-Canol unconformity (Hume and Link, 1945; Warren and Stelck, 1977; Norris, 1997). Alternatively, Muir et al (1984) proposed that the Canol shale is both coeval to and younger than the Kee Scarp and Ramparts Formations through field and subsurface core-based observations. Recent industry activity within the Central Mackenzie Valley has resulted in the acquisition of Hare Indian and Canol Formation long cores (~150 m) within the distal part of the shale basin. These long cores and outcrop observations at the Mountain River Tributary combined with the recent development of portable X-Ray Fluorescence (XRF) equipment has allowed for additional stratigraphic insights into the stratigraphic relationships between the Kee Scarp Reef and Canol Formations. High-resolution XRF data acquisition (10cm spacing) of the Husky Little Bear N-09 (distal shale basin), Esso O-45X (shallow carbonate platform) cores, and the Mountain River outcrop allows the Canol and Hare Indian Formations to be placed within a sequence stratigraphic context. Through identifying time-synchronous surfaces within the Canol of the N-09 and O-45X cores and recruiting previous interpretations and observations (Muir et al., 1984; Pyle et al; 2014) we are able to establish the timing of Kee Scarp Reef growth within the basinal Canol shale units. Our observations show that the Kee Scarp Reef is coeval to the basal most ~10m of Canol Formation deposition and that most of the Canol

Formation post-dates Kee Scarp Reef growth.

## **GAMMA-RAY SPECTROMETRY AND URANIUM PROSPECTIVITY OF THE 1.9 GA KILOHIGOK PALEOSOL IN MELVILLE SOUND, NUNAVUT**

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Proterozoic sedimentary basins in Canada have proven prospectivity for uranium, yet many remain largely unexplored. A prominent example is the Paleoproterozoic Kilohigok Basin, located in the Kitikmeot Region of Nunavut. Its northeastern region includes a 1-km-thick siliciclastic succession, the ca. 1.9 Ga Burnside River Formation, which nonconformably overlies Archean (~2.7 Ga) basement rocks of the Canadian Shield. In Melville Sound, ~150 km southwest of Cambridge Bay, the Burnside River Formation overlies a paleosol horizon developed on granitoid rocks of the Slave Province, or meta-igneous and meta-sedimentary rocks of the Hope Bay greenstone belt. We present stratigraphic and gamma-ray spectrometry data collected along a transect of ~80 km, and discuss the results in terms of uranium prospectivity, and development of Precambrian weathering profiles.

Paleo-saprolite, up to 15 m thick, is well developed on granitoid rocks displaying a distinctive three-fold zonation in fabric and

mineralogy. A lowermost, fresh syenogranite (Kfs±Qz±Pl±Ms) is overlain by a “lower saprolite” devoid of plagioclase, enriched in iron oxide (Qz±Kfs±Ms±Hem), and showing mild fracturing. The overlying “upper saprolite” is devoid of plagioclase and K-feldspar, shows pervasive sericitization, and is heavily fractured. The Burnside River Formation sharply overlies the paleosol and consists of pebbly sandstone with quartz-overgrowth cement, sericite, and iron-oxide mineralization. Profiles of natural radioactivity indicate that peak concentrations of uranium (up to 30 ppm) occur in the lower saprolite. Lower concentrations of uranium (up to 15 ppm) also occur in a pebbly sandstone that immediately overlies the paleosol.

A paleo-saprolite is also weakly developed on meta-igneous and meta-sedimentary rocks of the Hope Bay greenstone belt. Examples are up to 5 m thick and display a two-fold zonation. A lower parent rock (typically consisting of gabbro or tholeiitic basalt) shows mild fracturing, and hydrothermal alteration highlighted by iron-oxide enrichment (Cpx±Pl±Hem±Ol). The parent rock is overlain by a saprolite zone composed of highly altered basalt and metapelites. The overlying Burnside River Formation consists of an open framework pebble-conglomerate hosted in erosional depressions interpreted as paleovalleys. Elsewhere, sandstone cemented by quartz overgrowth and iron-oxide directly overlies the saprolite. Profiles of natural radioactivity reveal uranium concentrations of ~10 ppm in the paleovalley-hosted pebble-conglomerate. Elsewhere, background concentrations were recorded from greenstone-derived saprolite and overlying sandstone deposits.

Results indicate that uranium is more likely to be concentrated in saprolite derived from granitoid rocks and developed in mature interfluvial areas that were subject to prolonged sub-aerial exposure. By comparison, poorly developed saprolite underlying a nonconformity with significant erosional topography demonstrate less prospectivity for uranium mineralization. These results shed light on possible styles of uranium mineralization in under-explored sedimentary basins of Arctic Canada.

## **“WE WATCH EVERYTHING”: A BOOTS-ON-THE-GROUND APPROACH TO CARIBOU MONITORING**

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The range of the Bathurst caribou, on the barrenlands of Northwest Territories, has undergone environmental changes during the last decades; the establishment of large-scale mines, increased exploration, climate change and increased human activity. These factors impact the dynamic between the hunting culture of the indigenous peoples and the barren-ground caribou herds. The direct effect is experienced by hunters in mainly two ways: the dramatic and rapid decline of the Bathurst caribou herd population, which has brought about tight hunting regulation for the indigenous hunters, and large changes to the migration routes of the herds, altering access to hunting. To investigate the cumulative impacts and current condition of the Bathurst caribou herd, the Tłı̄chq Government initiated the boots-on-the-

ground caribou monitoring program on the summer range of the herd at Contwoyto Lake.

The pilot year of the program was completed this summer, and established a “do as hunters do” methodology for monitoring caribou and a framework based on the traditional knowledge perspective of Tł̨ch̨ elders and hunters. From the elder's holistic concept “we watch everything”, we identified: (1) traditional knowledge indicators of a healthy environment by assessing caribou and habitat conditions, impacts from predators, climate change and industrial activities, and (2) established a methodology based on the lifeways of hunters; by identifying and waiting at specific na'oke (water crossings) and following caribou herds by boat and on foot.

The long term, on the ground approach allows us to be the eyes and ears of the land, as we watch and wait days and weeks, as hunters do, for caribou to come. The boots-on-the-ground approach is a continuation of creating, learning and recording Tł̨ch̨ traditional knowledge live: a qualitative approach to understand current dynamics between caribou, their habitat and cumulative impacts. As healthy caribou population is central in the Tł̨ch̨ harvesting economy, the program uses long-established methods of the hunters to produce answer for current issues - and thus the ability to sustain the cultural practice of travelling on the land for caribou.

## **LIARD BASIN SHALE GAS: A SIGNIFICANT RESOURCE IN CANADA'S NORTH**

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The marketable, unconventional gas potential of the Mississippian-Devonian Exshaw and Patry shales of the Liard Basin's Besa River Formation have been evaluated in a joint assessment by the National Energy Board, the British Columbia Oil and Gas Commission, the British Columbia Ministry of Natural Gas Development, the Northwest Territories Geological Survey, and the Yukon Geological Survey. Volumetric and adsorbed-gas equations were used to determine the amount of in-place gas while decline-curve analysis was used to determine expected well EURs and marketable gas. The thick and geographically extensive Exshaw and Patry shales are expected to contain 35.37 trillion m<sup>3</sup> (1213 trillion cubic feet) of in-place, dry gas and 6.20 trillion m<sup>3</sup> (219 trillion cubic feet) of marketable natural gas.

The mid- to late-Devonian Horn River shales, also part of the Besa River Formation of the Liard Basin, were also assessed in the Yukon and Northwest Territories. The Horn

River shales are estimated to contain another 5.89 trillion m<sup>3</sup> (208 trillion cubic feet) of in-place, dry gas. Because of a lack of production data from the Horn River shales in the Liard Basin, the amount of marketable gas was not determined.

## **NWT CUMULATIVE IMPACT MONITORING PROGRAM: REVIEW OF CURRENT RESULTS RELEVANT TO MINING AND OIL AND GAS DEVELOPMENT**

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The Northwest Territories Cumulative Impact Monitoring Program (NWT CIMP) annually funds and conducts approximately 30 environmental research and monitoring projects in the NWT. The purpose of this review is to provide a high level summary of the program's 2016 research and monitoring results relevant to mining and oil and gas development in the territory, and to direct interested parties to where they can find more detailed information.

The main objective of NWT CIMP is to support better resource management decisions by furthering our understanding of cumulative impacts, environmental trends and baseline conditions. Grounded in the priorities of local environmental regulators, co-management boards and Aboriginal governments, the program is focused on key knowledge gaps related to caribou, water and fish. NWT CIMP strives to place relevant information in the hands of all parties involved in resource management decisions. As such, the program focuses on

reporting back to many groups, including communities, environmental regulators, industry and their consultants. For more information on the program, visit [www.nwtcimp.ca](http://www.nwtcimp.ca).

In 2016, ten NWT CIMP-funded projects were completed with directly relevant results to mining and oil and gas development in the territory. Six were related to caribou (CIMP94, 146, 153, 158, 165, 172), three were related to water (CIMP149, 159, 161) and one was related to fish (CIMP155). Relevant results include baseline scientific and Traditional Knowledge, modeling tools and results, standardized monitoring protocols, and specific resource management guidance. Project results can be found by searching for the above noted CIMP number on the NWT Discovery Portal at [nwtdiscoveryportal.enr.gov.nt.ca](http://nwtdiscoveryportal.enr.gov.nt.ca).

## **NORTHWEST TERRITORIES GEOLOGICAL SURVEY – 2016 OVERVIEW**

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The Northwest Territories Geological Survey (NTGS) is a division of the Department of Industry, Tourism and Investment (ITI), Government of the Northwest Territories (GNWT). It carries out and supports geoscience studies that contribute to a modern, comprehensive geoscience knowledge base for the Northwest Territories (NWT). This knowledge is used by stakeholders and NTGS staff to support evidence-based decision making. NTGS staff also provide advice and educational/outreach services to

individuals, communities, governments, and industry.

Research and related work activities are conducted by 23 staff in five functional working groups. These are Mineral Deposits and Bedrock Mapping, Petroleum Geosciences, Environmental Geoscience, Geomatics and Information Technology, and Geoscience Information Services. These groups regularly collaborate on NTGS work objectives and in providing a variety of client services.

The NTGS also works with other geoscience organisations and universities in pursuit of various research goals. Chief among these are the Geological Survey of Canada and university Earth Science departments across Canada. Following Devolution in 2014, collaboration has become increasingly common with other ITI divisions and GNWT departments in addressing land-based government decisions and objectives.

Despite relatively high logistical costs, geological fieldwork remains a primary data-gathering activity. During 2016, field research was conducted in the Slave and Rae cratons, East Arm Basin, Interior Plains, and Cordillera. The Geological Survey of Canada's Geo-mapping for Energy and Minerals program provides an opportunity for collaborative research in less-studied regions of the NWT including the Northern Cordillera, Arctic Platform, and southern Rae Craton.

The Mining Incentive Program, managed by the NTGS, remains a flagship ITI program. It currently funds five prospector and six company projects that focus on gold or diamond exploration. The program is merit-based and requires a detailed description of proposed work. Successful applications tend to be well-conceived and emphasise the use

of northern goods and services. The Mining Incentive Program was introduced in 2014 as part of the GNWT's Mineral Development Strategy.

The NTGS is uniquely situated to work with third party funders in addressing northern environmental and economic development needs. In this regard, the NTGS would like to highlight the work of the Canadian Northern Economic Development Agency in supporting a number of GNWT initiatives, including those related to the mineral industry.

## **GEOSCIENCE INFORMATION FROM A REGIONAL MINERAL DEVELOPMENT STRATEGY PERSPECTIVE**

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The Northwest Territories Geological Survey (NTGS) is a division of the Department of Industry, Tourism and Investment, Government of the Northwest Territories. It carries out and supports studies that contribute to a modern, comprehensive geoscience knowledge base for the Northwest Territories (NWT). Geoscience knowledge managed by the NTGS can be used as one of several tools in building a mineral development strategy that addresses the realities and needs of a region and its residents. The NWT is geologically diverse, and this diversity plays a role in how mineral resources are found and mined. The building of a Regional Mineral Development Strategy can benefit from an understanding of regional geology and mineral potential.

# THE NORTHWEST TERRITORIES MINERAL DEVELOPMENT STRATEGY ANNUAL REPORT 2015-2016

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The Northwest Territories Mineral Development Strategy (MDS) is an inclusive strategy integral to the broader effort to build a sustainable Northwest Territories (NWT) economy. Its implementation documents the continuing realization of the vision of responsible and sustainable mineral resource development in the NWT.

The Mineral Resources Division (MRD) within the Department of Industry, Tourism and Investment is responsible for monitoring implementation of the MDS and coordinating annual reporting. Presented here is the second report of MDS implementation, offering highlights of key activities and their results and an overview of the monitoring and reporting process applied.

## **DETAILS FROM BEDROCK MAPPING OF THE BEAULIEU RIVER VOLCANIC BELT AT SUNSET LAKE**

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The Northwest Territories Geological Survey has undertaken a multi-year bedrock mapping initiative along the Beaulieu River

Volcanic Belt in the southern Slave Province. The Sunset Lake study area is approximately 110 km east-northeast of Yellowknife and has recently been burnt by a forest fire. The current exposure is superb and allows for detailed mapping at 1:10 000 scale; a significant improvement from previous 1:50 000 scale maps.

During 2016, a five-week bedrock mapping program was conducted along the Beaulieu River on, and near, Sunset Lake. Mapping focused on lithology, alteration types, alteration intensity, structures (primary, ductile, brittle), and how this information can increase the understanding of the economic potential in this volcanic belt and the Slave Craton as a whole.

The volcanic rocks of the Beaulieu River volcanic belt sit structurally on top of rocks of the Central Slave Basement Complex (Sleepy Dragon Complex) and, where preserved, the Central Slave Cover Group. The volcanic rocks and associated sedimentary rocks are dominantly tholeiitic basalts (pillows, massive, pillow breccias etc.), andesites, dacites, rhyolites, interflow argillites, banded iron formation, and many variations of volcanoclastic deposits. These rocks are intruded by related volcanic dykes, Amacher Granite and younger mafic Proterozoic dykes. The region has experienced greenschist- to lower amphibolite-facies metamorphism, multiple distinct ductile deformational events, and several periods of movement along the Beaulieu River fault at different crustal levels.

The Sunset Lake area is situated in a part of the Beaulieu River volcanic belt with known mineral endowment and has potential for additional discoveries. The area contains volcanogenic massive sulphide (VMS) deposits including the “Sunrise” and “Bear”



deposits. The rocks also host the past producing “Sunset” Au mine (production unknown). The Beaulieu River volcanic belt shares similarities with the Yellowknife volcanic belt in rock types, metallogeny, and relationship to a long lived Archean structure. Despite previous mapping, multiple generations of mineral exploration, and relatively close proximity to Yellowknife; fundamental questions about the rocks and mineralizing systems remain. The present mapping program, utilizing unparalleled rock exposure, is advancing our understanding of this area and aims to provide new tools for future exploration efforts.

## **PERMAFROST AND TERRAIN RESEARCH FOR THE DEMPSTER AND INUVIK- TUKTOYAKTUK HIGHWAY INFRASTRUCTURE CORRIDORS**

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Permafrost thaw and climate change are major stressors on northern infrastructure. The Dempster and Inuvik to Tuktoyaktuk Highways (ITH) comprise a critical 400-km long infrastructure corridor within NWT where research on geohazards and terrain responses to disturbance and climate warming should be focused. These gravel bed roads link the western Arctic to southern Canada and are constructed through

challenging terrain underlain by ice-rich permafrost. The corridor straddles transitions from warm (0 to -2 °C) to cold (<-4 °C) permafrost, traverses glaciated and unglaciated terrain with varying ice contents, and crosses a range of hydrological and ecological environments. The nature of anticipated climate change and infrastructure related challenges are likely to vary with landscape heterogeneity. The objective of this presentation is to summarize recent scientific research results conducted along the Dempster-ITH corridor with focus on: A) Spatial heterogeneity in ground temperatures in natural settings and along infrastructure; B) Terrain mapping and ground ice distribution; and C) Utilization of new remote sensing techniques to document landscape change in natural environments and around infrastructure. These summaries provide context for part 2 of the presentation which pertains to developing a regional research strategy related to terrain, permafrost and infrastructure.

The Dempster-ITH road corridor presents a unique opportunity to develop a societally-relevant, northern-driven permafrost research network to support planning and maintenance of infrastructure, regulation, monitoring of climate change impacts and informed adaptation. The network should promote collaboration and encourage pure and applied studies that engage stakeholders and support northern interests. Successful implementation requires leadership from the Government of the Northwest Territories (GNWT), coordination between northern partners and research organizations to define key research priorities, human and financial resources to undertake studies, and protocols to manage data collection and reporting. The development of resilient researcher-stakeholder-community relationships is also necessary for the research initiatives to reach their potential. Future studies along the

Dempster-ITH corridor include: A) Consolidation and dissemination of existing datasets; B) Monitoring conditions at abandoned quarries and development of best practices guidelines to manage these sites; C) Monitoring thermal evolution of permafrost across climate and ecological gradients to provide baseline data for assessing thermal conditions in road embankments; D) Study of permafrost hydrology and road interactions; E) Monitoring terrain and roadbed stability across different permafrost environments. The GNWT is actively working with government, academic and industry partners to implement many of these studies. Co-ordination of these studies and other, ongoing research in the region through a GNWT led research framework can help focus key infrastructure, resource management and climate change research efforts and build important synergies within government and with the research community.

## **GEOPHYSICAL MODELLING OF THE NECHALACHO DEPOSIT AT THOR LAKE, NT**

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The world-class Nechalacho rare earth element deposit is located within the Blatchford Lake Intrusive Complex (BLIC) at Thor Lake, NT. High concentrations of heavy rare earth elements (HREE) as well as niobium, zirconium and tantalum occur at relatively shallow depths making it one of the world's largest undeveloped deposits. The minerals associated with these elements are hosted within a cumulate sequence of the Nechalacho syenite, which lies beneath the

Thor Lake syenite, within the eastern lobe of the BLIC. This sequence has undergone significant hydrothermal alteration, resulting in further enrichment of HREE as well as the formation of secondary magnetite as an alteration by-product. The magnetite and high density cumulate associated with the deposit present an opportunity to model the deposit using the anomalous magnetic and gravitational field signals.

Geophysical inversion techniques use airborne magnetic field data as well as gravitational field data to solve for three-dimensional models of the subsurface. Core magnetic susceptibility and density measurements from over 400 drillholes in the area are used to constrain the subsurface models. Results of these modelling techniques show a shallow, sub-horizontal layer of high magnetic susceptibility and density starting near the surface and extending to depths of up to 250 metres. This anomaly, inferred to represent the layers of the deposit containing high concentrations of rare earth elements, spans approximately 2000 metres in either direction laterally. In addition to delineating the deposit, geophysical inversion techniques show evidence of their ability to map other subsurface geologic features such as dyke swarms in the region.

# **SIMULATED THAW DEVELOPMENT AND GROUNDWATER FLOW WITHIN A PEAT PLATEAU-BOG COMPLEX IN DISCONTINUOUS PERMAFROST**

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Air temperatures at high latitudes have increased at rates that exceed globally averaged trends, and this warming has produced rapid permafrost degradation in many areas. In discontinuous permafrost regions of the Taiga Plains of northwestern Canada, past climate warming has created a complex landscape mosaic of thawed bogs/fens and remnant peat plateaus underlain by thin permafrost. The thawing of peat plateaus can alter the landscape hydrologic connectivity by creating pathways to efficiently convey water from bogs to nearby rivers and lakes. Extensive monitoring of the thermal regime of a peat plateau-bog complex in the Scotty Creek watershed (61.3°N, 121.3°W), Northwest Territories has identified rapid permafrost degradation in the past decade. In addition, satellite images indicate major landscape evolution due to permafrost thaw since 1970, and these changes have resulted in increased discharge at the watershed outlet. These long term comprehensive data facilitate the numerical modeling of idealized permafrost environments based on observed data. The objective of this project

is to elucidate processes that contribute to multi-dimensional permafrost thaw and associated hydrological changes in discontinuous permafrost regions.

The thaw evolution in this peat plateau-bog complex is simulated using SUTRA, a numerical groundwater flow and heat transport model that has been modified to include freeze-thaw processes. To accommodate complex surface processes, long term measured climate data are used to drive a separate soil-vegetation-atmosphere-transfer model. Near-surface temperatures produced by the vertical transfer model for the peat plateau and bog are applied as the upper thermal boundary conditions for the multi-dimensional subsurface heat transport simulations. The simulated thaw development of this peat plateau is compared to satellite imagery to assess the ability of this modeling approach to reproduce observed permafrost degradation.

## **2016 NORTHWEST TERRITORIES PETROLEUM RESOURCES DIVISION & PETROLEUM INDUSTRY ACTIVITY OVERVIEW**

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The Government of Northwest Territories' oil and gas administration is guided by the Oil and Gas Operations Act (OGO) and the Petroleum Resources Act (PRA) along with several sets of regulations and policies.

This presentation provides an overview of the activities of the GNWT's Petroleum Resources Division including strategic

projects mandated by the 18<sup>th</sup> Legislative Assembly and operational and programmatic work. 18<sup>th</sup> Assembly priorities include an Oil and Gas Strategy, a review of the PRA and OGOA and offshore petroleum management negotiations with Canada and others. Operational and programmatic work includes promotion and marketing, administration of petroleum land tenure, Aboriginal capacity building and benefits plans and support for the Environmental Studies Research Fund.

## **DIAVIK CLOSURE PLAN**

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As a modern mine, Diavik has been preparing for closure since the beginning - drafting the closure plan while drafting the mine development plan. Join us in this session as we discuss how we will close the mine's north inlet water storage area, the open pits and underground mining areas, the buildings/infrastructure, the north country waste rock pile, and the processed kimberlite containment area.

## **ASSESSING THE SEASONAL VARIATIONS IN GROUND TEMPERATURES ALONG THE ITH ALIGNMENT THROUGH MATHEMATICAL AND STATISTICAL ANALYSIS OF THE RELATIONSHIP BETWEEN GROUND TEMPERATURE AND AIR/SURFACE TEMPERATURE TIME SERIES**

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Upon completion of the Inuvik-to-Tuktoyaktuk Highway (ITH), regular monitoring is required to understand the state of permafrost beneath it and to establish the effects the road has on it. Thawing permafrost threatens the stability of the ITH, but also has longer term effects associated with climate change, such as carbon release and associated self-reinforcing feedback loops that affect the surrounding area, thus thermistors have been installed along the alignment to assess temperature changes over time. However, the temperatures during the winter construction seasons were abnormally warm, and therefore corresponding natural seasonal increases in ground temperatures are expected to occur irrespective of construction. How is it possible to discern, then, what variation is natural seasonal fluctuations, and what (if any) part of this increase is due to construction, and, in future, usage?

Currently, most research on ground temperature change uses empirical models requiring physical and material parameters that are site specific, many of which can only be at best approximated. Here, a

different approach is taken: rather than consider the specific properties at a site, mathematical and statistical analysis and modelling is done directly on the respective temperature time series to establish an expectation of how the variation in air/surface temperature should affect the ground temperature if the site was to remain undisturbed. An assumption is made that changes in attributes like soil and moisture composition, vegetation, etc. will either be negligible or will already be reflected within the time series (e.g. a linear trend), and hence that ground temperature fluctuations at an undisturbed site will correlate with external temperature fluctuations in a predictable manner. Once a relationship between ground temperature and external seasonal temperature variations can be identified, one can pursue explanations for unexpected ground temperature variations. For example, a decrease in mean air temperature corresponding with a marked increase in ground temperature during construction could imply a non-negligible contribution of heat passing to the ground from construction.

As this project is only in the preliminary stages, major results have not yet been achieved. However, an introduction to the approach, methodology used, and rudimentary observations on motivating examples will be given, along with details about the advantages and applications afforded by this method to better understand the effects of the ITH on the underlying permafrost. Since there are currently no designated control sites along the ITH alignment, establishing seasonal effects will be done based on comparison to still undisturbed sites along the alignment. In addition, since these time series are relatively short (installed April 2013), and manual logging of data has resulted in ground temperature readings for less than

1% of the total days over this period, analysis of time series relationships of proxy sites both in Canada and in Russia will be done to inform assessment at the ITH sites.

## **LEARNING FROM LEADERSHIP: ADOPTING PRINCIPLES FROM AIDEA INTO NORTHERN INFRASTRUCTURE DEVELOPMENT**

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The Liberal Government has committed to establish a Canada Infrastructure Bank, which resembles the industry's recommendation in the Levelling the Playing Field report to establish a northern infrastructure bank. This commitment was noted in the mandate letters to the Minister of Infrastructure and Communities and Minister of Finance. However, the language within the letters explicitly mention the provinces and municipalities, but not the territories. Given the disproportionately acute infrastructure deficit in the territories compared to the rest of Canada, and the barrier this deficit prevents for sustained socio-economic development activity, specific consideration for northern challenges and opportunities must have its place in the proposed mechanism.

The National Aboriginal Economic Development Board's January 2016 report, Recommendations on Northern Infrastructure to Support Economic Development, also recommends that the Government of Canada establish a new North-specific infrastructure investment fund to invest in infrastructure that supports

economic development and Indigenous communities in the region. The rationale for the fund was that key investments in transportation, energy and connectivity could create the conditions to support Indigenous community and business development and facilitate greater employment opportunities.

Depending on how the Canadian model is developed, direct and indirect job creation, tax and royalty revenue generation, and broad-based social and economic development considerations can be weighed in assessing the public value of an applicant's business case. Further, special consideration could be given to infrastructure investments that enhance the economic viability of projects in regions with high unemployment and limited alternative development opportunities. Considerations such as these require a recognition of the unique challenges and opportunities facing northern Canada. By creating a mechanism that facilitates economic growth, over time, remote and northern regions will be able to further develop their potential for business development, thus reducing their reliance on federal support.

MAC sees value in incorporating the strengths of the Alaskan Industrial Development and Export Authority (AIDEA) into the proposed Canadian mechanism. Alaska, one-third the size of Canada's Arctic, has seven times more people (710,000), has a \$50 billion Heritage Fund, and has seven large-scale operating mines. Alaska also has the Prudhoe Bay oil fields and pipeline, as well as 25 seaports. Despite being northern, infrastructure has significantly reduced the remoteness of these regions, facilitating both social and economic development and prosperity, as well as enhancing sovereignty claims by

increasing mobility and territorial accessibility. AIDEA has been strategic in facilitating this success.

## **METEOROLOGY AND SYNOPTIC CLIMATOLOGY OF STREAMFLOW IN THE SNARE RIVER BASIN**

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Drought is an important component of many ecosystems in North America, resulting in environmental and socioeconomic impacts. In the context of ongoing climatic and environmental changes, issues of drought are becoming problematic in northern Canada, which have not been traditionally associated with drought-like conditions. Since this region relies primarily on the production of hydroelectricity as an energy source, prolonged periods of below normal precipitation could threaten the energy security of communities. Across Northwest Territory (NWT), water levels and streamflows were significantly lower in 2014/2015. The Government of the NWT had to spend nearly \$50 million to purchase diesel fuel to generate enough electricity to supplement the reduced hydroelectric power generation.

Climate records of past precipitation patterns and drought or drought-like conditions in the southern NWT are relatively short. For example, the climate record from Yellowknife only extends back to 1943. While short in duration, these climatic records provide detailed information about climatic conditions at timescales ranging from hourly to monthly conditions, allowing us to gain important insights into climatic variability during the

past ~70 years and the potential drivers of this variability. With this in mind, the aims of this presentation are i) to characterize the return period of drought conditions similar to those in 2014/2015 using the short instrumental record, and ii) to identify the relationships between meteorological variables and the hydraulic conditions of the Snare River Basin. The hydrograph from the 2014 water season compared with the average streamflow of the instrumental period shows variations in timing and magnitude of the peak flow. The return period of such a low freshet discharge was estimated to 40 years. The lag in the correlations between precipitation and discharge corroborates that autumn precipitation is an important component of the streamflow magnitude in the subarctic Canadian Shield. Therefore, the key synoptic systems of 2013 fall were classified. An abnormally low frequency of cyclones above southern NWT and high frequency of Aleutian lows, along with strong meridional winds and unfavorable conditions for cyclogenesis were distinct patterns leading to hypotheses about the large scale climatic drivers of precipitation in the Yellowknife region.

Given the relatively high return period estimated from the instrumental period, these preliminary results advocate for a longer reconstruction of past precipitation patterns in the Snare River Basin and the southern NWT. Climate reconstructions of past precipitation levels can help us better understand the periodicity and trends in moisture conditions, identify the large-scale climatic conditions responsible for triggering drought episodes, and to better estimate the return period of persistent drought hazards across longer timescales.

## **FLOW-THAW FEEDBACK – HOW THAWING PERMAFROST AND GROUNDWATER INTERACT**

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The hydrology of the arctic is rapidly changing due to climate change, as observed by increases in arctic river discharge and the disappearance of arctic lakes. As permafrost (ranging from several meters to hundreds of meters in thickness) thaws from above, a deeper seasonal active zone (the shallow subsurface layer that freezes and thaws annually) develops, and more through-going thawed zones (i.e. taliks) develop that connect the supra- and sub-permafrost zones. Despite this potential for increasing groundwater movement in warming arctic environments, predictive models of permafrost thaw and distribution generally consider only the conduction of heat through the subsurface, and do not incorporate advective heat transport (movement of heat due to flow). To understand these systems and potential feedbacks, the SUTRA numerical groundwater model, which couples groundwater flow and heat transport, was modified to include freezing processes. When temperatures are below freezing, the model simulates variable saturation, permeability, and thermal properties as a function of ice saturation, and includes the latent heat of formation of ice.

We simulated groundwater flow and permafrost thawing across a hillslope cross section, with sinusoidal hills and valleys, which has an initially continuous permafrost layer. The mean air-temperature increases by 0.5 °C per 100 years, and in some cases

this long-term warming trend is superimposed on a seasonal  $\pm 10$  °C temperature variation that drives the yearly freeze/thaw cycle in the shallow subsurface. Simulation results compare changes in permafrost distribution over a few thousand years of climate change due to (1) purely conductive heat transport (equivalent to essentially no groundwater flow) and (2) advective-conductive heat transport (equivalent to regions with significant groundwater flow).

The results indicate that where groundwater flows, the advective transport of heat enhances the rate at which permafrost thaws, increasing transmissivity and the movement of warmer recharge water and deep water, further increasing the rate at which the edges of the permafrost warm and thaw, in a positive feedback. Additionally, groundwater is shown to be a significant control on the pattern of residual permafrost in the landscape.

### **PREDICTIVE MAPPING OF THE THAW SENSITIVITY OF PERMAFROST ALONG THE DEMPSTER HIGHWAY CORRIDOR BASED ON LANDFORM-GROUND ICE ASSOCIATIONS**

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Ice-rich permafrost within fine-grained materials is prone to rapid and irregular thaw after disturbance, whether due to climate change or anthropogenic activities. Understanding the distribution of thaw-sensitive materials is critical to the cost-

effective development and maintenance of infrastructure in regions of permafrost. Geophysical surveys and shallow drilling provide a reliable basis for determining the thaw sensitivity of permafrost in a particular area, but the completion of such detailed investigations at suitable intervals within large study areas or along long study corridors is cost-prohibitive. Predictive mapping of the thaw sensitivity of permafrost based on landform-ground ice associations provides an effective means of prioritizing areas for more detailed subsurface investigations and appropriate field data collection methods.

Predictive mapping of the thaw sensitivity of permafrost was completed along the 736 km-long Dempster Highway corridor to inform estimation of installation costs for a proposed fibre optic line, and forecast upcoming highway maintenance requirements. The mapping was produced by integrating interpretations of high-resolution aerial photography and LiDAR-derived elevation models, with references to historical aerial photography, satellite imagery, regional-scale surficial geology mapping, and geotechnical data. The interpretations were based on established landform-ground ice associations, with limited field reconnaissance. A 100 m-wide corridor centred along the highway was divided into areas (polygons) according to inferred active layer thickness (<1 m or >1 m) and ground ice potential. These divisions were based on vegetative and drainage indicators, interpreted soil texture, and surface expression of periglacial features and processes. Each polygon was then classified according to its permafrost-related ground movement potential following ground disturbance in the absence of any mitigation measures.

The results of the predictive mapping reveal



that the highest potential for permafrost-related ground movement potential is concentrated in two broad landscape contexts: (1) in valleys, particularly within low-gradient, slope-toe aprons and on organic-rich, abandoned floodplains; and (2) on gently undulating plains of fine-grained glacial diamictons locally overlain by peaty, organic material. The terrain with the lowest potential for permafrost-related ground movement is on well-drained hillsides with southerly aspects, and along rubbly ridge crests where expression of bedrock structure is visible. These results underscore the importance and benefit of predictive mapping of the thaw sensitivity of permafrost to support infrastructure development in northern Canada.

## **FEATURES OF APATITE IN KIMBERLITES FROM EKATI DIAMOND MINE AND SNAP LAKE, NORTHWEST TERRITORIES: MODELLING OF KIMBERLITE COMPOSITION**

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Kimberlites are volcanic ultramafic rocks originate from the upper mantle, and some are diamond bearing. Due to assimilation of mantle and crustal material, loss of volatiles, significant alteration and variable compositions of kimberlite seen at the surface, the primary composition and proportion of melt fluids (H<sub>2</sub>O, CO<sub>2</sub>) are unknown. Kimberlitic fluid and melt composition have significant effects on the

preservation and quality of diamonds carried to the surface. In an attempt to gain predictive knowledge of the economic viability of a kimberlite, it is important to understand the primary and evolving compositions of kimberlite magmas, as well as the behaviour of volatiles during kimberlite eruption. Apatite is a common groundmass mineral in kimberlite, and has a composition sensitive to volatiles and trace elements [Ca<sub>5</sub>(PO<sub>4</sub>)<sub>3</sub>(F,Cl,OH)]. This study will examine the variation of apatite occurrence, composition, texture and trace element distribution in relation to varied kimberlite geologies and explore the potential of apatite as an indicator of fluid history and melt composition.

Seven kimberlites have been selected for a study of groundmass apatite. The six Ekati property kimberlites (Koala, Misery, Panda, Beartooth, Leslie and Grizzly) have been chosen for their varying facies and styles of eruption. Panda and Beartooth are resedimented volcanoclastic kimberlites. Misery and Koala are massive volcanoclastic kimberlites. Leslie and Grizzly are pipe-fill coherent kimberlites. The seventh kimberlite, Snap Lake, is a coherent kimberlite dyke. All kimberlites are located in the Northwest Territories, Canada. Selecting kimberlites with diverse eruption styles allows us to test the apatite indicator model for a variety of potential volatile histories. Back scatter electron imaging has been used to identify and discriminate significant differences in apatite abundance and textural characteristics from Ekati kimberlites and Snap Lake. Wavelength dispersive spectroscopic analysis for major and some trace elements (LREE's, Sr, Ba) reveals primary substitution mechanisms for rare earth element (REE) incorporation into apatite structure. Previous studies show that distribution of trace elements into apatite greatly depends on the growth media.

Partitioning of the LREE's relative to Sr is significantly different between silicate melt, carbonate melt, and aqueous fluid. Experimental partition coefficients between apatite and various growth media are used to test existing hypotheses of kimberlite melt composition. The future aim of this project is to establish apatite as an effective indicator of magmatic fluid and outline the applicability of groundmass apatite as an indicator of diamond preservation potential in kimberlites.

## **HYDROGEOLOGICAL CHARACTERISATION OF A DEGRADING PERMAFROST ENVIRONMENT: A CATCHMENT-SCALE STUDY IN UMIUJQ, QUÉBEC, CANADA**

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The cryo-hydrogeology of a small catchment with discontinuous permafrost near the Inuit community of Umiujaq in northern Québec, Canada, is being investigated to determine the impact of permafrost degradation on groundwater resources. Located on the eastern shore of Hudson Bay, the two square kilometer catchment became deglaciated about 7500 years ago and lies in a valley containing 30-

40 m of glacial-fluvial and marine Quaternary sediments. Remaining permafrost extends from a few meters below ground surface to depths of about 10-30 m within a layer of marine silt. Instrumentation has been installed to measure groundwater levels, temperatures and heat fluxes, as well as groundwater and surface water geochemistry, isotope signatures (including  $\delta^{18}\text{O}_{\text{H}_2\text{O}}$  and  $\delta^2\text{H}_{\text{H}_2\text{O}}$ ), and stream flow. Meteorological conditions including air temperatures, precipitation and snowpack are also being monitored. Near-surface geophysical surveys using electrical resistivity tomography (ERT), induced polarization tomography (IPT), georadar, and seismic refraction tomography have been carried out to characterize the catchment and to build a 3D geological site model.

Groundwater geochemical analyses show a distinction between shallow aquifer waters with very low TDS and deeper groundwater with more evolved geochemical signatures, but still representing young water. Stable isotope signals of groundwater ( $\delta^{18}\text{O}_{\text{H}_2\text{O}}$  and  $\delta^2\text{H}_{\text{H}_2\text{O}}$ ) generally matched those of local precipitation (i.e. the local meteoric water line), thus indicating dominance of recent rain- and snow-input to the groundwater system, while a clear evaporation signal was evident from shallow thermokarst lakes. Isotope signatures from shallow permafrost ice (<5 m below the permafrost table) also generally followed the local meteoric water line, suggesting similar recharge temperatures as for the groundwater, although its age of formation is not clear. Two- and three-dimensional numerical models of coupled groundwater flow and heat transport, including thermal advection, conduction, freeze-thaw and latent heat, are also being developed for the catchment to help develop the conceptual model and to assess future impacts of permafrost

degradation due to climate warming. Temperature-dependent functions of unfrozen moisture content and relative permeability are included as well as latent heat. The numerical codes (HydroGeoSphere and Heatflow/Smoker) are being tested against analytical solutions and using benchmarks developed by the INTERFROST modelling consortium. A conceptual 2D vertical-plane model including several permafrost mounds along a 1 km section shows dynamic seasonal behavior with preferential melting due to sub-permafrost groundwater flow and discharge to surface water through taliks. Under current environmental conditions, the simulations suggest the remaining permafrost in the basin could completely thaw within 50-80 years.

This study is providing new insights into the groundwater flow dynamics and thermal regime within the catchment. Longer-term monitoring will help develop optimal investigative methods for monitoring hydrogeological systems under permafrost-degrading conditions, and will help determine how new groundwater resources may become available for public use, for example as a source of drinking water for northern communities as permafrost thaws and as recharge to aquifers increases.

## **OVERFLOW GENERATION FOR ICING FORMATION: A CONCEPTUAL MODEL**

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Icings (also aufeis, naled) form in winter by freezing of water that overflows across frozen surfaces (ground and/or ice). Icing development is most common in, but is not

restricted to, permafrost regions. Source water may seep from the active layer, flow from a spring, emerge from a stream channel, or may be a combination of these inputs. Regardless of the water source, icings occur where lower boundary conditions of the source aquifer are confining, and where winter conditions are sufficient for the freezing front in the ground to contact the water table and also freeze any overflow. If the freezing front has reached the water table, water can move to unsaturated unfrozen zones for storage. When the frost table contacts the water table, the closed flow conditions initiate hydrostatic water level rise. If the hydrostatic level rises above the surface (ground or ice), an icing may develop. With continued downward freezing throughout the winter the water level rises gradually, but the level fluctuates rapidly with short-term air temperature change. Following a cold interval the level declines, but the subsequent rise in air temperature is followed by a rise in hydrostatic head, and the peak value is above the previous maximum level. Exfiltration (overflow), sometimes accompanied by vertical movement of the ground and ice, coincides with the hydrostatic level peak. The hydrostatic base value of each succeeding decline increases, as do peak values succeeding rises. Additionally, because of shallow overburdens, large fluctuations in water pressure can occur due to barometric loading, snowfall, icing in the adjacent stream, but may also be expected due to temperature expansion and contraction of overburden. Here, I suggest that as pressure changes are rapid and are related to air temperature fluctuations, the driving mechanism originates near the surface, and in a manner analogous to pressure changes observed in lake ice. Thermal contraction cracks that develop on the frozen surface of lakes during cold intervals infill with water

from below that freezes in place and increases the mass of ice. Due to this increase, ice expansion during a warming interval is to a volume greater than the volume preceding contraction. This volumetric increase raises the internal pressure of the ice as the ice sheet is confined (not the water below). On large lakes this results in pressure ridges. Within closed-flow systems, small water volume changes induce large pressure variations. Thus I hypothesize that within closed-flow systems, infiltration of thermal contraction cracks in ice or frozen saturated ground by water from the unfrozen zone may reduce the hydrostatic head (water volume) during the cold interval. Subsequent expansion of frozen overburden with greater mass leads to an overall increase in volume and pressure of the upper boundary condition. When the pressure of the upper boundary increases, so must the pressure of the confined water, leading to exfiltration (i.e. icing) and/or surface uplift (and/or injection ice) where overburden is least resistant.

## **HIGH RESOLUTION INTER-LAKE ASSESSMENT OF ENVIRONMENTAL CONTROLS OVER THE DISTRIBUTION OF THE BIOINDICATOR ARCELLININA (TESTATE LOBOSE AMOEBAE) IN THE CANADIAN SUBARCTIC: IMPLICATIONS FOR ENVIRONMENTAL MONITORING**

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The gold mining industry has been a major economic driver for the NT, with mines like Con, Giant (GM) and Discovery mines, generating in excess of \$5 billion in revenue since the first mine opened in 1938. The operations of these mines, especially GM, left a massive legacy of arsenic (As) contamination and serious environmental degradation of the surrounding landscape. Following closure of the GM in 2004 the very expensive GM Remediation Project (estimated cost of ~ \$1 billion) was undertaken. While current efforts are primarily focused on the remediation of As contamination within specific areas of concern (e.g. the mine site and known watersheds), little attention has been devoted to evaluating the true spatial extent of As contamination and the impact it has had on lake systems. With new gold mines under

development in the productive Yellowknife Greenstone Belt, a multidisciplinary and quantitative investigation of background and present-day As levels in lacustrine sediments around GM is critical. This data is required to provide mine developers, planners and policy makers with a cost-effective and robust tool for assessing the intensity of As contamination, required for development of mitigation strategies and remediation targets in impacted lakes.

Testate Lobose Amoebae (TLA, Arcellinina) have been developed as a cost-effective and reliable tool for assessing environmental and paleolimnological levels of As and other contaminants in lacustrine environments. Their utility is enhanced by their high reproductive turn-over rate, great abundance in the substrate, and excellent preservation potential. Assessment as a proxy for As levels was based on analysis of samples from 59 lakes sampled by helicopter in August 2012, within a radius of ~30 km of the GM. TLA analysis revealed a strong correlation between high levels of As and stress-tolerant TLA taxa, thus providing new insight into the sensitivity of the entire spectrum of the group to varying levels of As in lacustrine environments.

The spatial survey was further expanded through the addition of a new set of surface samples from 32 lakes in the same area during the 2014 field season. Multivariate (e.g. ordination) and geospatial (e.g. spatial interpolation) analyses will be performed on all proxies to quantify the spatial relationship between TLA, As and other possible controls and determine the distribution of As in the region at a high spatial resolution. This additional coverage will specifically aid in: 1) improving the spatial coverage of the 2012 survey, which will be critical for mapping As concentrations in lakes throughout the

region; 2) enhance the quantification of the spatial relationship between TLA and As levels; 3) determine additional key environmental controls over the distribution of TLA in the Yellowknife area.

## **TRANSPORTATION CORRIDORS AND ACCESS TO RESOURCES IN THE NORTHWEST TERRITORIES (NWT)**

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In a largely greenfields region like the NWT, there are opportunities to plan new infrastructure projects with resource potential firmly in mind. Under the GNWT's Department of Transportation's (DOT) Transportation Strategy, DOT is advancing the planning for three transportation corridors: the Slave Geological Province (SGP) transportation corridor, the Tlicho all-weather road and the Mackenzie Valley Highway.

The SGP is a region of high mineral potential and is host to the NWT's diamond mines and most of the NWT's past producing gold mines. The SGP has the potential to sustain the NWT mineral development cycle for decades to come. The route currently advanced uses mineral potential mapping to guide the planning to maximize the potential for future resource projects. This talk presents an overview of the current infrastructure initiatives and priorities underway and planned by the GNWT, highlighting the role of mineral potential mapping in scoping of the SGP route.

## REDUCING ENERGY COSTS FOR REMOTE MINES AND COMMUNITIES THROUGH IMPROVED LIQUEFACTION TECHNOLOGY FOR LNG

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Liquefied Natural Gas (LNG) is increasingly becoming the fuel of choice for power generation and space heating requirements for mining and other industrial uses. Besides the environmental benefits of reduced CO<sub>2</sub> emissions and particulate matter, economics is a major driver. On an energy equivalent basis, natural gas is selling at roughly \$2.50/GJ (AECO based) compared to diesel at \$1.00/litre which is equivalent to \$25/GJ. Displacement of diesel fuel with natural gas has sufficient energy price spread to build out the regional LNG supply chain in Northern Canada for the benefit of the mining industry.

Sonoma Resources Ltd. of Calgary has recently funded the development, fabrication, and successful testing of a small pilot LNG plant using new and innovative liquefaction technology developed by CRNG Energy Inc. This pilot plant, situated southeast of Calgary, produced its first LNG on June 14, 2016, at rates between 400 and 500 US gallons per day, depending on ambient temperature. It is economically scalable making it suitable for both large and small scale commercial applications.

The patent pending technology is known as the “Dense Phase Liquefaction Cycle” (DPLC<sup>TM</sup>) and is designed to significantly reduce both capital and operating costs allowing very competitive pricing to diesel

as well as to LNG from other liquefaction technologies presently in use. The technology does not require the use of cryogenic rotating equipment which reduces capital costs and shortens project execution timelines.

Sonoma plans to construct its first full scale LNG facility using the DPLC<sup>TM</sup> technology at the existing Talbot Lake brownfield site in Northern Alberta, with an anticipated completion date of late 2017. Initially, the plant will be capable of producing 80,000 US gallons per day (7,000 GJ/d), which can be readily expanded to 250,000 gallons per day (22,000 GJ/d).

The location of the Sonoma Talbot Lake LNG plant (900 km south of Yellowknife, NT) establishes a secure and geographically close LNG supply point for the Northwest Territories mining industry. Feed gas supply for the Talbot Lake facility is provided by a direct connection to TransCanada's intercontinental pipeline grid, providing flexible fuel contracting strategies and a guaranteed source of supply.

## REGIONAL AND LOCALIZED DISTRIBUTION OF ARSENIC IN SOILS IN THE YELLOWKNIFE REGION

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The roasting of gold-bearing arsenopyrite (FeAsS) ore at legacy mines in the Yellowknife area resulted in the release of arsenic trioxide (As<sub>2</sub>O<sub>3</sub>) to the surrounding environment via airborne emissions. Recent studies have highlighted a persistent legacy

in local lake sediments and surface waters 50 years after the bulk of these emissions were released. Questions still remain about the amount and nature of arsenic residing in soils. The objectives of this research are to: 1) characterize the regional distribution of arsenic in Yellowknife area soils; 2) identify factors that explain regional patterns of distribution; 3) identify factors affecting local variation in the distribution of arsenic within small defined areas.

A total of 415 soil cores were collected within a 30 km radius of Yellowknife during the summers of 2015 and 2016 to explore the regional variation in soil arsenic concentrations. Sampling targeted four distinct terrain units, including: outcrop soils, forest canopy soils, forest canopy outcrop soils, and peatland soils. In order to investigate local scale variation in soil geochemistry, 119 samples were collected within two grids, measuring 0.07 km<sup>2</sup> and 0.01 km<sup>2</sup>, respectively.

Total element analyses have been completed on the Public Health Layer for 232 of the 415 samples collected. The Public Health Layer is defined as the top 5 cm of material. Peatland soils ranged from 4.1 to 4,900 mg/kg with a median of 150 mg/kg. Outcrop soils ranged from 10 to 3,000 mg/kg with a median of 150 mg/kg. Forest canopy outcrop soils ranged from 6.1 to 550 mg/kg with a median of 115 mg/kg. Finally, forest canopy soils ranged from 1.5 to 460 mg/kg with a median value of 32 mg/kg. Digital elevation models (DEMs) will be used to explore transport of arsenic along terrestrial drainage pathways. Select cores will be used to identify the solid species of arsenic present within the soil units using a combination of micro-analytical techniques. Anthropogenic sources of arsenic will be characterized by the presence of As<sub>2</sub>O<sub>3</sub> and

distinctive arsenic-bearing iron-oxides derived from roaster stack emissions. Using these analytical methods to identify the mineralogy of arsenic is important because speciation influences the bioaccessibility of arsenic, which is important to consider for risk assessment.

This regional soil sampling initiative complements previous lake, sediment, and soil geochemical surveys undertaken throughout the area. This research will work towards understanding the connections between terrestrial and aquatic systems in the region by filling knowledge gaps in soil geochemistry, mineralogy, and mobility. This research will also supply important data that can support future assessment of risk to human and ecological health from arsenic derived stack emissions.

## **GAHCHO KUÉ MINE – A WELCOME NEW ADDITION TO THE NWT AND CANADIAN ECONOMIES**

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The Gahcho Kué Mine, located 280 kms northeast of Yellowknife, is the largest new diamond mine under construction and commissioning the world, with full production anticipated by Q1 2017. This mine was constructed and commissioned ahead of scheduled and under budget. The second mine for De Beers in the NWT and third for DeBeers in Canada in the last eight years, it aligns with De Beers transformation of the business in Canada, which includes a relocation of De Beers head office from Toronto to Calgary in July 2016, where a new Operational Support Centre opened closer to our mines in the NWT.

The industry and socio-economic impacts of this new NWT mine and company transformation in Canada has garnered positive headlines around the world.

## **THE RECOVERY OF YELLOWKNIFE AREA LAKES FROM 50 YEARS OF MINING EMISSIONS: THE INFLUENCE OF LANDSCAPE SCALE AND WITHIN-LAKE PROCESSES**

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Lakes are a dominant feature of the landscape in the Yellowknife area and are an important part of the cultural and recreational fabric of the community. The early years of historical mining activities in the region resulted in the release of large amounts of arsenic, antimony, and metals to the surrounding area. Fifty years after the bulk of these emissions were deposited, surface waters of many local lakes continue to exhibit elevated concentrations of contaminants, particularly arsenic. It is important to identify the processes that influence the recovery of lakes across a range of scales for on-going mitigation and monitoring of legacy pollution. This talk will highlight recent research investigating the influence of landscape features and within-lake processes on the chemical recovery of Yellowknife area lakes.

A recent survey of 98 lakes within a 30 km radius of Yellowknife was used to investigate the distribution of arsenic in surface waters across the landscape. Regionally, the concentration of arsenic in surface waters decreased with distance from the historical ore roasting operations, and concentrations were highest in lakes downwind and proximal to the historical stacks. However, substantial variation in surface water arsenic existed within this hotspot area. An evaluation of the hydrological and physical properties of these lakes demonstrated that large lakes, well connected to lake network chains had lower arsenic concentrations than smaller headwater lakes, likely due to the higher flushing rate of the well-connected lakes.

Four lakes within this hotspot area representing a range of physical and hydrological properties were sampled regularly for one year to investigate seasonal variation in the concentration and speciation of arsenic in surface waters. Arsenic concentrations increased considerably (93 to 182%) under ice throughout the winter for three of the four study lakes. Peak under ice concentrations of arsenic were accompanied by large increases in iron and manganese concentrations and were observed under low oxygen or completely anoxic conditions suggesting diffusion of metals from sediment porewaters to lake waters. Arsenate, the less toxic inorganic species of arsenic, dominated in well-oxygenated surface waters, whereas the proportion of total inorganic arsenic as arsenite increased substantially (from < 1% to > 90%) under ice as aquatic environments transitioned from oxic to anoxic conditions over the duration of winter. Evidence of cryoconcentration by solute exclusion was observed in all four study lakes, as



conductivity and major ion concentrations increased under ice between 13 and 360%.

These results demonstrate that impacts to Yellowknife area lakes from legacy mining pollution vary across the region and highlight the importance of understanding both landscape level and within-lake processes. It is particularly important that regulators and land managers consider the importance of winter processes in a region where lakes are ice covered for two-thirds of the year. These data enhance our understanding of the processes that control surface water concentrations of arsenic in Yellowknife area lakes and will be useful for land managers in the development of remediation and discharge criteria that reflect current baseline conditions.

## **LIFE CYCLE GREENHOUSE GAS EMISSIONS FROM URANIUM MINING AND MILLING IN CANADA**

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To reduce greenhouse gas (GHG) emissions from the production of electricity, the world economy needs to shift from primarily consuming GHG-intensive energy sources, such as coal and natural gas, to consuming primarily low-GHG energy sources such as solar, nuclear, wind, and hydroelectric. To accomplish the transition from high- to low-GHG energy sources, it is necessary to understand the GHG emission intensity from energy sources and their fuel cycles using

transparent well-documented methods to quantify GHG emissions.

Life cycle GHG emissions from the production of nuclear power (in g CO<sub>2</sub>e/kWh) are uncertain due partly to a paucity of data on emissions from individual phases of the nuclear fuel cycle. Here, we present the first comprehensive life cycle assessment of GHG emissions produced from the mining and milling of uranium in Canada. The study includes data from 2006-2013 for two uranium mine-mill operations in northern Saskatchewan (SK) and data from 1995-2010 for a third SK mine-mill operation. The mine-mill operations were determined to have GHG emissions intensities of 81, 64, and 34 kg CO<sub>2</sub>e/kg U<sub>3</sub>O<sub>8</sub> at average ore grades of 0.74%, 1.54%, and 4.53% U<sub>3</sub>O<sub>8</sub>, respectively. The production-weighted average GHG emission intensity is 42 kg CO<sub>2</sub>e/kg U<sub>3</sub>O<sub>8</sub> at an average ore grade of 3.81% U<sub>3</sub>O<sub>8</sub>. The production-weighted average GHG emission intensity drops to 24 kg CO<sub>2</sub>e/kg U<sub>3</sub>O<sub>8</sub> when the local hydroelectric GHG emission factor (7.2 g CO<sub>2</sub>e/kWh) is substituted for the SK grid-average electricity GHG emission factor (768 g CO<sub>2</sub>e/kWh). This results in Canadian uranium mining-milling contributing only 1.1 g CO<sub>2</sub>e/kWh to total life cycle GHG emissions from the nuclear fuel cycle (0.7 g CO<sub>2</sub>e/kWh using the local hydroelectric emission factor).

# QUANTIFYING ANTHROPOGENIC VERSUS NATURAL IMPACTS ON NORTHERN LAKES: NEW TOOLS FOR HIGH QUALITY, RAPID COLLECTION AND COST-EFFECTIVE (QRC) DATA ACQUISITION

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Understanding the link between climate variability and metal loading is complex due to the lack of long-term data, and the spatial complexity of Canada's vast northern region. The ways in which climate regimes are changing differ among regions across the north, making it challenging to determine broad trends of climate change impacts on lake ecosystems from single lake studies. Paleolimnological research by our group is being carried at the landscape scale (multiple study lakes and cores from multiple basins) and at high temporal resolution (sub-decadal) from lakes in the Yellowknife area and 200 km to the NE, adjacent at the former Tundra Mine site, to quantify regional trends in aquatic ecosystem change and to distinguish

multiple stressors and their cumulative environmental impacts. This research requires sample collection over large scales and varied landscapes/environments, sample analysis at high resolution, and in various materials (water, sediments, biological). To meet these criteria, a well-designed environmental research initiative should comprise three key elements: 1) high quality, and high-resolution sample/data acquisition; 2) rapid collection and analysis for both spatial and temporal data; and 3) cost-effective approaches to maximize results upon which to derive solid evidence based conclusions (QRC) in support of societal initiatives. Examples of initiatives where we are striving to develop new comprehensive methods for QRC data acquisition in the NT include: 1) integrated use of side-scan sonar/sub-bottom profiling, coupled with bioindicator assessment, ICP-MS analysis and kriging techniques, collected using our novel freeze core (FC)-freeze core microtome (FCM) methodology to quantify the volume and ecologic impact of contaminated sediments in Frame Lake, within the Yellowknife city limits.

This QRC approach provides detailed, cost-effective, basin-wide information on temporal changes in arsenic and other metals of contamination, which is critical for the determination of remediation targets and mitigation strategies; 2) development of novel new QRC technologies and techniques to reliably pair FC and ITRAX-XRF to analyze Subarctic lake sediments at high (0.2 mm, subdecadal) resolution. This approach permits the accurate determination of baseline depositional conditions as well as accurate assessment of anthropogenic influences, permitting us to better understand the impact of climate cycles on subarctic systems and how these cycles may alter "natural" concentrations of key contaminants (i.e. arsenic). This approach is

also being used to study the response of contaminants to climate change in lakes above and below the treeline to see if there are major differences in hydroecological response; and 3) utilization of QRC geospatial methods to produce statistically robust inter- and intra-lake spatial surveys to quantify the relationships between bioindicators, arsenic and other contaminants of concern using our new ITRAX-XRF sequential sample reservoir technology and conventional ICP-MS analysis.

## **PRELIMINARY STRUCTURAL CONSTRAINTS ON THE GEOMETRY OF SELWYN BASIN FROM SUMMIT LAKE TO HOWARD'S PASS, NAHANNI MAP SHEET (NTS 105I), NWT**

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Mesozoic crustal shortening related to continental collision during the Cordilleran Orogeny is well documented throughout Yukon and Northwest Territories. The Mackenzie foreland fold and thrust (FAT) belt is characterized by thrust systems having long flats, discrete zones of imbricate fans, and box shaped detachment antiforms. The metamorphic grade is sub-greenschist and internal deformation of thrust sheets is limited to localized cleavage development and minor parasitic folding. Towards the hinterland to the southwest, rocks of the Selwyn fold belt have undergone penetrative, ductile, layer-parallel shortening

(LPS) and are deformed by several generations of folding and foliation development between widely spaced thrusts. The geometry and kinematic history of LPS in much of the Selwyn Basin is not well understood, and the kinematic relationship of this LPS to non-penetrative, brittle shortening in the Mackenzie foreland FAT belt is also poorly constrained. This study aims to address these deficiencies via a detailed structural analysis of penetrative LPS in the Nahanni area of the southeast Selwyn Basin.

Preliminary results are presented for one of three structural domains defined via mapping during 2015-2016 fieldwork: a 16km section trending northeast from Summit Lake to the Howards' Pass district. The section traverses the Narchilla, Gull Lake, Rabbitkettle, Duo Lake, Steel, Portrait Lake, and Prevost formations. Kilometer-scale folding is constrained via stratigraphic repetition and mesoscopic parasitic fold vergence. Folds have a near-Class 2 geometry and axes plunge shallowly and trend variably northwest-southeast. A regionally consistent, steeply-dipping, penetrative foliation (S2) is axial-planar to folding at all scales. S1 is visible only in thin section and is not associated with meso- or macroscopic folding within the Summit Lake to Howard's Pass section. Bedding, preserved in all lithologies, is rotated near-parallel to S2 in high-strain fold limbs. Locally, S2 is strongly refracted between bedding layers. S2 is overprinted by a variably and widely spaced, steeply dipping, asymmetric kinks (S3) that have not significantly altered F2 geometry. The S2 foliation and F2 folds are equally developed across all lithologies. Chlorite-zone metamorphism and phyllitic texture is consistent across this section. Poorly constrained discontinuities in the fold train are interpreted as late, high-angle normal

faults with minor offset. Mapping across the March Fault, a regional west-northwest-striking thrust, has not revealed structural or stratigraphic evidence for significant thrusting.

Preliminary results indicate that there is no geometric requirement for significant displacement along thrust faults within the Summit Lake to Howard's Pass section. Development of penetrative foliations, consistent metamorphic grade, continuity of near-Class 2 folds, and lack of evidence for thrust or detachment shortening along the section indicates that rocks of the Nahanni region in Selwyn Basin were deformed at greater depth than rocks of the Mackenzie foreland FAT belt. It is unclear whether LPS in Selwyn Basin rocks is related to deformation internal to a large imbricate thrust sheet, or whether it represents a transition from foreland-domain detachment folding and thrusting to hinterland-domain pervasive ductile shortening.

## **THE BIG PICTURE: ENGAGING ON THE GIANT MINE REMEDIATION PROJECT**

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Following the discovery of gold in the Yellowknife, Northwest Territories area, Giant Mine officially opened in 1948. After the mine closed in 2004 the care and control of the mine fell to the Department of Indigenous and Northern Affairs Canada (INAC), and attention focused on the environmental issues left behind, including the arsenic trioxide stored in underground chambers. The Giant Mine Remediation

Project was created in 2005, between INAC and the Government of the Northwest Territories, with the overall goal to protect human health and safety, and the environment.

The site lies within the Mackenzie Valley watershed, and is regulated by the Mackenzie Valley Resource Management Act (MVRMA). The MVRMA is federal legislation aimed at protecting the lands and waters within the Mackenzie Valley watershed. Since the site is under the care and custodianship of INAC, it is also subject to other federal acts, such as the Canadian Environmental Protection Act, the Fisheries Act and the Migratory Birds Convention Act, among others.

Giant Mine lies within the Akaitcho Dene asserted territory and is in the near vicinity of the Yellowknives Dene First Nation (YKDFN) communities of N'dilo and Dettah. Giant Mine is also within the traditional land use area of the Tlicho, known as Mowhi Gogha De Niitlee, and it falls within the provisions of the Tlicho Agreement (2003).

It is also situated within the municipal boundaries of the City of Yellowknife, and so is impacted by the City's bylaws and permitting requirements.

The site has always had a high profile within the community, with special interest groups, and with the local media for both positive and negative reasons. This interest, along with specific requirements established through the MVRMA and other acts, agreements, and by-laws make it incumbent on the project team to engage with community members and other stakeholders when determining and implementing the final remediation plan for the site.

The objectives of this presentation are to describe the methods the project team is taking to fulfill the consultation and engagement requirements of the regulatory process and other commitments, discuss the challenges this can present, and the lessons learned for delivering a successful project to remediate the Giant Mine site.

## **THE GEOCHEMISTRY OF DIAMOND INDICATOR MINERALS FROM THE HORN PLATEAU AND TROUT LAKE REGIONS OF THE NWT INTERIOR PLATFORM**

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The Horn Plateau and Trout Lake Candidate Protected Areas are located in the Central Mackenzie Valley (CMV) of the Northwest Territories. This region, between the western margin of the Slave craton and the Cordillera, is occupied by a major Phanerozoic sedimentary basin. Although the region is considerably outside the bounds of the exposed Slave craton, both LITHOPROBE and more recent regional-scale surface wave seismic studies indicate the likely presence of lithospheric mantle extending into the diamond stability field (e.g., Priestley and McKenzie, 2006; Schaefer and Lebedev, 2014).

Since Olivut Resources Ltd.'s commencement of their HOAM Project in 1993, they have discovered 29 kimberlites in the CMV. However, the indicator mineral chemistry of the discovered kimberlites

([www.olivut.ca](http://www.olivut.ca)) does not match with that obtained during regional till and river sampling by the Geologic Survey of Canada (GSC) and Northwest Territories Geologic Survey (NTGS) in 2003, 2005, and 2008. We present new geochemical data on the regional indicator minerals with the aim of obtaining geotherm and depth of mantle sampling constraints on those indicator minerals discovered to date. A statistical evaluation of the data will compare the indicator mineral chemistry with each other, and with other parts of the Slave craton to evaluate the source region for the CMV indicators.

In total, ~3600 and ~640 kimberlite indicator mineral grains were picked from the 0.25-2.0 mm size fractions for the Horn Plateau and Trout Lake, respectively. For the Horn Plateau, peridotitic garnet grains dominate (46%), followed by magnesium ilmenite (26%), with decreasing individual proportions <15% of chromite, low-chrome diopside, olivine, chrome-diopside and eclogitic garnet. Trout Lake is characterized by peridotitic garnet grains (45%), followed by chromite (22%), chrome-diopside (21%), olivine (10%), and 1% of both ilmenite and eclogitic garnet. A sub-sample of ~3100 Horn Plateau and ~500 Trout Lake grains were analyzed by EPMA. From this, a further split of ~700 - Horn Plateau and ~170 - Trout Lake peridotitic garnet grains were selected for LA-ICP-MS trace element analysis. Nickel concentrations from these grains yield TNi (Canil, 1999) values ranging from ~800-1350°C with the majority between ~1000-1200°C. Using a central Slave craton geothermal gradient (Hasterok and Chapman, 2011), equilibration pressures for these garnet grains were determined to provide a mantle sampling profile. For the Horn Plateau, 581 (81%) of the erupted peridotitic garnet grains were derived from within the

diamond stability field (Kennedy and Kennedy, 1976).

Application of a new Al-in-olivine geothermometer (Bussweiler et al., in press) to olivine LA-ICP-MS trace element data of compositionally screened mantle garnet peridotites from both regions will be used to compare the mantle sampling profiles of olivines with the garnets from the two regions.

Analysis and compositional screening of clinopyroxene grains from both regions yields variable proportions of garnet peridotite source lithologies. Thermobarometry of these grains, assuming they were all derived from the same mantle section, yields P-T arrays consistent with garnet and olivine geothermometry results.

A sub-set of kimberlitic Mg-ilmenite grains (1.0-2.0 mm size fraction) were analyzed by MC-ICP-MS for Hf-isotopic compositions to constrain source kimberlite emplacement ages. The Hf compositions suggest multiple eruption ages, from potentially undiscovered sources. These results are encouraging for diamond exploration.

## **STRUCTURALLY- CONTROLLED MESOTHERMAL-STYLE GOLD MINERALIZATION IN THE UPTOWN GOLD PROSPECT, YELLOWKNIFE, NORTHWEST TERRITORIES, CANADA**

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The Up Town Gold Project is a high grade Archean lode gold prospect adjoining the Giant Mine in Yellowknife, Northwest Territories. It is located approximately 6 km North of downtown Yellowknife. It consists of 6 mining claims covering 3227 hectares. The project is located on the western boundary of the Yellowknife Greenstone Belt in the southern Slave Province (Slave Craton) consisting of basement granitoids, associated with the Neo Archean Defeat group, dated as old as 4.05 Ga and younger (2.73 – 2.63 Ga) overlying in-folded greenstone belts. These belts consist of mafic through felsic volcanics, overlying terrigenous clastics, and turbidites and are associated with the Neo Archean Kam group in the study area. Both the underlying basement rocks and overlying greenstone belts are intruded by younger Archean granitic rocks and finally by several generations of Proterozoic diabase dyke swarms.

Mineralization exhibits strong structural control associated with NNE to NE structures hosted in foliated granitoids of the Defeat Group. Ten gold showings have been

## **AHEAD OF THE HERD: A SUMMARY OF RECENT RESULTS FROM VARIOUS GOLD PROJECTS IN NUNAVUT AND NWT**

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Silver Range Resources is a prospect-generator working in the Northwest Territories, Nunavut and Nevada. In April 2016 the company purchased a portfolio of exploration properties in NWT and Nunavut and expanded this by acquisition during the summer. In the Kitikmeot region, the company is working in the Contwoyto Lake – Back River area on five properties (Itchen, Gold Bugs, Esker Lake, Bling and Uist) and on two projects near the proposed Grays Bay Road (Happy Thought and Grumpy). In Kivalliq region, work this summer was completed on properties at Ennadai and Quartzite Lakes. At Hard Cash near Ennadai Lake, results were particularly promising and greatly expanded the highest grade zone of known mineralization at the Swamp Showing. Other projects in the NWT and Nunavut are briefly described. The company is also actively exploring and acquiring new projects in Nevada during the winter off season.

identified, collectively defining two corridors of structurally hosted high-grade gold mineralization sub-parallel to the shear zone hosting the Giant Mine Deposit (8.1 Moz Au). The eastern Fox South Shear is 1,100 m west of the Brock Shaft at the Giant Mine and consists of a reverse shear zone 10 to 70 m wide mapped over a strike length of 400 m. Further west, eight showings define a 4.5 km long, 500 m wide corridor of structurally hosted gold occurrences which includes the Rod Vein, a laminated quartz vein carrying disseminated pyrite, galena, chalcopyrite and free gold hosted in a NNE striking, moderately SSE dipping reverse shear. The Rod vein is 100 m long at surface, up to 3.0 m wide has returned grab samples assaying to 318 g/t Au and core assays of 2.22 m at 27.47 g/t Au.

The recent prospecting program identified two mineralized veins (exhibiting grades from grab samples of 5.1 g/ton Au and 3.1 g/ton Au). Furthermore, a vein described by the Geological Survey of Canada to be gold bearing with no values reported (11S Vein) was relocated. Sampling along the previously mapped 300 m strike length returned highest grab sample results of 19.1 g/t Au. Additional vein mineralization was identified another 100 m along strike, returning best grab sample assays of 145.5 g/t Au. These discoveries along with previous findings makes the Up Town Gold project a promising area adjunct to the greenstone belt mineralization trend.

## **THE IMPORTANCE OF A FEDERAL/TERRITORIAL NORTHERN AVIATION INFRASTRUCTURE SUPPORT STRATEGY**

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Resolution Number 2016-2 Northern Air  
Carrier Economic Issues

Whereas Northern Air Carriers are an integral component in the northern economy, accounting for a substantial proportion of territorial gross domestic product and of private sector territorial employment, and; Whereas Northern Air Carriers provide important investment and career opportunities for Aboriginal people, and; Whereas all of the aforementioned attributes of Northern Air Carriers are consistent with the established mandates of public sector northern stakeholders including the Territorial Departments of Economic Development and Tourism, the Federal Department of Aboriginal Affairs and Northern Development (AANDC), the Canadian Northern Economic Development Agency (CanNor), and Transport Canada, and; Whereas Federal and Territorial travel represents a significant proportion of northern route network traffic and thus could be used effectively to support the established mandates of the aforementioned public sector northern stakeholders by providing Northern Air Carriers with valuable core revenues.

Therefore be it resolved that:  
Transport Canada work with NATA to review the Emerson report on the Canadian Transportation System and CTA Review to

develop policy that recognizes and supports the role of Northern Air Carriers in the northern economy and in Canada's air transportation network, and; Other Federal and Territorial northern stakeholders, including Territorial Departments of Tourism and Economic Development, AANDC and CanNor also reference the Canadian Transportation Agency Report and develop travel and other policies that recognize and support the role of Northern Air Carriers in the northern economy.

Passed at the 40th Annual General Meeting in Whitehorse, April 28, 2016 P.O. Box 20102, Yellowknife, NT X1A 3X8  
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## **MAPPING AND REGIONAL CORRELATIONS OF THE HORN RIVER AND EXSHAW FORMATIONS IN THE LIARD BASIN, NORTHWEST TERRITORIES, CANADA**

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The Liard Basin straddles the Northwest Territories (NWT), British Columbia (BC) and Yukon (YT) borders, covers an area of 8400 km<sup>2</sup> and is an area of significant shale gas exploration and production in northern BC. In the past five years, two stratigraphic intervals within this basin have demonstrated good to excellent shale gas productivity. These include the Devonian age, Lower Besa River Formation (Horn River equivalent) and the Mississippian age, Upper Besa River Formation (Exshaw equivalent). A resource assessment of the Horn River and Exshaw Formations was initiated in 2015 by the National Energy



Board (NEB), in collaboration with the NWT, YT and BC geological surveys, to further understand possible gas resource distributions associated with these formations in the Liard Basin.

The geological surveys' role in the resource assessment was to gather territorial and provincial data pertinent to the NEB's volumetric resource calculations. These data included well bottom hole temperatures and temperature gradients, pressure gradients, gross and net shale isopach mapping, depth to formation maps, and weight % total organic carbon (TOC).

Analysis of the compiled data shows the following described trends. The Horn River Formation shallows from over 5000 m deep in BC to 470 m at the northern edge of the Liard Basin in NWT. Its gross shale isopach ranges from 450 m at Pointed Mountain, NWT to as little as 5 m along the northeastern margin of the basin. The net pay thickness ranges from 0 m on the eastern edge of the Liard Basin to 344 m at Pointed Mountain. The depth of the Exshaw Formation has a similar regional trend as the Horn River Formation, ranging from 4500 m at the BC-NWT border to outcropping at the surface near the South Nahanni River. The gross shale thickness ranges from 25 m at the north and eastern edges of the basin to 275 m thick at 60 °N. The net pay isopach ranges from 250 m to less than 25 m at the northern and eastern basin margins. Bottom hole temperatures in the Liard Basin increase from north to south, ranging from 90 °C to 170 °C. The average pressure and temperature gradients are 8.81 kPa/m and 4.11 °C/100 m, respectively. In the NWT, the Horn River and Exshaw formations are considered to be good source rock with average TOC values of 3.65 wt. % and 3.36 wt. %, respectively.

Well control in the NWT and YT is sparse with only 81 and 13 wells in each territory, respectively. The wells also tend to cluster in small areas of formerly productive gas pools. Furthermore, no seismic data were incorporated into regional mapping. For these reasons, it should be understood that the current resource volume estimates are qualitative in nature and subject to change as more data becomes available and is incorporated into the assessment.

## **LONG TERM LANDSCAPE AND FOREST RESPONSES TO CLIMATE CHANGE IN THE CENTRAL NORTHWEST TERRITORIES: INSIGHTS FROM BIOLOGICAL PROXY DATA**

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Palaeolimnological studies from sites above the modern treeline in the Northwest Territories have revealed the dynamic nature of the response of the boreal ecozone to inferred climate warming during the mid-Holocene. However, limited palaeoecological data exist from the Great Slave Lowlands and few records extend back to the first few millennia after deglaciation. Knowledge of the timing and character of landscape evolution in the early Holocene in particular remains poorly understood. This period was characterised by complex environmental changes as

glacial meltwaters drained from the region and boreal forest communities migrated northwards in response to climate amelioration. This paper will draw upon peatland and lake sediment records from a transect of sites (n=9) that extends from the central Great Slave Lowlands into the tundra ecozone ca. 200 km to the northeast to provide new insights into rates of peatland initiation, vegetation colonisation and treeline mobility in the early to mid Holocene and will appraise the utility of a range of proxies (pollen, plant macrofossils, stomata, diatoms, chironomids and charcoal) for understanding climate-environment interactions during this time. Such insights have the potential to provide important context for understanding the impacts of future climate change in the region. Quantitative temperature reconstructions will be presented that are derived from fossil chironomid (non-biting midge) assemblages preserved in sediment cores from three lakes (Matthews Lake, Horseshoe Lake and Frame Lake). Together these records span >7000 <sup>14</sup>C years and provide a basis for further re-assessment of the character and timing of regional climate fluctuations.

## **HYDROGEOLOGY - WORKING ON AND BELOW DEEP PERMAFROST**

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Establishing the natural hydrogeological conditions at mine sites in areas of deep permafrost and how these will change due to the influences of mining can be challenging. A review of the methods and techniques used in discontinuous and sub-permafrost hydrogeological systems over the last decade on sites in the arctic is presented to

show how representative data can be collected. Testing/monitoring methods for sub-permafrost systems, such as using multilevel monitoring systems filled with antifreeze for pressure and fluid monitoring, hydraulic packer testing in brine filled holes, and deep grouted VWP installations will be presented. The presentation will focus on the challenges of doing hydrogeological work in permafrost regions (especially deep sub-permafrost work), why testing and water chemistry characterisation is more problematic, and why this needs to be taken into account when assessing data (i.e.: problems with zone development, etc.).

The aim of this review is to help inform our discussion on how we should plan our work in permafrost environments, what testing/monitoring techniques/methods are successful, the recognized limitations, and what can be expected for reasonable site assessments and compliance/performance monitoring objectives. A better understanding of what can be achieved can then be used to assess potential risks due to incomplete understanding of these complex and difficult to access sub-permafrost systems in order to provide a more robust hydrogeological understanding to protect the environment and reduce impacts.

# **BASELINE HYDROLOGIC ASSESSMENT OF REMOTE NORTHERN CANADIAN TERRAIN IN ADVANCE OF SHALE OIL AND GAS DEVELOPMENT**

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The development of hydrocarbon resources in northern Canada has been evolving for many decades. Much of the terrain of interest is ecologically pristine and potentially sensitive to any type of industrial activity as well as being vital First Nations and Métis lands. One proposed approach to detect and quantify environmental impacts from hydrocarbon development in these areas has been to document the natural, pre-development state through the collection of baseline hydrologic data. These data represent reference values that can be used to assess the potential occurrence and magnitude of any changes in the local hydrologic conditions associated with future development of the hydrocarbon reserves. Over the last several years, oil and gas companies working in collaboration with the Government of the Northwest Territories (GNWT) and their consultants have initiated a series of baseline monitoring programs in the Sahtu Settlement Area (SSA) of the Central Mackenzie Valley (CMV) in the Northwest Territories (NWT). This region has been the focus of shale oil and gas

exploration from the Canol Formation, a Devonian petroliferous shale, with one area being located along the Mackenzie River between Tulita and Norman Wells. Due primarily to economic drivers, the exploration activities within the SSA have been significantly reduced over the last few years and the GNWT has proposed the idea of expanding the baseline understanding of the Sahtu region during this brief hiatus in oil and gas exploration. In this presentation, a summary of the initial baseline monitoring efforts in this region will be presented with a specific focus on the utility of different data streams to inform potential environmental impacts in the long term. Potential remaining gaps in hydrologic data and understanding will be discussed relative to the main challenges involved in expanding the baseline knowledge. Field investigation can be exceptionally challenging and costly due to access limitations and difficult climatic conditions in this area. A particularly unique aspect of the SSA region is the presence and influence of discontinuous permafrost that varies considerably in spatial occurrence and thickness and which significantly impacts the dynamics of the hydrologic cycle within the surface and subsurface environments. In consideration of the challenges and limitations, several emerging opportunities and technologies have been identified to extend the baseline knowledge that do not depend on costly field activities and limit the need for extensive site access over the course of the year. Several of these approaches will be briefly presented and discussed relative to their potential to cost-effectively fill critical data gaps within this type of remote landscape setting.

## **REVEALING THE HIDDEN MESSAGE IN SURFICIAL EXPLORATION DATA USING SETTING-SPECIFIC DATA STANDARDIZATION AND EVALUATION TECHNIQUES: PROJECT HIGHLIGHTS FROM CANADA AND BEYOND**

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Surface sediment mineralogical and geochemical data are fundamental components of many exploration programs. So often, however, the full interpretive potential of surficial exploration data is not realized due to the limitations of as-delivered data sets, an incomplete understanding of the surficial environment and its influence on data, or unresolved internal variation in data sets compiled from multiple sampling programs. It is essential that exploration programs extract the maximum amount of information from data sets, and recognize and avoid erroneous evaluations that could otherwise mislead exploration efforts. Through a series of exploration projects across contrasting landscapes, we have adapted a method of data standardization and evaluation that can be tailored to specific data sets and surficial environments. This presentation will convey the fundamental approaches used to identify and mitigate internal variability in the data set related to sampling and analytical procedures, standardize the data such that mathematical and statistical procedures can be appropriately applied, and apply a surficial context to these approaches that improves the efficacy of data evaluation.

We illustrate our approaches using examples from various data sets in both glaciated and unglaciated landscapes. We demonstrate the use of property-scale surficial mapping and data levelling techniques to refine the limits of kimberlite indicator mineral dispersal patterns near Lac de Gras, NWT. We show how mitigation of sampling and analytical variability in combination with multi-variate analysis of geochemical data defined a dispersal pattern and refined a gold exploration target near Norman Wells, NWT. We outline the application of transport modelling in target identification in regional till and lake sediment data sets in central British Columbia. We demonstrate the value of surficial mapping in creating subpopulations of soil geochemistry data, based on spatial differences in geochemical dilution, in Yukon's unglaciated White Gold District. We highlight techniques for data standardization and multi-variate analysis of soil samples to increase the resolution of drill targets in Paraguay. The effectiveness of these data standardization and evaluation techniques for exploration for different commodities in different surficial environments underscores the importance of their role in exploration programs.

## **THE SPATIAL DISTRIBUTION, SOLID-PHASE SPECIATION, AND POST-DEPOSITIONAL MOBILITY OF ARSENIC IN LONG LAKE SEDIMENTS**

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Arsenic (As) concentrations in lake sediments in the Yellowknife area may be elevated as a result of the natural weathering of mineralized bedrock or as a result of the roasting of gold-bearing arsenopyrite (FeAsS) ore at historical gold mines in the region, which resulted in the release of more than 20,000 tonnes of arsenic trioxide (As<sub>2</sub>O<sub>3</sub>) to the atmosphere as stack emissions. Arsenic trioxide, which is more bioaccessible than naturally occurring arsenopyrite, has potentially accumulated in the sediments of Long Lake, which is used for swimming and recreation by Yellowknife residents. Therefore, understanding the spatial distribution, solid-phase speciation, and post-depositional mobility of As in Long Lake sediments is important and will provide valuable information to support risk assessment.

A sediment survey was conducted to determine how As concentrations, total organic carbon, and grain size in the top 0-5 cm of sediments vary spatially with changes in water depth. Two sediment cores were also collected from shallow- and deep-water sites to understand how solid-phase concentrations of As and other redox-sensitive elements potentially involved in the release and sequestration of As by sediments (Sb, Fe, Mn, and S) vary with depth in the sediment column. Select sediment samples were analyzed using scanning electron microscopy coupled with mineral liberation analysis (SEM-MLA), electron microprobe analysis (EMPA), and synchrotron-based microanalyses to characterize the solid-phase hosts of As. The deep-water core was age-dated using <sup>210</sup>Pb methods. The post-depositional mobility of As in sediments from the shallow-water site was also assessed by sampling sediment porewaters using dialysis arrays (peepers).

The sediment survey indicates that As concentrations in the top 0-5 cm of Long Lake sediments are elevated relative to both the Canadian Interim Sediment Quality Guideline of 5.9 mg kg<sup>-1</sup> and the site-specific guideline of 150 mg kg<sup>-1</sup> for lake sediments at the Yellowknife boat launch. Arsenic concentrations are highest in deep-water sediments (>1000 mg kg<sup>-1</sup>) and are lower in shallow-water areas (<50 mg kg<sup>-1</sup>); sediment As concentrations and water depth are highly correlated ( $r = 0.8103$ ). This spatial variation is interpreted to be a result of sediment focusing processes. In the shallow-water core, the maximum sediment As concentration (90 mg kg<sup>-1</sup>) occurs in a thin layer beneath the sediment-water interface (SWI), where the dominant host of As is Fe-oxyhydroxide (mean As content of 4 wt.%). Congruent porewater profiles for As and Fe indicate that the post-depositional mobilization of As is governed by the reductive dissolution of As-bearing Fe-oxyhydroxide. In the deep-water core, the maximum sediment As concentration (1500 mg kg<sup>-1</sup>) occurs 17.5 cm below the SWI. The sediments from this interval are enriched in As<sub>2</sub>O<sub>3</sub> (as identified by SEM-MLA) likely originating from stack emissions; <sup>210</sup>Pb dating indicates that this horizon corresponds to the period of maximum emissions from the Giant roaster. The presence of As-bearing sulfides, however, suggests that the dissolution of As<sub>2</sub>O<sub>3</sub> leads to the formation of less bioaccessible phases where reduced sulfur is available.

## **OVER 10,000 YEARS OF PROSPECTING – ARCHAEOLOGY NORTH OF 60**

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As long as people have lived in the North they have relied on the extraction of materials from the earth to advance technology. Now those advances in technology are helping archaeologists collect baseline data to assist modern day exploration projects move through the project life cycle, from exploration through closure and reclamation. This paper focuses challenges specific to mining projects related to heritage baseline assessment across the North and how advances in technology are used to address the challenges.

One of the challenges that archaeologists face in collecting baseline data for mining projects is that modern geologists are continuing in a long tradition, of over 10,000 years, of extracting resources. These modern geologists are often targeting the same areas that were utilized in the past by people seeking materials to make tools. If heritage studies are not conducted in advance of modern ground disturbance archaeological sites may be accidentally disturbed. Having studies conducted early in the mining life cycle can help with obtaining and maintaining social license to operate, increase the value of projects, and preserve the heritage of the North.

New technology is driving emerging approaches of the collection of baseline data and redefining the outcomes of managing heritage resources research with applications

across the mining life cycle. Archaeologists are increasingly turning to innovative uses of technologies such as 3-D modelling, GIS, side scan sonar, remotely operated vehicles, photogrammetry, predictive modeling, drones and LiDAR. This is improving the quality of the data collected, the speed at which it is collected, processed and ultimately how heritage resources are managed early on in the mining life cycle.

## **NUNAVUT EXPLORATION OVERVIEW 2016**

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The Territory of Nunavut is well positioned in terms of mineral production, with two operating mines and a third mine poised for start-up in 2017. There has, however, been a decrease in overall mineral exploration with spending intentions down to \$110 million from estimated expenditures of \$215 million for 2015.

Gold remains the primary target for explorers in Nunavut, accounting for more than 80 percent of mineral exploration expenditures. The approval of the proposed Vault pit expansion has extended the mine life at Agnico Eagle's Meadowbank gold mine into 2018. The company also increased the inferred resource at its Amaruq project, a proposed satellite operation for Meadowbank, and established further underground development and surface infrastructure at its Meliadine project.

TMAC Resources' Doris North deposit, part of the Hope Bay project, is planned for production start-up in early 2017. This year the company completed upgrades to its

airstrip and is assembling the processing plant for commissioning in December. TMAC also continued exploration on the “Below the Dyke” zone at Doris North, and conducted regional exploration at the Madrid trend and at the Elu Belt east of Hope Bay.

The Nunavut Impact Review Board determined that Sabina Gold & Silver's Back River gold project should not proceed to licensing and permitting at this time. The Minister of Indigenous and Northern Affairs' response to this determination is pending.

Several earlier stage gold projects also saw activity. Auryn Resources expanded the land package at its Committee Bay project, completed drilling to expand known gold mineralization at the Three Bluffs deposit and conducted property-wide reconnaissance surveys. Northquest Ltd. released a maiden inferred resource for the Vickers deposit, part of the Pistol Bay project. Silver Range Resources is a new entrant to the territory that has acquired a portfolio of six gold projects in the Kivalliq and Kitikmeot regions.

Operations have continued at the Mary River iron mine, owned by Baffinland Iron Mines Corporation. This year, 2.75 million tonnes of ore are projected to be shipped from the mine.

Kivalliq Energy announced plans for a \$500 thousand program at the Yat prospect at its Angilak uranium project. No results have been released at time of writing. AREVA Resources has suspended its Kiggavik uranium project indefinitely following the Indigenous and Northern Affairs Minister's decision to uphold the Nunavut Impact Review Board's determination that the project not proceed.

Peregrine Diamonds Ltd. released a favourable preliminary economic assessment for its Chidliak diamond project. The report outlines a 10 year mine life producing 1.67 carats per tonne.

Aston Bay Holdings signed an option agreement with BHP Billiton, followed by a program of drilling, geophysical surveys and soil sampling at its copper and zinc Storm project.

Despite the downturn in mineral expenditures affecting industry worldwide, exploration for all major commodities has continued in Nunavut, indicating continued interest in the territory's mineral potential.

## **TERRAX MINERALS INC. - YELLOWKNIFE CITY GOLD PROJECT - UPDATE ON DRILLING**

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During 2016 TerraX completed 17,352 metres of diamond drilling in 91 NQ drill holes. Five new targets (Mispickel, Sam Otto, Pinto, AES and VSB) and three previously drilled targets (Homer, Barney Shear Zone and Hebert-Brent) were tested. Gold mineralization was intersected in all targets except VSB and Pinto. The most significant gold mineralization was intersected at the Mispickel and Sam Otto targets.

The Mispickel target consists of gold bearing quartz veins hosted within interbedded greywacke, mudstone, siltstone, argillite and intermediate to mafic ash tuff of the Walsh Formation. Three zones of gold mineralization veins have been intersected.

## ENVIRONMENTAL MONITORING AT GAHCHO KUÉ

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The main zone consists of 1 to 3 metre wide shear zones with 3 to 5%, 1 to 10 cm, boudinaged, quartz-chlorite-pyrrhotite veins. These veins are sub-parallel to the main schistosity, cutting it at low-angle. Visible gold occurs as pinpoint (<1 mm) to match head-sized (1 – 4 mm) grains within these veins. Hanging and footwall zones to the main zone consist of 3 to 10 metre wide shear zones with, 25-30%, 3-10 cm grey quartz veins with associated sericite alteration and medium to coarse-grained arsenopyrite. Some of the more significant intersections are:

- 60.60 g/t Au over 8.00 m including 212.48 g/t over 2.25 m in hole TWL16-016
- 12.47 g/t Au over 5.85 m including 67.00 g/t over 1.00 m in hole TWL16-019
- 9.37 g/t Au over 2.00 m in hole TWL16-022

The Sam Otto target consists of quartz veins hosted in intermediate and felsic tuffs of the Banting Group. The main mineralized zone is a 10 to 20 metre wide strongly developed shear zone with strong sericite alteration, cross-cut by pyrite and arsenopyrite mineralized quartz veins. Fine-grained, <1-2% pyrite and <1-3% arsenopyrite needles occur throughout the altered wallrock to the quartz veins in the main zone. Moderate developed matrix chlorite and silica define 3-10 metre wide hanging wall and footwall zones with <1-2%, fine grained pyrite.

- 1.00 g/t Au over 49.70 m including 2.54 g/t over 10.35 m in hole TWL16-011
- 1.33 g/t Au over 30.70 m including 2.02 g/t over 15.00 m in hole TWL16-013

The Ni Hadi Xa agreement was signed in December of 2014, providing for the establishment of a cooperative monitoring approach for the Gahcho Kué Mine. Oversight is not uncommon in our territory, but Ni Hadi Xa is designed to differently than other boards and agencies. Though there is some overlap in mandates, Ni Hadi Xa uses a fundamentally different approach – Traditional Knowledge Monitoring – as the primary means of monitoring for effects as a result of the mine. Ni Hadi Xa's central purpose is to aide in minimizing the effects of the mine in order to allow the Dene and Métis people to successfully exercise their rights and customs in the area around the mine.

The cooperation agreement made resources available to undertake three types of monitoring to support the overarching goal: observational, technical, and traditional knowledge. Traditional knowledge monitoring uses Northern people's history and experience to evaluate how the land and water are responding to changes in the local environment around Kennady Lake. The program uses specialist staff and families from the communities travelling to the area adjacent to the mine, to live in the area, and provide their observations of the land and wildlife.

The other monitoring methods are more conventional - the second monitoring stream is observational, where a Ni Hadi Xa staff member is at site, embedded within the De



Beers environment team. Their purpose is to provide eyes and ears for the Governance Committee on site, reporting back and ensuring that any incidents are being appropriately relayed. The final monitoring stream is through technical review of the environmental management plans and is similar to other oversight efforts in the territory.

This presentation will focus on how Ni Hadi Xa achieves the monitoring described here, how it was designed to be different, and what results it will provide to the Dene and Métis signatories of the agreement.

**ORIGINS OF KIMBERLITE  
INDICATOR MINERALS ON  
BANKS ISLAND, NWT:  
EVIDENCE FOR UNKNOWN  
ARCTIC KIMBERLITE(S) AND  
THE POTENTIAL OF BEDROCK  
INHERITANCE**

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Since 1996, exploration for diamond-bearing kimberlite by Monopros, Diamonds North and Rio Tinto has occurred on Banks Island, NWT. There have been 3 aeromagnetic survey programs, and 2 field-based exploration activities. The aeromagnetic surveys have yielded only weak-moderate anomalies. The stream and surface sediment sample collections have yielded generally low abundances ( $n < 20$ ), but nonetheless diverse kimberlite indicator mineral (KIM) assemblages (predominantly chromites), and include rare G10 and G10D garnets. To date, no kimberlite body has been identified on Banks Island although many are known regionally from east-

central Victoria Island, Darnley Bay, and mainland NWT (north and east of Great Bear Lake). The GSC's Geo-mapping for Energy and Minerals (GEM) Program study was devised to re-examine industry-reported data using a new model of glaciation, and to assess the potential for hosting diamond-bearing kimberlites on Banks Island. Sediment samples were collected over two summer field seasons, and were designed to test different terrains and specific glacial deposits for KIM contents, and assess the potential for down-flow glacial dispersal using the new ice flow model in areas where industry had previously recovered KIMs.

Fieldwork as part of this study identified numerous scattered outliers of Beaufort Formation gravelly-sands on upper pediment surfaces on northeastern Banks Island. Previously, Beaufort Formation strata were only reported from central and western Banks Island. Many of the catchments where industry had recovered KIMs on northeast Banks Island were recognized to contain these Beaufort Formation outliers. Because the Beaufort Formation is a Pliocene fluvial deposit, known to contain rare granitic material (hence have a potential Shield-derived component), it was targeted for KIM sampling. Results indicate that the Beaufort Formation deposits represent a potential bedrock-inherited KIM source. The Upper Cretaceous Isachsen Formation is another fluvial unit on Banks Island, also known to contain rare granites, and was the subject of field sampling this past summer. Geochemically distinguishing KIMs from either of these two bedrock units from local/distally glacier transported KIMs is important to resolving the kimberlite story on Banks Island.

Hafnium isotope dating of non-crustal ilmenites was used to discriminate potential KIM sources. If the ilmenite hafnium ratios matched those of known regional

kimberlites, then it would support glacial dispersal of distally-sourced KIMs onto Banks Island. Analytical results to be presented identify an ilmenite age that is not in accordance with any of the known regional kimberlites. They do, however, match other kimberlites situated far south of Banks Island, but is incongruous with our understanding of glacial dispersal were that the mechanism by which they were transported onto Banks Island. Evidence thus exists of unknown kimberlite(s) on or proximal to Banks Island.

## **2016 BEDROCK GEOLOGY MAPPING IN THE TEHERY- WAGER GEOSCIENCE PROJECT AREA, NORTHWESTERN HUDSON BAY, NUNAVUT**

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A second field season of regional bedrock-geology mapping was conducted in the summer of 2016 in the Tehery Lake–Wager Bay area on the northwestern coast of Hudson Bay, Nunavut. This work is part of a multi-year, multidisciplinary mapping campaign led by the Geological Survey of Canada's Geo-mapping for Energy and Minerals program and the Canada-Nunavut Geoscience Office. Field work resulted in the identification and spatial constraint of rock units in the western and northern parts of the study area which were sampled for geochemical, geochronological, and petrographic analysis, as well as to assess their economic potential. The study area is

dominantly underlain by Archean granodiorite to tonalite orthogneiss that contains panels of supracrustal rock packages of unconstrained age. Other mapped lithologies include weakly to undeformed monzogranite bodies (likely associated with the 1845-1795 Ma Hudson suite), plug-style intrusions of ultrapotassic rocks (possibly related to the Paleoproterozoic Christopher Island Formation), and dominantly undeformed monzogranite to monzodiorite bodies spatially associated with the Wager shear zone. The main highlights from our mapping and field observations include the 1) recognition of a previously unknown, large granulite-facies metamorphic domain in the southern part of the study area; 2) possibility of two different supracrustal rock sequences; 3) better delineation of the northeastern and western continuations of the Chesterfield fault and Wager shear zones, respectively; and 4) documentation of generally high, locally variable peak-metamorphic grades across the study area. Further analytical work is required to fully characterize rock units, compare and correlate them with other well-studied lithologies, and determine the geological history and economic potential of the Tehery Lake–Wager Bay region.

## **WHAT IS A REGIONAL MINERAL DEVELOPMENT STRATEGY? EXAMPLES AND CASE HISTORIES**

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A more regional-driven natural resource development approach has been evolving in the NWT. Since the signing of the Devolution Agreement, working together

- TECHNICAL PROGRAM -

with Aboriginal Governments has increased opportunities for regional benefits from resource development. Direct benefits include creation of local jobs and business opportunities and the sharing of resource royalties and other tax revenues. In November 2015, the GNWT held a one-day workshop on key characteristics of a mineral strategy, offering examples of other national, provincial and Aboriginal strategies already in use. Representatives from all regions of the NWT attended. In July 2016, the GNWT held the first ever regional workshop in the Dehcho with more than 40 participants from all Dehcho regions, including elders and youth. Interest in mineral development has been identified through the Tli Cho Kwe Beh Working Group, the Inuvialuit Settlement Region, the Sahtu and the Dehcho Areas.

The NWT Mineral Development Strategy (MDS) was created in 2013 and includes as one of its goals the support of mineral development strategies with regions. Pillar Three is entitled Enhancing Aboriginal Engagement and Capacity and identifies the need to ensure effective engagement and participation with Aboriginal governments and communities in decisions about the use of land and resources as a core principle. This talk will provide an overview of what composes a mineral strategy contains, examples of mineral strategies developed elsewhere and offers a close-up look at the NWT Mineral Development Strategy, including lessons learned, the making of the MDS, examples of what worked and what didn't.

## **2015 NWT REGIONAL ABORIGINAL MINERAL DEVELOPMENT STRATEGY WORKSHOP - COMMUNITY LEARNINGS**

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At the 2015 NWT Geoscience Forum, Aboriginal leaders from Quebec, Nunavut and the NWT came together to discuss the benefits of and lessons learned from Aboriginal-led regional mineral strategies. This presentation provides a summary of the presentations made by community members on their learnings from and strategic approaches to Aboriginal-led regional mineral development. The presentation will include a review of the Cree Nation Mining Policy, the Tli Cho's Kwe Beh Working Group, and the Nunavuk Inuit Mining Policy. An overall summary of approaches to a Regional Aboriginal Mineral Development Strategy will be provided for discussion.

## **OUTCROP DESCRIPTION OF THE HORN RIVER GROUP AT ARCTIC RED RIVER EAST AND FLYAWAY CREEK, PEEL PLATEAU AREA, NWT**

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Bluefish and Canol shales of the Middle and Upper Devonian Horn River Group in the Mackenzie Plain (NWT) are good to excellent source rocks for hydrocarbons and

are thermally mature over large areas, and in addition may be self-sourcing unconventional reservoirs with excellent economic potential. Both stratal units are present across the Mackenzie Plain, Peel Plain and Peel Plateau areas of the Northwest Territories; their thermal maturity and hydrocarbon potential has, however, not been adequately studied in the latter regions. From 2009 to 2014, the Northwest Territories Geological Survey (NTGS) Petroleum Geosciences Group conducted regional geoscience studies of the Bluefish and Canol shales in the Mackenzie Plain to determine their hydrocarbon potential. The purpose of these studies were to assess vertical and lateral variation in litho geochemistry, thermal maturity and source rock characteristics as well as provide detailed lithological and stratal descriptions of analyzed outcrops. There is evidence that both the Bluefish and the Canol shales are present and are of significant thickness toward the west in the Peel Plateau and Peel Plain areas, and may be either locally or regionally thermally mature for hydrocarbons. To better understand the thermal maturity and hydrocarbon potential of the Bluefish and Canol shales in the Peel Plateau, a subsurface Rock-Eval/TOC sampling program was initiated by the NTGS in 2015. In the summer of 2016 two outcrops were investigated and sampled to infill data gaps in Bluefish and Canol source rock and thermal maturity data for the Peel Plateau area. These outcrops are termed Arctic Red River East and Flyaway Creek. This talk highlights preliminary results of the field work.

At both localities the top of the underlying Hume Formation and a near-complete section of the Horn River Group is exposed. In total 70 m of section was measured at the Arctic Red River East locality, and 52 m at

Flyaway Creek. The sections were photographed and described with a focus on lithostratigraphic divisions. Samples for geochemical and mineralogical analysis and spectrometer data were collected at one metre intervals. At both localities nodular carbonate strata of the Hume Formation is gradationally and conformably overlain by the siliciclastic Bluefish Member of the Hare Indian Formation. The Bluefish Member is a few metres thick, and comprises fissile black shale with few carbonate beds and concretions in its lower half. The upper part of the Hare Indian Formation, informally termed the Bell Creek member, is composed of friable shale up to several tens of metres thick, but is typically heavily weathered and poorly exposed at both localities. The Canol Formation is several tens of metres thick and comprises fissile, dark grey siliciclastic shale locally interbedded with carbonate and sandstone beds. The top of the Canol Formation is not exposed, but observations during fly-bys at both localities indicate that it is directly overlain by the Imperial Formation. The results of this study will enhance our knowledge of the thermal maturity and hydrocarbon potential of Devonian shales in the Peel Plateau, and guide future investigations in the region.

**THE WHOLDAIA LAKE SHEAR  
ZONE; UNRAVELING THE  
NATURE OF  
PALEOPROTEROZOIC  
TECTONOMETAMORPHISM IN  
THE SOUTH RAE, NORTHWEST  
TERRITORIES, THROUGH  
STRUCTURAL ANALYSIS,  
PETROCHRONOLOGY AND  
METAMORPHIC PETROLOGY  
OF A ~1.9 GA CRUSTAL-SCALE  
FAULT**

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Pervasive high-pressure metamorphism at 2.5 and 1.9 Ga is documented along the eastern margin of the Rae craton from Baffin Island to beneath the Athabasca Basin. The >2000 km extent of this high-pressure belt is analogous to the footprint of Phanerozoic large orogens such as the Himalayas, yet conditions of its formation and exhumation are controversial and are the subject of this study. In the southern Rae of Saskatchewan and Northwest Territories, this high-pressure belt is postulated to have formed at 1.9 Ga during burial and crustal thickening related to continental collision with the Hearne craton. Others have interpreted this high-pressure belt to have formed at 2.5 Ga and exhumed along an intracratonic fault, the Snowbird Tectonic Zone (STZ), at 1.9 Ga by a series of intracontinental thrust and strike-slip shear zones.

New mapping in this poorly understood ca.

1.9 Ga high-pressure belt in the southern Rae craton, Northwest Territories, has uncovered a 300 km long, 5-20 km wide crustal scale shear zone, the Wholdaia Lake shear zone (WLSz). This northeast trending structure dips steeply to the southeast and parallels the STZ, which separates the Rae and Hearne cratons to the east. To the west of the WLSz, the Firedrake domain consists of polydeformed ca. 2.7 Ga orthogneiss intruded by voluminous 1.83 Ga magnetite-bearing granodiorite migmatite. East of the WLSz the Snowbird domain contains polydeformed, infolded, ortho- and paragneiss metamorphosed at ca. 2.5 and 1.9 Ga respectively. The total field magnetic signature of the WLSz displays both the Firedrake and Snowbird domain map patterns being transposed into the WLSz with dextral sense of shear.

Metamorphism in the WLSz is recorded by episodic monazite and zircon growth. High-Y prograde monazite included in garnet yields ages of ca. 1.93-1.92 Ga at conditions of 9 kbar and 850°C using conventional thermobarometry. Additional syn-kinematic low-Y monazite growth at ca. 1.93-1.90 Ga indicate continued high-metamorphic conditions in the garnet stability field. Metasedimentary rocks of the Snowbird domain to the east were deposited at ca. 2.0 Ga on orthogneiss metamorphosed at ca. 2.5 Ga. These metasediments also record high-Y prograde monazite growth at ca. 1.93-1.92 Ga and additional low-Y monazite growth at ca. 1.93-1.90 Ga. These metasediments also contain 1.91 Ga metamorphic zircon growth. Dextral normal-oblique shearing in lower grade amphibolite facies mylonites within the WLSz has a minimum age of 1.86 Ga constrained by late crosscutting granite dikes. These results imply the WLSz accommodated exhumation from lower to mid-crustal levels between 1.93 and 1.86 Ga

with at least some component of normal-sense extension.

Further refinement of the Pressure-Temperature-time-deformation details for the WLSz, in conjunction with other detailed studies of adjacent lithotectonic domains and structures, will be used elucidate the nature and exhumation history of ~1.9 Ga tectonometamorphism in the south Rae craton.

## **SIGNS OF LIFE? THE STATE OF THE CANADIAN EXPLORATION INDUSTRY**

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PDAC past-President Rodney N. Thomas will provide an update on the state of mineral finance in Canada and globally. He will also comment on the factors affecting whether that capital is deployed in Canada, assessing why Canada has lost its status as the best place in the world to explore - officially conceding first place to Australia in 2015 (as measured by SNL Metals & Mining). He will also outline what PDAC is doing to help companies access capital and land, and explore responsibly in the Canadian context.

## **SPATIAL AND TEMPORAL CHANGES IN SEASONAL RANGE ATTRIBUTES IN A DECLINING BARREN-GROUND CARIBOU POPULATION**

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During the last two decades the Bathurst caribou herd has declined from 400,000 to 16,000 animals. Traditional Knowledge (TK) has recently observed the later arrival of the herd below the treeline, an attribute of the autumn range. Science also predicts that seasonal range attributes (e.g., area, location) likely vary with population size, and perhaps climate. We used TK and science to identify several seasonal range attributes that were examined for changes through time (decreasing population abundance). Attributes of seasonal ranges for female Bathurst caribou were calculated using satellite collar data from January 1996 through October 2013. Climate data from CircumArctic Rangifer Monitoring and Assessment Network were analyzed for trends from 1979 to 2009. Analyses showed a significant decrease in area of post-calving and autumn ranges, but no changes in winter and spring ranges. Results supported TK that female caribou have shifted the autumn range farther from the treeline and moved into the forest later in the year. Analysis of climate variables found no trends at the spatio-temporal scales of the ranges. This analysis demonstrates how including TK can lead to stronger connections and results,

with potential to provide new and different insights for further investigations.

## **INDIN LAKE GOLD PROJECT - EXPLORATION UPDATE**

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Nighthawk Gold Corp. is a Canadian based mineral exploration company currently focused on advancing its Indin Lake Gold Property, a 222,203 acre land package located 200 kilometres north of Yellowknife, Northwest Territories within the Indin Lake Gold Camp.

An Inferred Mineral Resource estimate of 2.101 million oz gold at a 1.64 g/t gold average grade (0.6 g/t gold cut-off) is defined at its Colomac property. Only a small portion of the mineralized Colomac intrusion is captured by this 2013 estimate, leaving an underexplored and highly prospective deposit that hosts several newly discovered extensive, high-grade gold zones, and broad domains of lower grade mineralization.

Nighthawk Gold Corp's model for gold mineralization at Colomac (and Goldcrest), as confirmed by extensive geochemistry conducted during 2012 and 2014, is after that of The Golden Mile, Kalgoorlie, Western Australia; both contain a differentiated mafic sill of similar age with a more sodic, siliceous, and brittle, host upper (quartz diorite) portion that is amenable to clean fracturing, fluid transport, and mineral deposition, and within which gold is preferentially concentrated.

Differentiated intrusions are known to contain large gold deposits. Kalgoorlie is

one of the world's largest gold deposits and lies within the Eastern Goldfields of Western Australia with production in excess of 50 million ounces of gold to date.

Compositionally the Colomac sill displays a fine to medium-grained, felsic to intermediate (quartz diorite) upper portion and a medium to coarse-grained (gabbroic) mafic base. Gold is concentrated within the sodic and silica-rich upper portion of the sill, which behaved in a brittle manner during regional structural deformation providing depositional sites for gold. This is in contrast to the ductile behavior of the (gabbroic) lower portion of the sill and the surrounding mafic volcanic rocks. The identification of hydrothermal breccias within the quartz diorite is consistent with Nighthawk observations at other Colomac Zones, and is further visual evidence of hydro-fracturing and the (precursor to) mineralization proposed by Nighthawk for Colomac.

Highlights of the Nighthawk's 2016 drill program to date have established the near surface dimensions of the recently discovered high-grade Zone 1.5 to be upwards of 125 metres long, 30 to 50 metres in true width, extending from surface to 260 metres, and open to depth. Better 2016 results from the Zone 1.5 include hole C16-03, which intersected 52.07 metres (40 metres true width) of 7.72 g/t gold, including 25.47 metres of 14.25 g/t gold, and including 12.35 metres of 9.58 g/t gold, and hole C16-03B, which cut 72.65 metres (50 metres true width) of 5.58 g/t gold, including 17.80 metres of 17.72 g/t gold, 100 metres below the C16-03 intersection.

The Company has identified similar bodies at Zone 3.5 and Zone 2.0, while three other possibilities were drilled over the course of this summer's program. Results for those holes are pending.

## IMPACTS OF MINING OPERATIONS ON THE FORAGE AVAILABILITY AND QUALITY FOR THE BATHURST CARIBOU

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How have mining operations inside the Bathurst caribou habitat affected the availability and quality of forage for caribou? In addition to mining operations, many natural factors may impact the availability and the quality of forage for caribou. For example, at a large spatial scale (e.g., global or continental), the species composition and the growth rate of vegetation, and hence the forage availability to caribou, in the Arctic are largely controlled by the climate. At the local scale, however, topography, disturbance history, and soil pH play the dominant roles (Gould and Walker, 1999). The rolling landscape of small hills with gentle slopes over the area is

probably related to the tectonic movements of the Earth. The last deglaciation process further marked the area with boulder fields and eskers. The values of soil pH are influenced by the parent materials and the accumulation of soil organic materials from vegetation growth.

Mining operations cause land use conversion from natural tundra ecosystems into human-made features (e.g., buildings, open pits, roads, and waste piles). They may also affect soil pH. The dust from a mining road usually has a pH value of higher than 9. The fine suspended particles (e.g., PM<sub>2.5</sub>), which are originated mainly from diesel fuel combustion and living waste incineration, often have a pH lower than 3. In comparison, the pH values of non-disturbed tundra ecosystems in this region are typically in the range of 4 to 6. The deposition of dust and PM<sub>2.5</sub> thus could potentially alter the soil pH and consequently vegetation species composition and growth rate. Finally, the deposition of dust and PM<sub>2.5</sub> can also impact the quality of forage for caribou.

To assess the impacts of mining operations on the availability and quality of forage for caribou, in this study we separated their effects from that of natural processes using a two-step procedure. First, we stratified all vegetation survey sites into land cover classes (e.g., boulder field, esker, lichen-rock tundra, dwarf shrub, low-high shrub, tussock, and graminoids wetland). Each of the land classes has similar topography feature, disturbance history, and soil pH values for natural areas. For areas affected by dust and PM<sub>2.5</sub> from mining operations, their soil pH values, and thus caribou availability and quality could be changed. Second, nearly all sites have different percentages of the area covered by boulders. Vegetation cannot grow on these boulders,



and their cover percentage should be excluded in the analyses of mining operation impacts. We quantified these changes using vegetation field survey data collected during August 14-23 in 2015 and August 15-29 in 2016. Land cover class, percentage vegetation cover, mean plant height, soil pH, and dust on leaves were surveyed at more than 300 sites over dozens of transects around the Ekati Diamond Mine. To accurately determine the topography along these transects, we also collected more than 100,000 GPS positions using two differential GPS units that have a theoretical accuracy of centimeters. In this presentation, we will report the initial results from our field survey and analyses.

## **ENVIRONMENTAL ASSESSMENT INITIATION GUIDELINES - GETTING OFF ON THE RIGHT FOOT!**

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The Mackenzie Valley Review Board is responsible for the Environmental Assessment process in the Mackenzie Valley, Northwest Territories. I will briefly summarize the Review Board's current policy initiatives, focussing on the development of draft Environmental Assessment Initiation Guidelines. The goal of these draft Guidelines is to ensure that clear and complete information is provided to the Review Board at the outset of the EA process. This includes a comprehensive project description and supporting information. This information will allow the Review Board, Aboriginal organizations, government departments, and the public to thoroughly understand the project proposal

and develop a preliminary understanding of its potential impacts on the environment. Such understanding will support effectiveness and efficiency during EA scoping, assessment of potential impacts and mitigations, information requests, and the entire EA process.

## **ADVANCING A DEHCHO REGIONAL MINERAL DEVELOPMENT STRATEGY**

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The Government of the Northwest Territories (GNWT) developed a Mineral Development Strategy (the Strategy) “to realize, responsibly and sustainably, the full potential of the NWT's rich mineral resources and use it to ensure lasting prosperity for NWT residents and communities.” The Strategy's third pillar, “Enhancing Aboriginal Engagement and Community Capacity Building” sets the goal: “Aboriginal governments are better positioned to effectively participate in all stages of the mineral development process in the NWT.” At the 2015 Yellowknife Geoscience Forum, the GNWT held a workshop with Aboriginal governments to explore the idea of developing regional mineral development strategies as a means of advancing this goal. In April 2016, the Dehcho First Nations requested GNWT support for a workshop to begin this process. Stantec was contracted to work with the Department of Industry, Tourism and Investment (ITI) and the Dehcho First Nations, to coordinate, facilitate and report on this workshop, which was held July 6-7, 2016 in Fort Simpson.

For the first day of the workshop, guest speakers provided participants with a comprehensive overview of the mineral exploration and development industry in the NWT, with aspects tailored to the Dehcho region as applicable, including how the industry works, the phases of exploration and development, geology and mineral potential, the regulatory environment, industry economics, training, employment, and economic opportunities. The second day involved facilitated discussions with participants to begin building the foundations for their regional strategy, including a vision for what they wanted to achieve, obstacles, strategic directions, key actions and next steps. The presentation will focus on the results of this workshop, and lessons learned for carrying out similar work in other regions of the NWT.

## **THE PRESENT STATE AND FUTURE FATE OF PERMAFROST: A PALEOENVIRONMENTAL PERSPECTIVE**

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The geologic, geomorphic, biologic and climatic history of a landscape combines to dictate present-day thermal and physical state of permafrost. The timing and extent of these past environmental conditions provides a foundation for understanding present-day terrain conditions and prediction of future fate of permafrost. Much of Canada's northern landscape reflects a glacial legacy, with the resulting suite of glacial and post-glacial deposits having implications for the amount and type of

ground ice retained today within permafrost. In addition, most near-surface permafrost has been environmentally-conditioned by processes occurring within the last 14,000 years, though in unglaciated regions this may be considerably longer.

We review the present-day thermal and physical state of permafrost in relation to modern, late Glacial, and Holocene environmental conditions in North America. We examine the distribution of modern biomes and the relation to present-day distribution and thermal state of permafrost. We then review past biome distributions in northern Canada, to examine major climate-driven environmental shifts that have affected permafrost regimes. Within this context, we discuss the distribution of various ground ice types. This includes the potential distribution of i) buried ice of glaciogenic origin in relation to glacial moraines and hummocky terrain and to glaciofluvial sediments (eskers, kames, and ice-contact deltas), ii) intra-sedimental ice (ice wedges and segregated ice) in relation to maximum (glacial) lake and marine limits. We highlight examples of how post-glacial landscapes and climatically-driven biome changes interact to influence the present-day sensitivity of permafrost to future changes. These include, i) preservation of glaciogenic sediments and ground ice within continuous permafrost; ii) climate-driven ground-ice accumulation and/or degradation in relation to past biome changes; iii) chronosequences within lacustrine and marine sediments containing intra-sedimental ground ice in permafrost regions.

## SUMMARY OF COMPLETION OPERATIONS AND TESTING OF THE CANOL SHALE IN THE CENTRAL MACKENZIE VALLEY

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Between 2011 and 2014 seven wells were drilled and completed in the Canol Shale in the Central Mackenzie Valley by ConocoPhillips Canada Limited, Husky Oil Operations Limited and MGM Energy Corp. The Canol Shale is a low permeability formation which requires hydraulic fracturing in order to flow oil and gas. An overview of the completion operations and testing conducted on the seven wells will be presented.

## GEOLOGICAL AND GEOCHEMICAL COMPARISONS BETWEEN THE DUVERNAY FORMATION IN ALBERTA AND THE CANOL FORMATION IN NWT WITH SOME INSIGHTS INTO EXPLORATION AND PRODUCTION OF THE DUVERNAY FORMATION

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During the mid to late Devonian, the western Canadian shelf hosted a number of different “basins” within which unique

organic-rich sediments (carbonates, shales, mudstones) were deposited. The Duvernay, Muskwa and Canol formations in Alberta and the NWT, were deposited in relatively protected shallow shelf areas surrounded by active carbonate reefs and platforms within a back-arc subduction system (volcanic deposits in certain areas) relatively close to the equator under subtropical climate conditions. Strongly stratified oceans with anoxic bottom waters and normal to slightly elevated bioproductivity in the warm surface waters resulted in black shale deposits where high amounts of organic matter were preserved. These deposits have received much attention over the last 6 years as they proven to be favorable targets for unconventional gas/liquid production plays.

This presentation draws comparisons between various parameters and settings of both the Alberta Duvernay Formation and the NWT Canol Formation. Rock compositions, organic content and geochemical profiles are presented and discussed in the context of the deposits. Both deposits have regional mineralogical and geochemical variability on both a vertical and horizontal scale and hence show a high degree of variability in reservoir characteristics. Such regional changes have marked implications for porosity, permeability and ultimately rock frackability. In addition, the original biological and mineral compositions have undergone major transformations and neof ormations during burial and basin uplift and examples of these will be shown and implications discussed.

An overview of the development of the Duvernay play will be presented together with a summary of well completions and production data. Investigations and early exploration of the Duvernay play started in 2008 but landsale activity did not peak until

2010/2011. In 2010, Trican Geological Solution released a basin-wide source rock maturity map based on cuttings and selected cores. A large number of companies have taken advantage of the dataset and developed the play based on the geochemical mapping along with sparse archived analytical information. Since then, ongoing production of >200 wells is providing details of the hydrocarbon composition which can be utilized to “verify” original “maturity” maps and trends from various government and private enterprises.

### **SELWYN ZN - PB PROJECT: AN UPDATE ON RECENT EXPLORATION ACTIVITIES AND GEOLOGICAL FINDINGS**

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The presentation covers recent drilling campaigns that mostly occurred in 2014 and 2015, current structural models derived from drilling outcomes, lithological interpretation based on geophysical survey both airborne and ground, geological mapping, collaboration with academic organizations and PFS progress.

## **TŁICHQ MINERAL POLICY**

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The Chief Executive Council of the Tłichq Government has mandated the development of a Mineral Policy under 7.4.2 of the Tłichq Agreement, and as it relates to 23.2.1 of the Agreement. One of the biggest assets the Tłichq have is the land, and therefore clear rules need to be in place on how the land will be managed and used by different users. A Mineral Policy will provide clear guidance to Tłichq people, the Tłichq Government, potential developers, regulators and others on how the Tłichq want mineral development to occur on Tłichq Lands. In this session, the Tłichq Government will review paths forward towards the Mineral Policy.

# Abstracts - Poster Presentations

Presenting Author denoted by \*

## CHARACTERIZATION OF ARSENIC-HOSTING SOLID PHASES IN TAILINGS AND TAILINGS DUST FROM GIANT MINE, YELLOWKNIFE, NT

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Mining and ore processing at Giant Mine occurred for over 50 years (1948 – 1999). Roasting the arsenopyrite-bearing gold ore generated As-bearing maghemite, As-bearing hematite, and arsenic trioxide (As<sub>2</sub>O<sub>3</sub>) which were co-deposited with flotation tailings. Arsenic trioxide is considered the most bioaccessible arsenic compound. After spring thaw in May the temperature is too low to apply any chemical surfactant to the Giant Mine tailings, thus there is a window of time when the tailings are exposed to surface conditions. This window coincides with north-northwesterly high velocity wind events (> 8.0 m/s) in May and June. There has been growing concern regarding the potential arsenic concentration and arsenic speciation of the dust from Giant Mine. The objective of this research is to characterize the mineralogy of the fine fraction of the tailings (particles <20µm in diameter) to determine what arsenic-hosting solid phases are present, and to identify the arsenic-hosting species. Eighteen samples of surface tailings (0-10cm) were taken from locations within the tailings ponds where dust

generation has been observed in the past. These samples have been sieved to <63µm to isolate the finest fraction for analysis. From May to July a Met One E-Sampler and a total suspended particulate (TSP) high volume air sampler were set up at the south end of the south-most tailings pond to collect samples of the airborne material that was transported from the mine property to N'Dilo – a community of Yellowknives Dene First Nations (YKDFN) located directly south of Giant Mine. A 47mm Teflon filter was collected from the E-sampler every 7 days, and a quartz filter was collected from the TSP high volume sampler every 3 days. For all of the surface tailings and dust samples we are using inductively coupled plasma mass spectrometry (ICP-MS) to determine the total concentration of arsenic in the samples, coupled with scanning electron microscopy-mineral liberation analysis (SEM-MLA) and synchrotron-based micro X-ray diffraction (µXRD), micro X-ray fluorescence (µXRF), and X-ray absorption near edge structure (XANES) work to speciate the arsenic in the surface tailings and tailings dust. By these methods we are compiling data that may be used in an assessment of the relative risk posed by the Giant Mine tailings dust.

## **A PRELIMINARY TELESEISMIC INVESTIGATION OF THE CRUST AND MANTLE LITHOSPHERE OBTAINED FROM BISN IN THE WESTERN CANADIAN ARCTIC**

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The tectonic evolution of the Beaufort Sea continental margin has contributed to establish this region as a major petroleum reservoir. Recent shallow off-shore data suggest that Banks Island represents the western edge of the rifted margin established during the opening of the Arctic Ocean. In this case, rifting of the western margin caused Banks Island to subside and accumulate sediments rich in petroleum source material. The cooling and further subsidence of these sediments is important for understanding the thermal maturation of petroleum products. Recently published surface-wave velocity models of North America indicate seismic velocity at 100-150 km depths is similar to those beneath Canada's diamond mines in the central Slave craton north of Yellowknife. These results suggest that Banks Island is part of the Canadian Shield and any kimberlites found thereon would be promising candidates to contain diamonds. However, the high velocities are inconsistent with this being a tectonically disrupted and thinned lithosphere along the Arctic margin of the

Canada Basin. The problem is therefore to reconcile mantle structure typical of the Canadian Shield with crust typical of a rifted passive margin. Furthermore, seismicity located within the Mackenzie River Delta and offshore in the Beaufort Sea has been previously observed, however its origin is currently unknown, though may potentially be related to incipient subduction of oceanic lithosphere beneath the North American craton.

Resolving these questions requires high-resolution seismic models obtained from an array of broadband seismograph stations. Here we present preliminary results on the structure of the crust and uppermost mantle underlying the western Canadian Arctic. These results are generated using new data from the Banks Island Seismograph Network (BISN), an array of 3 stations installed over the summer of 2015; these are augmented with several USArray Transportable Array stations and older POLARIS and CNSN stations on neighbouring Arctic Islands.

## **TROPICAL WEATHERING IN AREA OF MELVILLE HILLS, NORTHWEST TERRITORIES**

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Laterite and its effect on kimberlite indicator minerals is not expected in Canada's glacial terrane and its presence if not recognized can have serious consequences for diamond exploration. There is considerable evidence of deep weathering in northern latitudes during the Eocene thermal maximum (55 Ma). Evidence of laterite in Talmora Diamond Inc.'s Horton River exploration area is presented and the effect of laterite on

kimberlite indicator minerals (KIMs) and magnetic anomalies is discussed.

Talmora's Horton River project is located on an upland plateau of flat lying Ordovician dolomite on the west flank of the unglaciated Melville Hills about 100 kilometers south of Paulatuk on the Arctic coast. The dolomite shows up as a brown area on Google Earth and is partly surrounded on three sides by areas of green coloured mudstones of the Cretaceous basin to the west.

Till samples taken in the Cretaceous basin contain the normal suite of kimberlite indicator minerals and many have been shown to be derived from sediments at the base of the basin. However, those from the Horton area outside the basin are deficient in silicates and the garnets that are recovered show diagenetic alteration (etch pits, colour leaching and weakening of grains), micro-ilmenite shows diagenetic rutile coatings and Mn-ilmenites alteration to ferropseudobrookite. The background mineralogy of the Horton area tills is rich in goethite or "laterite" and laterite cobbles are common especially down-ice of magnetic targets. KIMs (mostly chromite and ilmenite) show a close relation to magnetic anomalies.

The Talmora magnetic anomalies have low amplitudes like the kimberlites at Darnley Bay, but as expected in deeply weathered kimberlite show little evidence of early remnant magnetism. In deeply weathered bedrock primary magnetite alters to secondary hematite and iron-hydroxides with a reduction in magnetic susceptibility.

Most of the Talmora anomalies coincide with marshy areas or shallow ponds. They are unlikely to represent sinkholes as some ponds on high ground drain downhill into

sink holes. Two anomalies were tested with a small packsack drill that penetrated through ~10 vertical meters of glacial till into dark brown compact clay with small dolomite fragments. A small section (~25mm) of weathered clay was recovered that has chemistry similar to tropically weathered kimberlites. Drilling cuttings from one hole contained chromites, with compositions that lie on a very narrow Fe/Mg crystallization trend line indicating a single population and nearby source.

A fan of diminishing Mg+Ca values down-ice of the Talmora dolomite area is accompanied by high Fe values at its down-ice end supporting the idea that an extensive iron-rich laterite surface was removed first by the advancing ice. Laterite boulders near magnetic anomalies represent small areas of deeper laterite not completely removed by the ice. Sanatana explained magnetic anomalies west of Talmora as remnants of paleo-weathered "laterite" just beneath the till cover.

The standard Canadian diamond exploration model of following pyropes (chrome diopsides) to magnetic anomalies with strong remnant magnetism does not apply if earlier deep weathering has not been removed by glaciation.

## **LOCAL STRATIGRAPHY OF THE DUO LAKE FORMATION AT HOWARDS PASS IN THE SELWYN BASIN REGION**

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Late Proterozoic rifting of the northwestern margin of ancestral North America (Laurentia) created the Selwyn Basin, which was a depocenter for off-shelf sediments throughout the Early Paleozoic. The district of Howards Pass comprises 15 stratabound shale-hosted Zn-Pb deposits within the stratigraphic succession of the Selwyn Basin, and is located along the border of the Yukon and Northwest Territories. Mineralization consists of sphalerite and galena with minor pyrite in fine laminations and cross-cutting veinlets within Ordovician and Silurian graptolitic, variably calcareous and siliceous mudstone of the Duo Lake Formation. The most widely accepted published structural model for Howards Pass holds that mineralization was syngenetic with the deposition of sediments, followed by two deformation events. An alternative structural interpretation suggests that mineralization was formed diagenetically, and that imbricated thrusts created a duplex structure that now hosts the Howards Pass district. The Duo Lake Fm. will be analyzed for graptolites and C-isotope chemostratigraphy and the results will be applied to the development of a robust framework for the internal stratigraphy of the formation, as well as to testing the imbricate-thrusting structural model for the district. Two drillholes were logged and one outcrop section measured from different parts of the Howards Pass trend, with each section described and sampled in detail. The graphic stratigraphic logs show correlations within the Duo Lake Fm. These new detailed stratigraphic sections through the ore-hosting unit at Howards Pass will help determine a specific timeframe of deposition and the structural controls on the distribution of ore.

## **DETERMINING THE IMPACT OF WILDFIRE ON STREAM SYSTEMS IN THE DEHCHO AND SOUTH SLAVE REGIONS (NWT) USING WATER CHEMISTRY AND BENTHIC MACROINVERTEBRATE ASSEMBLAGES**

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Changing climatic conditions, including increasing temperatures and modified precipitation regimes, are impacting the functioning of natural ecosystems throughout the world. In high latitude regions, climatic change is occurring at rates that exceed those in the mid- and lower latitudes. Temperatures in northern regions for example, have increased nearly 2X faster than mid-latitude regions during the past few decades. The impact of these changing climatic conditions on the boreal forest are numerous, including increasing frequency and severity of natural disturbance events such as wildfire and changes in species composition (e.g., deciduous tree species increasing at the expense of coniferous species). Disturbances can reduce the availability and quality of important resources, therefore, monitoring these events and their impacts is essential.

Freshwater environments, such as lakes and streams, generate economic, environmental and culturally important goods and services. Despite this, the majority of wildfire studies



focus on impacts to terrestrial ecosystems. The Dehcho and South Slave regions of the Northwest Territories contain a large network of freshwater streams and lake systems, many of which were impacted by the numerous forest fires that occurred during the 2014, 2015 and 2016 fire seasons.

In 2015, we commenced a monitoring program with the aim of studying the impacts of these recent forest fires on stream systems in the Dehcho and South Slave regions. Select streams from the Dehcho and South Slave regions were sampled for water chemistry and benthic macroinvertebrate analyses. Benthic macroinvertebrates are small aquatic organisms that live within or on the substrate of streams and lakes and have been proven to be good indicators of changing water quality. Water chemistry parameters that were analysed included trace metals, major ions, nutrients, and general physical measures. Multivariate statistical analyses were used to compare spatial differences in chemical parameters across the landscape, while benthic macroinvertebrate indices were calculated to determine general ecological characteristics for the sample sites. Based on generalized stream classifications, conclusions about the potential impact of forest fires on water chemistry and benthic macroinvertebrate assemblages will be made.

**MINERAL DEPOSITS OF  
ARCTIC CANADA: EXCERPTS  
FROM A CHAPTER IN  
"MINERAL RESOURCES IN  
THE ARCTIC"**

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Arctic Canada is first divided into the cratons or granitic and metamorphic roots of the Canadian shield which contain much of the gold, copper, nickel, iron, uranium, rare earth elements and diamonds. Second are the bounding Mesoproterozoic to Phanerozoic platforms, basins and accreted terrains of the Interior Platform and Canadian Cordillera which extend into the High Arctic and contain much of the zinc, lead, gold, silver, copper, molybdenum and tungsten.

Basement nuclei in the Canadian shield are the Archean cratons of which four are present. Oldest of these is the Slave craton (4030-2550 Ma) on the west side of the shield. It is bound by Paleoproterozoic orogens: Thelon-Taltson to the east and Wopmay to the west. The Slave craton is associated with orogenic gold, volcanogenic massive sulphides (VMS), diamond-rich kimberlites and a large rare earth mineral deposit.

Lying to the east and underlying most of the remaining parts of the Canadian shield across the Canadian Arctic are the Rae (3250–2580 Ma) and Hearne (2740–2540 Ma) cratons. Significant in the Neoproterozoic Rae craton are supracrustal rocks containing important resources of iron, orogenic gold of Paleoproterozoic age, uranium associated with a sub-Paleoproterozoic unconformity, nickel and commercially significant diamond-rich kimberlites. Deposits in the Hearne craton include nickel, copper, platinum group elements (PGE), uranium and VMS.

The fourth craton is represented by the Superior craton, mostly located south of latitude 60 but also exposed in the northern extremity of Quebec. It is bound to the north by the Paleoproterozoic Cape Smith belt (1870–1800 Ma), part of the circum-

Superior Trans-Hudson orogen. This belt is noted for its important resources of nickel, copper and platinum group minerals. The other significant Paleoproterozoic belt is represented by the Wopmay orogen (1890-1840 Ma) which lies west of the Slave Craton. This features an eastern sedimentary belt and, to the west, the plutonic and volcanic rocks of the Great Bear batholith. Noteworthy resources include iron oxide copper gold (IOCG), polymetallic veins and vein uranium.

The Precambrian cratons and Paleoproterozoic basins are fringed to north and west by widespread shelf carbonate deposition that begins in the Mesoproterozoic and continues through the upper Paleozoic. These rocks have carbonate-hosted (MVT) zinc-lead deposits. Also present in this realm are iron deposits, notably the very large Crest deposit in Neoproterozoic strata. Southwestward the shelf succession gives way to Cambrian to Devonian deep water sediments of Selwyn Basin. Important resources are represented by shale-hosted zinc-lead mineralization of which there are three large deposits in the Yukon. Also present in Selwyn Basin are VMS copper-zinc deposits of which there are two significant ore bodies.

The western part of the Yukon is dominated by Jurassic and Cretaceous accreted terranes and by associated granitoid intrusive rocks. This is a key realm for gold, polymetallic silver-lead-zinc veins and nickel-copper-PGE. Also associated with Mesozoic intrusives are tungsten and copper skarns, and copper-molybdenum porphyrys. Rounding out the resources of the Yukon are eleven gold placer districts of which the Klondike is most significant.

## INTERSECTING FOLD BELTS IN THE BATHURST ISLAND REGION, NUNAVUT

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Mostly situated above latitude 75° North in the central part of the Canadian Arctic Islands, the Bathurst Island archipelago includes Bathurst Island proper and six other significant islands to north and west. The area is known for its former oil production from the Bent Horn oil field (1985-1996) and mining of the Polaris zinc deposit on nearby Little Cornwallis Island (1981-2002). Qausuittuq National Park has recently been created for northern Bathurst Island and the Governor General Islands to the west.

Significant components of the report area include Precambrian seismic basement, the Franklinian shelf (Cambrian to Devonian), the Ellesmerian foreland clastic wedge (Middle- Upper Devonian), and outliers of the Sverdrup Basin (Carboniferous-Cretaceous). Total thickness of the Cambrian to Devonian succession is 7.6 to 8.8 km in the island group but is locally more than 14 km on adjacent islands. Oldest identified strata are evaporites of the Middle Ordovician Bay Fiord Formation. These form a ductile detachment that at a depth of 4100 to 5500 m everywhere underlies thrust-folds. Above this are shelf carbonates, deep water mudrocks, and shallow to deep water strata associated with Silurian to Lower Devonian Boothia Uplift and Cornwallis Fold Belt.

Westward facies changes are numerous and readily identified on air photographs. These include lower Bathurst Island beds (Ludlow to Lochkovian turbidites) grading to Devon

Island Formation, Goose Fiord Formation (Lochkovian to Pragian carbonates) grading to medial Bathurst Island beds, Stuart Bay beds (Pragian-Emsian turbidites) grading to upper Bathurst Island beds, Prince Alfred Formation (Pragian-Emsian conglomerate and redbeds) grading to Stuart Bay beds, and Disappointment Bay Formation (carbonates; Emsian) grading to upper Stuart Bay Beds. The end of deformation through Cornwallis Fold Belt is marked by widespread deposition of shelf carbonates (Blue Fiord beds) that grade westward to clinofomed mudrocks of the Eids beds (late Emsian-early Eifelian). The Blue Fiord beds are the reservoir for oil at Bent Horn in subsurface Cameron Island and the lower Eids is a potential source rock. Uplift-related deposition is succeeded in the later Devonian by shelf-deltaic and fluvial sandstones and other clastic rocks.

Named structures of Cornwallis Fold belt include the Driftwood Bay structure which is an eastward transported thrust panel featuring evidence of unroofing during deposition of Bathurst Island and Stuart Bay beds and Prince Alfred Formation. To the west are the northerly-trending Queens Channel and Scoresby Hills anticlines with a similar structural style and unroofing history. Prominent on Scoresby Hills Anticline is an angular unconformity below off-lapping Pragian and Emsian strata. Also included with Cornwallis Fold belt are westerly-transported thrust panels imaged and inferred on seismic profile 1497 through central Bathurst Island. In plan view these are kinematically linked to presumed easterly- and northeasterly-striking wrench faults that are reactivated as thrusts during the development of Parry Islands Fold Belt. Deformation in Parry Islands Fold Belt features upright surface folds, subsurface thrusts, ductile deformation and detachment in Ordovician salt and Devonian shale.

Structures include northerly- and southerly-transported thrusts, zig-zag structures, pop-up and pop-down structures.

## **TILL COMPOSITIONAL DATA FROM A REGIONAL RC DRILLING PROGRAM IN THE LAC DE GRAS REGION, NT; INSIGHTS INTO THE NET EFFECT OF ICE FLOW SHIFTS ON 3-D PATTERNS OF INDICATOR MINERALS AND PATHFINDER ELEMENTS**

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Drift prospecting is an integral part of mineral exploration in the Northwest Territories (NT). This technique looks for indicator minerals and geochemical pathfinder elements within glacial sediments that have been dispersed by glacial processes over an area much larger than the bedrock targets. The area southwest of Lac de Gras, NT, contains a surficial spatial signature of two kimberlite indicator mineral (KIM) trains. The Monument indicator train, which has a known source, and the Coppermine indicator train, which is more enigmatic as it is lacking a known source. A new approach is needed in order to gain additional knowledge from previous studies. Typically, drift prospecting uses ice flow indicators (e.g. landforms, striae) and surface samples to identify the dispersion vectors and the compositional footprint resulting from a buried source, information is then compiled to map the surficial 2-D

pattern. This approach has been successful, especially in areas of thin drift; however, it does not capture the full 3-D dispersal pattern, which may be important in areas of complex ice flow history and till production. This research utilizes shallow subsurface data (0 to 28 m, 2.1 m mean, and 1.1 m median depth) from a regional RC drilling program designed to investigate the potential effect of older ice flow phases on sediment dispersion and how it may (or may not) relate to the surficial patterns. This work will give new insights into locating source areas for dispersal trains that have yet to be related to a buried source. Our methodology uses field work observations, combined with KIM data and geochemical data from 156 samples of a regional RC drilling program (52 boreholes at ~0.13 boreholes/km<sup>2</sup>), as well as available legacy data, GIS spatial analysis, and 3D visualization. Results so far show that there is a clear record of ice flow shifts in the ice flow indicator dataset displaying three main regional ice flow directions that are progressively younger in a clockwise direction from SW to NW. The KIM dataset and the geochemical pathfinder background and anomalous values are being analyzed due to the distinction between the elevated values in the lower portion of the till column relative to shallower data. The deeper till may be a different stratigraphic unit in places, or it may have a higher compositional inheritance from older ice flow phases. Preliminary results suggest that there is good evidence for complex three-dimensional dispersal patterns that match with the ice flow history. The challenges are related to the distribution and low density of subsurface data, and other complicating factors, such as potential local bedrock topographic effects on till deposition and dispersal patterns. Overall, the dispersal patterns appear to be discontinuous, but in agreement with the glacial reconstructions

based on independent data; the full 3-D compositional patterns reveal a complexity that is not captured by the surficial data, and this style of exploration may have implications for ongoing and future exploration in the Lac de Gras area.

## COMPILATION OF GROUND TEMPERATURE RECORDS IN THE NORTHWEST TERRITORIES, CANADA

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Knowledge of the ground thermal regime is an essential component of permafrost research, environmental monitoring, planning resource development projects, as well as infrastructure design. In the Canadian North, various needs drive the collection of ground temperature data including government and academic monitoring and research, regulatory monitoring, and industry-supported infrastructure projects. Research and monitoring programs typically summarize the ground thermal regime in academic publications. Regulatory monitoring data typically accompanies obligatory reporting to the responsible authorities. Ground temperatures collected for infrastructure

purposes may also be summarized in design or maintenance reports.

Although ground temperatures are measured every year in the Northwest Territories (NWT), the actual data usually reside with the research institute, government agency or private industry consultant that collected the data, and are typically not retained by institutions that are best suited to manage and archive temperature data and records, such as the Northwest Territories Geological Survey (NTGS), or Geological Survey of Canada (GSC). As ground temperature data are expensive to collect, and because access to historical ground temperature data is of great value, it is beneficial to organize and host these data so that it can be efficiently accessed for use in future projects for the Government of the Northwest Territories, the wider research community, industry and other users.

The first step towards compiling this information has been to establish a metadata reporting template so that ground temperature measurements are described in a common format. The metadata standard developed for the NWT was revised based on feedback received from permafrost researchers, thermal modellers, geotechnical engineers, public and private sector geologists, and civil servants involved with infrastructure performance monitoring. Our team has produced a metadata template that is divided into seven sections: (1) Project details; (2) Location of ground temperature measurements; (3) Installation of ground temperature cable; (4) Ground temperature record; (5) Site conditions; (6) Permafrost conditions; and (7) Related publications and data.

The metadata template is now finalized and existing ground temperature datasets collected by the NTGS, GSC, and

collaborators are being compiled so that the data can be published as NWT Open Reports. The next step is to identify all historical and ongoing ground temperature data collections and archive the metadata for these records. Ultimately, the project team will work with other departments in the Government of the Northwest Territories, and northern regulatory and research agencies to develop strategies that leverage ground temperature data and make it accessible through a data management system.

The compilation of ground temperature records in the NWT will have multiple benefits. As ground temperature data will be readily available, evidence-based decision-making in the territory will be better supported. Future permafrost monitoring initiatives will benefit from information on the nature of the ground temperature data and where it has been measured. International permafrost research will be enhanced as scientists will have access to NWT ground temperature data. Finally, other jurisdictions, such as Nunavut, who are interested in managing ground temperature data can adapt this approach to meet their needs.

**GEOCHEMISTRY,  
SEDIMENTOLOGY, AND  
TECHNOLOGY OF THE HARE  
INDIAN FORMATION AT  
MOUNTAIN RIVER,  
MACKENZIE MOUNTAINS, N.T.**

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The middle to late Devonian Hare Indian Formation within the Central Mackenzie

Valley of the Northwest Territories has been interpreted to record distal basin-fill sedimentation (Muir et al., 1984; Pyle et al., 2014). This shale succession is subdivided into a lower organic-rich Bluefish Member and the overlying clay-rich Bell Creek Member (Pyle and Gal, 2016). Previous work has established the Bluefish Member as a source rock with increasing attention as an unconventional play opportunity.

This study assesses the sedimentological, geochemical, and ichnological characteristics of the Hare Indian Formation at the Mountain River outcrop located in the northwest Mackenzie Mountains. The outcrop was logged to document lithologies, contacts, and bioturbation. Samples were collected at 10-50 cm intervals throughout the formation for high-resolution analysis with x-ray fluorescence (XRF) and thin-section petrography. Trace- and major-element data obtained by XRF is used as proxy for terrigenous detrital input, paleo-anoxia, and basin isolation (Rowe et al., 2012; Tribovillard et al., 2006). Plant and animal fossils were collected in order to gain paleo-environmental information. Future work will incorporate data from other outcrops and core in order to develop an integrated depositional and sequence stratigraphic model for the Hare Indian Formation. An enhanced understanding of this poorly understood unit will aid in paleo-environmental interpretations and subsurface mapping efforts.

## **TILL COMPOSITION AND GLACIAL DISPERSAL PATTERNS IN SOUTH RAE CRATON, NORTHWEST TERRITORIES**

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Surficial geology mapping at a 1:100 000 scale and a reconnaissance-scale till sampling survey within the 75A and 75B NTS map sheets were started in 2015 during the first year of the South Rae activity of the Geo-Mapping for Energy Program (GEM-2) of the Geological Survey of Canada. The area lies in the southern part of the Rae Craton and is in large parts covered with glacial sediments. The mapping and geochemical interpretation of the glacial sediments will inform bedrock mapping and mineral exploration programs, and assist with land resource management decisions in this region.

Ground observations were recorded at 157 sites and 94 till samples were collected for compositional analyses including geochemical and heavy minerals. Erosional ice-flow indicators (striations, grooves, roches moutonnées) and streamlined features (crag-and-tail, drumlins) were measured across the two map sheets. Four phases of ice flow have been identified. At a few sites, an old flow of unknown sense (SSE/NNW) and temporal relationship is deduced from poorly defined striations. In contrast, well defined indicators reveal a regional clockwise rotation in ice-flow directions evolving from a southward to a

southwestward flow. A late westward flow is recorded only in the north of the map area. The dominant flow is to the southwest. Bedrock exposure varies from 0 to 40%. The sediment cover consists mostly of till (till veneer, till blanket, hummocky till) intersected by NE-SW trending eskers systems and meltwater corridors. These corridors are eroded into the landscape and contain a mixture of glacial and glaciofluvial landforms, and bedrock exposures. The sediment accumulation varies from 1 to 15m and is less abundant in the southern part of the map area.

A study of till composition and ice flow reconstruction is underway to delineate and interpret glacial dispersal patterns. To investigate the U+REE signature in till, a small orientation survey was conducted at the Hoidas Lake REE deposit in Northern Saskatchewan. Samples were taken up-ice and down-ice from known mineralization. Future comparisons will be made to see if the U+REE mineralization signatures in till can be found in the same kind of geological context along the continuation of the Black Bay fault zone in the Northwest Territories. The poster will present preliminary results focusing on the ice flow reconstruction, till composition and the spatial distribution of major and trace elements of the till matrix geochemistry, gold grains and selected indicator minerals.

## HIGHLIGHTS OF REGIONAL GEOLOGY AND MINERAL POTENTIAL FROM 2016 MAPPING IN SOUTH RAE PROVINCE, NWT

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The South Rae Province in the Northwest Territories has seen little research since it was first mapped by canoe and float plane at reconnaissance scale in the 1950-1960s. Under the GEM2 program, the collaborative GSC-NTGS South Rae 1:250,000-scale bedrock mapping project is improving understanding of the evolution, economic potential and role of this region in assembly of the Canadian Shield.

Field work in 2016 was focused in NTS 75G and the western half of 75H and covered over 17,500 km<sup>2</sup> of previously unmapped ground. This mapping provides insights on six new, informally-named, geophysically and isotopically defined domains, each with a distinct record of magmatic and tectono-metamorphic events and metallogenic potential. The domains have boundaries that strike roughly northeast-southwest and are described from southeast to northwest. The Firedrake domain comprises ca. 2.66 Ga felsic to intermediate orthogneiss, mafic to ultramafic rocks and rare paragneiss, all

injected by widespread migmatitic granitoids. This domain shows evidence for early 1.89 Ga granulite metamorphism at 8-11 kbar and subsequent decompression to 4-6 kbar amphibolite conditions around 1.84 to 1.80 Ga. The McCann domain consists mainly of biotite +/-garnet +/- orthopyroxene tonalite, granodiorite and granite, with sparse mafic-ultramafic rocks, paragneiss and iron formation enclaves, cut by ca. 2.15 Ga Orpheous gabbro dykes. It records the medium pressure and high temperature Arrowsmith orogeny at ca. 2.45-2.32 Ga and ca. 1.88 Ga metamorphism at minimum 8 kbar. The Penylan domain includes hornblende-clinopyroxene +/- garnet anorthositic gabbro, massive to variably foliated monzogranite and quartz diorite which all yield crystallization ages between 2.03-2.05 Ga. The anorthosite-gabbro complex is much larger than previously mapped extending over 100 km northeast-southwest. The Howard Lake domain is defined by an intense magnetic low and includes distinct rocks such as andalusite-bearing wacke, muscovite schist, biotite schist, and calc-silicate, as well as foliated to gneiss granodiorite, anorthositic orthopyroxene gabbro, and granite. Preliminary synthesis suggests the newly mapped surpracrustal rocks are a continuation of the sequence that hosts the Boomerang U deposit to the north. The Lynx Lake domain is comprised of granodiorite to tonalite with abundant enclaves of surpracrustal origin, including basaltic schist, plagioclase-phyric andesite, sillimanite-garnet-biotite paragneiss and iron formation. The Porter domain consists mainly of hornblende-biotite and orthopyroxene-clinopyroxene bearing granodiorite with gabbroic enclaves and dykes. Broad zones of cataclastic and brittle-ductile greenschist-facies deformation and associated chlorite-hematite-epidote alteration are widespread.

The boundaries between the various domains are generally characterized by ductile high strain and appear to be the locus of multiple movements.

Preliminary mapping suggests a widely distributed alkali magmatic event along the Firedrake-McCann boundary where some newly mapped syenite bodies exhibit a similar mineralization style to that responsible for Hoidas deposit (REE, U and Au) in northern Saskatchewan. Various young and poorly constrained (2.20-1.74 Ga?) clastic sequences have been mapped and may be correlative with the Nonacho, Amer and Wharton groups. The presence of Proterozoic Nonacho Group sedimentary rocks unconformably overlying the Porter domain highlights the potential for U and Au deposits in this poorly explored area of the NWT.

## **SURFICIAL GEOLOGY STUDIES ACROSS THE KEEWATIN ICE DIVIDE, TEHERY-WAGER GEOSCIENCE PROJECT AREA, NUNAVUT**

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Targeted surficial geology studies as well as glacial and stream sediment sampling continued during the summer of 2016 in the central and western parts of the Tehery-Wager GEM-2 Rae Project area, mainland Nunavut. This work provided an opportunity



to gather data on the nature, distribution, and patterns of surficial sediments and landforms, chronology of potential relict weathered terrain, and changes in ice flow trends during the last glaciation and ice retreat phases. Till, stream sediment and water samples were collected for provenance and evaluation of mineral potential.

The uplands south of Wager Bay and Brown Lake, which coincide with the Keewatin Ice Divide (KID) zone, are dominated by a mixture of till blankets and veneers, bouldery till with orthogonal, giant ice-wedge polygons, weathered bedrock, and felsenmeer. The ice divide zone itself is relatively narrow and characterized by either the absence of ice-flow indicators or the presence of opposing ice-flow directions. South of the divide, the predominant regional trend of streamlined till features indicates ice flow to the SE and ESE, parallel to main striation directions. Late SSE striae, parallel to a later, more SSE esker trend, locally cross-cut the predominant streamlined terrain. Along the southwestern shores of Wager Bay, early northward and late ice flows into the bay are observed in the landform and striation record as far east as Masivak Creek and suggest that the KID lay in a narrow zone inland southwest of the bay and then continued into Wager Bay. A complex system of sub-glacial meltwater corridors and proglacial meltwater channels are interspersed between the streamlined, thin and thick till that extend outward from the KID. North of the KID, very few eskers are present and meltwater corridors are absent. The post-glacial limit of marine inundation increases from ~118 m asl south of Wager Bay to 140 m west of Roes Welcome Sound and stays relatively constant at 140-150 m towards Tehery Lake. At the marine limit, erosion and reworking of glacial sediments

have formed bouldery beaches, wave-washed surfaces, terraces, glaciomarine deltas, and wave-cut notches in till. Below the marine limit, silty sandy marine veneers and blankets are scattered in low areas; bouldery beaches skirt some esker ridges or fill in embayments between bedrock outcrops along the coastal areas.

Till samples were collected at 40 sites to provide more detail on geochemical anomalies identified in 2015 and along two 200 km-long transects roughly parallel to ice-flow and across the KID to characterize the regional glacial transport. Vertical profile samples in frost boils were collected at two selected sites above and below the marine limit to evaluate the effects of marine reworking on till texture and geochemical composition. Stream sediment and water samples were collected at 67 sites, predominantly from the headwaters of the Lorillard River, as well as along a transect across a Paleoproterozoic supracrustal package with several gossanous horizons in the western part of the study area. Preliminary results from the till and stream surveys will be presented as they have implications for mineral exploration.

## **GEOCHEMICAL BASELINES AND METAL(LOID) MOBILITY IN A CHANGING NORTHERN CLIMATE**

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Geochemical baselines provide guidance for mineral exploration and facilitate the development of remediation objectives upon mine site closure. Presently, most environmental assessments and mine site remediation projects rely on national environmental quality guidelines based on Canada-wide average metal(loid) concentrations in soils, sediments, and surface waters (e.g., Canadian Council of the Ministers of the Environment Interim Sediment Quality Guidelines). Within naturally mineralized regions, however, the naturally occurring concentrations of metal(loid)s often exceed these national baseline values. Metal(loid) concentrations in lacustrine systems reflect local variations in the concentration of elements in the environment and are influenced by many variables, including the underlying bedrock composition, the degree of weathering, and biological processes. In northern regions, accelerated climate change has also been shown to impact the mobility of certain metal(loid)s, such as mercury, and influence lacustrine geochemical baselines in sub-arctic regions. However, the influence of climate change on the mobility of other

elements that are naturally enriched in sub-arctic mineralized regions (e.g. arsenic, antimony, zinc) is not well established. This study examines the mobility of arsenic near a former gold mine in the Slave Geological Province, NWT, and the effects of Holocene climate variation on the baseline values and speciation of arsenic in local lake sediments.

## **GEOPHYSICAL DATA PROJECTS 2016-2017**

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The Northwest Territories Geological Survey holds a large collection of industry and government geophysical data. New high-quality geophysical data are being acquired by NTGS over areas for which such data have been lacking. Industry continues to submit new data to the collection in accordance with the NWT Mining Regulations. However, while the NTGS's online data access systems are being upgraded, there is no single place where clients can discover what exists in this collection. Therefore, all the aeromagnetic data available for the NWT has been summarized in an ArcGIS project, which will be available by mid-November (NWT Open Report 2016-XX). Shapefiles show the footprints of all aeromagnetic surveys in the NWT conducted by federal and territorial governments and by industry. Survey metadata include the year of collection, line spacing, survey platform and height, and a reference to download the survey data.

The geophysical data submitted by industry in assessment reports is being checked for errors, and enhanced by the addition of new interpretive grids such as vertical

derivatives, analytical signal and magnetic susceptibility. Industry-standard geosoft formats are used, and in addition, new and original grids have been converted into georeferenced tiff images for the user's convenience. This project is ongoing.

Early in 2016 NTGS conducted a high-sensitivity aeromagnetic survey over the Chan Lake area, approximately 110 km west of Yellowknife (NWT Open File 2016-03). NTGS has performed a geophysical interpretation (NWT Open File 2016-07) whose objective was the identification and mapping of structures that might be related to mineralization as well as the definition of targets for future follow-up. A number of computer-based methods were used, namely Keating correlation coefficients, Euler deconvolution, and source parameter imaging techniques.

Two types of geophysical survey were carried out for the Slave Province Surficial Materials and Permafrost Study. The main objective of both surveys was to detect the top of the bedrock beneath overburden, to aid future exploration for kimberlite. The test area is located approximately 25 km SE of Lac de Gras. A capacitively-coupled resistivity (CCR) survey was performed with 5m dipole length and ground penetrating radar (GPR) survey was performed with a 50 MHz RTA antenna. In the area tested, the CCR data provides more reliable results around lakes (water) and near-surface frozen material, whereas the GPR data does a better job of imaging changes in lithology, has greater depth of penetration, and is more useful in areas where the top of the bedrock is too deep for the CCR method. A combination of the two methods works best to provide greatest confidence in the interpretation of overburden thickness.

## UPPER JURASSIC-LOWER CRETACEOUS PALYNOSTRATIGRAPHY IN THE AKLAVIK RANGE, NORTHWEST TERRITORIES

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The Mackenzie Delta area of northern Canada has been a focal point for petroleum exploration since the discovery of hydrocarbons in the 1950's. Understanding the subsurface stratigraphy and relationships between various rock formations of this area will contribute to accurately estimating and evaluating hydrocarbon resources. In this study, we are particularly interested in Upper Jurassic-Lower Cretaceous strata that have potential as petroleum source rocks. However, regional correlation of these Mesozoic rocks using detailed chronostratigraphy is limited by the undefined age of the Jurassic-Cretaceous boundary. The Jurassic-Cretaceous boundary is difficult to define for many reasons; they include: i) a lack of a significant change in fauna and flora across the lower boundary of the Berriasian Stage; ii) biogeographical provincialism of Tethyan and Boreal biota; and iii) the paucity of index fossils, such as ammonites and bivalves, in high-latitude regions. Palynological analyses can be used to improve biostratigraphy in these rocks as highly resistant palynomorphs, such as spores and pollen, are widespread and abundant, allowing for a relatively accurate reconstruction of the Boreal paleoenvironment and improved

chronostratigraphy. We use quantitative and statistical palynological analyses to observe changes in the palynological signature across the Jurassic-Cretaceous boundary.

Palynological samples were collected in two localities in the Aklavik Range of the northern Richardson Mountains, Northwest Territories; this is a major area from which most of our knowledge of Jurassic-Lower Cretaceous geology is based. This study is primarily focused on the Husky Formation and its four members; in descending order, they are the Upper, Red-Weathering, Arenaceous, and Lower members. The Husky Formation, predominantly composed of dark-coloured shales and siltstones, is thought to encompass the Jurassic-Cretaceous boundary at, or near, the contact between its Red-weathering and Arenaceous members. This is inferred from the presence of *Buchia okensis*, a bivalve considered diagnostic of the basal Cretaceous, within the first few meters above the contact between the Red-weathering and Arenaceous members.

This research project aims to provide insight on the paleoenvironments represented by Upper Jurassic-Lower Cretaceous strata in high-latitude regions by using quantitative and statistical analyses of palynoassemblages, create new knowledge on terrestrial paleoecology and its dynamics in high-latitude Jurassic-Cretaceous ecosystems, and improve regional correlation of Mesozoic strata in the Mackenzie Delta area. In support of the Geo-Mapping for Energy and Minerals (GEM) Mackenzie Project, the research is expected to expand on the stratigraphic and depositional history of northern Canada, and the tectonic evolution of Mesozoic source rocks. This work will also be in support of the International Commission of Stratigraphy – Berriasian Working Group to

help define the Jurassic-Cretaceous boundary.

## **THE INFLUENCE OF FOREST FIRES ON METAL LOADING TO NORTHERN LAKES**

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In recent years, intense and extended wildfires affected the North Slave Region and the impacts to water quality of surrounding freshwater systems are unclear. Wildfires may remobilize heavy metals previously accumulated in plant biomass and in soils, and deposit a portion of these metals in freshwater systems. Remobilisation can occur via the volatilisation of mercury to gaseous form or the transport of metals by ash fall, or on a longer time scale by increasing the drainage of metals from catchments.

In the summer of 2016, lake sediment cores were collected from 10 lakes in the North Slave region along a gradient of recent wildfire exposure to evaluate the co-

variability of charcoal deposition (a proxy for historical wildfire events) and metal loading over the last few centuries. Eight peat cores were also collected near the sample lakes, which provide a purely atmospheric signal of metal deposition from forest fires. Preliminary results indicate increased charcoal in the upper portions of a sediment core, suggesting greater wildfire activity in recent times compared to the historical record. Radioisotope dating and metal analyses of the sediment records are currently underway.

Measurements of total mercury and other metal concentrations in the sediment cores, along with the charcoal history will allow us to evaluate if forest fires have been a significant source of metal loading to lakes in the North Slave region. We will also examine the influence of wildfire on lake mercury deposition in relation to distance from the fire and compare the relative impact of direct deposition versus subsequent catchment erosion on mercury deposition following a fire. This research will provide important new insights into the role of wildfire on metal accumulation in northern lakes, information that is essential for the adaptation of northern communities to global climate change.

## **THE EFFECTS OF MINERALOGICAL COMPOSITION AND TEXTURE ON INDUCED POLARIZATION (IP) EFFECTS IN GOLD- BEARING ROCKS FROM THE HERBERT-BRENT GOLD SHOWING, YELLOWKNIFE GREENSTONE BELT**

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In June 2015, geological mapping discovered significant concentrations of gold in Hebert-Brent (HB) situated within an 11 m-wide highly sulphidized sericite-ankerite schist shear zone, hosted in a 10-15 m-wide, quartz-feldspar porphyry. On July 29<sup>th</sup>, 2016, two 400 m long IP/resistivity survey lines, with 5/10 m electrode spacing using a multi gradient array, were completed over TerraX Minerals Inc. HB gold showing. The HB gold showing is located within the Barney Deformation Corridor of the Yellowknife Greenstone Belt (YGB), Northwest Territories. Thirty-three samples were collected from all the mineralized and non-mineralized rock types from across the main mineralized gold zone at 0.45 m increments using a rock saw.

The methodology for determining the resistivity and chargeability values for each sample will involve use of a two-electrode lab apparatus capable of measuring voltage drops produced by applying small, controlled currents across samples with constant cross-sectional area. The apparatus will measure:

**PORPHYRY OR  
PYROCLASTIC? A  
PETROGRAPHIC COMPARISON  
OF LITHOLOGIES FROM THE  
HEBERT-BRENT SHOWING IN  
THE YELLOWKNIFE  
GREENSTONE BELT, NWT**

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The Yellowknife Greenstone Belt (YGB) is located within the western part of the Archean Slave craton, Northwest Territories, Canada. This study is focused on the local geology of the Hebert-Brent gold showing, which is part of the Barney Deformation Corridor. The showing consists of replacement-style gold mineralization hosted in massive to pillowed, bleached mafic volcanic flows that are intruded by variably altered feldspar-quartz and quartz-feldspar porphyries. Due to the complicated metamorphic and deformation history of the YGB, questions remain as to the origin of these units. To shed some light on these porphyries, eight drill core samples were examined petrographically.

Transmitted and reflected light petrography was used in conjunction with micro-X-Ray Fluorescence to characterize the overall mineralogy, alteration and textural variations of each thin section. The original description of the eight porphyry samples had seven identified as feldspar-quartz porphyries and one as a quartz-feldspar porphyry. The overall mineralogy consists of phenocrysts of quartz, minor relict amphibole and sericitized twinned plagioclase set in a crypto- to

- 1) IP effect in the frequency domain, by measuring resistivity as a function of frequency; and
- 2) IP effect in the time domain, by determining chargeability from the voltage decay that follows a step change in current across each sample.

In addition, reflected light petrography and microXRF EDS mapping will be used for point analysis of polished thin sections in order to identify:

- 1) All various mineral phases and their textural variations
- 2) Any significant non-sulphide IP sources
- 3) The dependence of IP effects on sulphide type, concentration, texture, grain shape and grain size

The results of the resistivity and chargeability analyses will be used to assist with interpretation of the IP/resistivity pseudo-sections and to define lithological and mineralized units associated with the HB gold mineralization.

The main goal of this study is to define and compare the chargeability and resistivity signatures of gold mineralized, non-mineralized sulphide-bearing zones and non-sulphide bearing zones. This will help determine the viability of using induced polarization and resistivity as an exploration method for HB style gold mineralization in the YGB.

microcrystalline groundmass of muscovite, quartz, calcite, pyrite, and Ti-oxides; samples are variably mineralized with arsenopyrite, chalcopyrite, and sphalerite. The samples were all evaluated for possible plutonic or pyroclastic textures to indicate the origin of the porphyries. Recrystallization textures were most often observed, including muscovite pseudomorphed after prismatic feldspar, quartz subgrain development along quartz grain boundaries, and quartz with undulose extinction. Variably sized (fine to coarse) spherical and amoeboid-shaped quartz grains, typically with embayed and scalloped margins, were found in most samples, as well as broken/dislocated quartz grains. It is possible that these textures represent fragmentation of the quartz grains due to changes in pressure; gases that became trapped during one level of emplacement may have burst during a decompression event. Of particular interest were the spherulites observed in one feldspar-quartz porphyry sample, a devitrification texture that is indicative of a volcanic rather than plutonic origin. The microanalytical techniques and textural observations will hopefully clarify the discussion regarding the various porphyries at the Hebert-Brent showing. The focus of this study was mineral and textural identification, although limited at this stage due to the microcrystalline nature of the groundmass/matrix. Future work will be aimed at identifying growth patterns in quartz phenocrysts and the identification of very fine-grained silicates, sulfides and oxides that were observed.

## **MICRON TO MINE: SYNCHROTRON SCIENCE FOR MINERAL EXPLORATION, PRODUCTION, AND REMEDATION**

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Synchrotron science for mineral exploration, production, and remediation studies is a novel niche presently under-utilized. Synchrotron light for micron-scale analysis is a powerful tool that provides industry with relevant geochemical information. Synchrotron micro X-ray fluorescence (SR- $\mu$ XRF) offers a direct, high-resolution, rapid, and cost-effective chemical analysis while preserving the context of the sample by mapping ore minerals with ppm detection limits. Speciation of trace and deleterious elements can then be probed using X-ray absorption near-edge structure (XANES) spectroscopy.

Large-scale (tens of cm)  $\mu$ XRF mapping and XANES analysis of samples collected at various locations in the Yellowknife Greenstone Belt from the Geological Survey of Canada Yellowknife EXTECH collection, including the historic Con and Giant mines, has been undertaken to address questions regarding mineralization history to develop novel trace element exploration vectors. This information provides integral insights into trace element associations with ore minerals, local redox conditions responsible for mineralization, and mineralizing mechanisms.

Gold is commonly intimately associated with sulphide mineralization (e.g., pyrite, arsenopyrite, sphalerite, galena, etc.) and is present both as inclusions and filling fractures in sulphide grains. Gold may also occur as nanoparticles and/or in the sulphide mineral crystal lattice, known as “invisible gold”. Understanding the nature and distribution of invisible gold in ore is integral to processing efficiency. Lattice bound refractory gold cannot be liberated by conventional cyanide and carbon absorption processes, and can exist in concentrations up to the weight percent level in arsenian pyrites. The high flux and energy of a synchrotron light source allows for the detection of invisible gold by  $\mu$ XRF, and can probe its nature (metallic Au<sup>0</sup> vs. lattice bound Au<sup>1+</sup>) using XANES spectroscopy.

The long-term containment and management of arsenic is necessary to protect the health of both humans and the environment. Understanding the relationship of arsenic mineralization to gold deposits in the YGB can lead to more sophisticated planning for mineral processing and the eventual storage of gangue materials.  $\mu$ XANES spectroscopy is an excellent tool for determining arsenic speciation within the context of the sample. Mineral phases such as arsenopyrite, scorodite, and arsenic trioxide can be accurately identified as well as relative amounts determined. With this information the oxidation-reduction of arsenic-bearing compounds can be monitored to optimize management practices for the long-term capture of arsenic contaminants.



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