Yukon Geological Survey 2022 overview

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Yukon Geological Survey

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Introduction

Yukon Geological Survey (YGS) had a busy year in 2022. Travel restrictions related to the pandemic were gradually lifted, enabling staff to attend conferences and allowing southern-based researchers to return to Yukon for fieldwork. While COVID did not hinder field activities, wildfires and flooding did affect access to some parts of the territory. The Yukon saw an unusual number of landslides over the spring and summer, and YGS invested significant resources assessing the slides and documenting the factors that caused them. This focus on geohazards is expected to continue into future years and be a "growth area" for the Survey.

This overview provides a summary of research highlights for 2022. Many of the projects described here are presented in more detail in the Yukon Exploration and Geology technical papers that are released with this Overview volume. Two highlights from 2022 are worth noting this year. First, 2022 marks the 30th anniversary of YGS. Since its creation, the Survey has grown and evolved into a multi-disciplinary organization that provides expertise across a range of disciplines (bedrock geology, regional tectonics, glacial history, geohazards and metallogeny) and excels at geoscience education and information management. The second noteworthy event to point out was the discovery of a mummified baby woolly mammoth (Nun Cho Ga) in June on Upper Eureka Creek. Two Survey staff had the privilege of assisting with the recovery of the mammoth and participating in the Tr'ondëk Hwëch'in First Nation ceremony that marked this scientifically and culturally important discovery. Jeff Bond subsequently mapped the discovery site in detail, documenting the conditions that led to the remarkable preservation of Nun Cho Ga.

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Snapshot of YGS

There were several staff changes in 2022, including the retirements of Derek Torgerson and Lara Lewis (both with the Minerals Geology unit). Tiffani Fraser (Bedrock Geology) accepted a permanent position with the department's Geothermal and Petroleum Resources Branch, where she will be leading the development of a Yukon Geothermal Resources Act, and Olwyn Bruce (Technical Services unit) joined Yukon's Information and Communications Technology Branch as their Enterprise Geomatics Manager. I would like to take this opportunity to thank all four of them for their long service to YGS and wish them the best in their current endeavors.

As well as these permanent departures, YGS has two staff away on a temporary basis. Kristy Kennedy took a year's leave to work for the Kluane First Nation as their Natural Resources Manager, and as of mid-December 2022, Diane Skipton began a year's maternity leave.

Yury Klyukin and Sarah Ellis joined the Minerals Geology unit this year, back-filling the two vacant Economic Geologist positions, and Chad Cote joined the Technical Services unit as a Geological and Spatial Database Administrator.

YGS' organizational chart is shown in Figure 1.

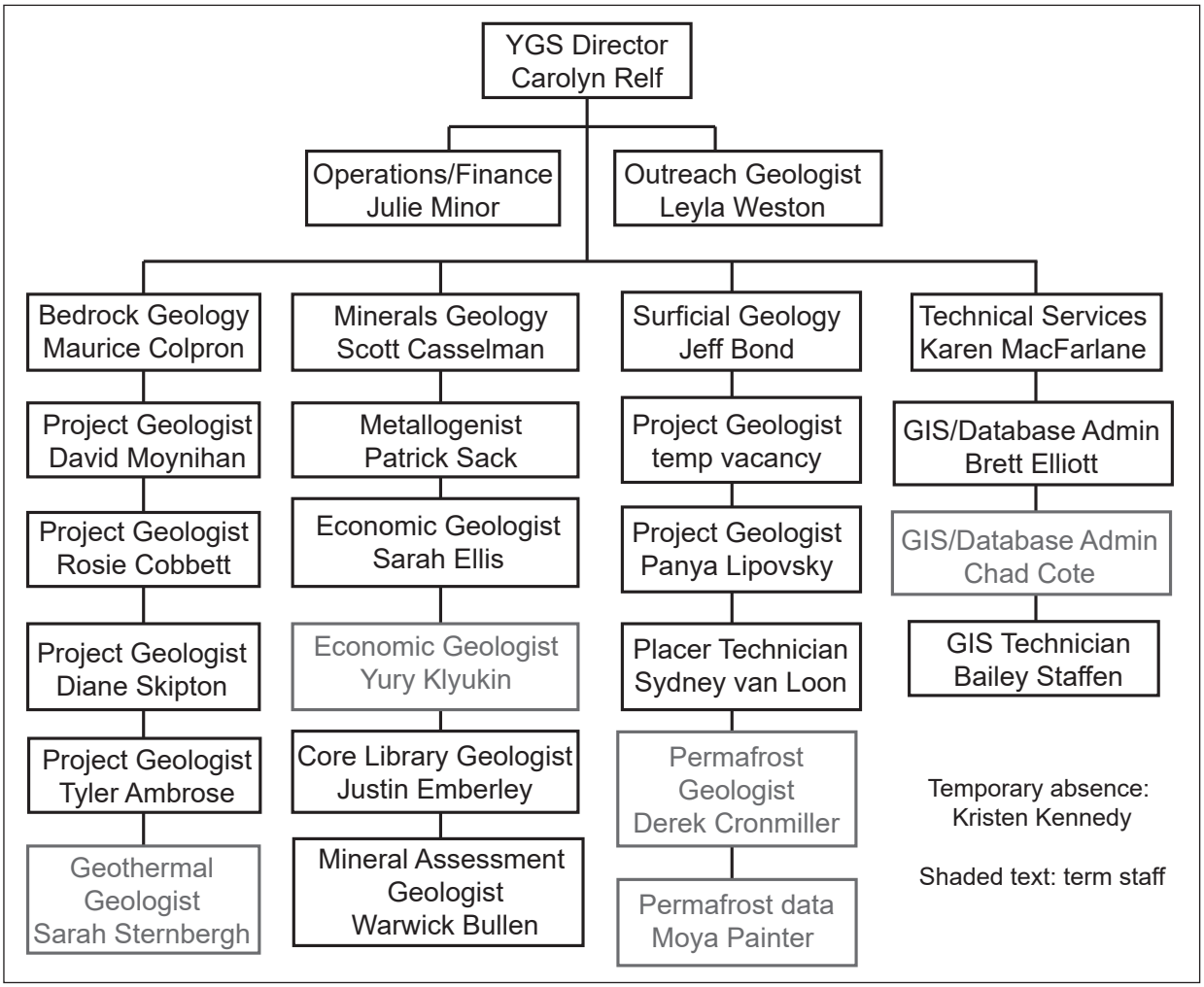

Figure 1. *Yukon Geological Survey organizational chart.*

YGS budget

YGS's operational budget for 2022–23 totalled $4 430 000, broken down as follows:

- $1 365 000 O&M, to cover office/administrative costs and project activities;
- $320 000 of federal money committed by Canada to support climate change initiatives in Yukon. This is to support mitigation of landslide hazards in Dawson City (see below);
- $270 000 from Yukon government to support "Our Clean Future" initiatives led by YGS: specifically, geothermal studies, permafrost hazards assessments in communities and along highways, and documenting changes in glaciers;
- $955 000 from NRCan's Emerging Renewable Power Program to support geothermal studies;
- $87 000 from Crown-Indigenous Relations and Northern Affairs Canada to install permafrost monitoring boreholes; and
- $1 433 000 for the Yukon Mineral Exploration Program (of which $1.4M are allocated to fund projects under the program).

In addition to the funds noted above, the Geological Survey of Canada (GSC) has committed $500 000 over two years to support a regional magnetotelluric survey along Yukon's highway corridors, as part of the geothermal research program (described below). The funding is part of their Geo-Mapping for Energy and Minerals (GEM) – GeoNorth Program.

Bedrock studies

YGS carried out three regional bedrock mapping projects and three thematic bedrock studies in 2022. Project highlights are summarized below and locations are shown in Figure 2. A fourth thematic project (at Volcano Mountain) is described below in the Outreach section of this paper.

Teslin map area

David Moynihan continued mapping Yukon-Tanana terrane rocks in the northwestern Teslin area, extending previous coverage southeastward to the South Canol Road (Fig. 2). 2022 marked his third year on this project. Fieldwork revealed that Mississippian metatonalite of the Simpson Range suite underlies much of the Mount Grant area. The metatonalite has been thrusted over a package of rocks that includes metachert and siliceous argillite (lowest exposed interval), quartzite and chlorite/muscovite schist (intermediate interval), and marble/calc-silicate rocks (upper interval; Fig. 3). Moynihan (2023) has proposed the term Evelyn Creek succession for this package of rocks.

A distinctive mauve-coloured metachert unit was identified northeast of the Mount Grant area. The unit, which has not been previously documented in this area, is tentatively correlated with the Old Highway Metachert found near the British Columbia–Yukon border. The metachert defines a distinct time-stratigraphic marker and may provide evidence for VMS-type hydrothermal activity.

The eastern-most part of the map area preserves low pressure/high temperature metamorphic assemblages in deformed country rock, intruded by mid(?)-Cretaceous plutons. The plutons are both foliated and crosscut foliation, suggesting their emplacement overlapped with metamorphism and deformation. For details of this summer's mapping, see Moynihan (2023).

Study of Paleozoic volcanic rocks

Rosie Cobbett completed a final year mapping and correlating volcanic rocks across lower Paleozoic continental margin strata in central Yukon and western NWT. Fieldwork focused on resolving outstanding questions from previous seasons' work. Based on field relationships, Cobbett has subdivided the Bouvette Formation into lower (interpreted as Cambrian to late Ordovician strata) and upper (Silurian to Devonian) members separated by volcanic and clastic rocks in the Castle Mountain area. Microfossil analysis is underway to refine the inferred age limits of the new members. In the Hart River area, a facies change was observed between "typical" upper Bouvette Formation (thick-bedded dolostone) and a recessive silty limestone and rudstone unit. The unit, previously mapped as Gossage Formation, contains shelly fossils not previously recognized in this part of the Cordillera (Blodgett, unpublished data).

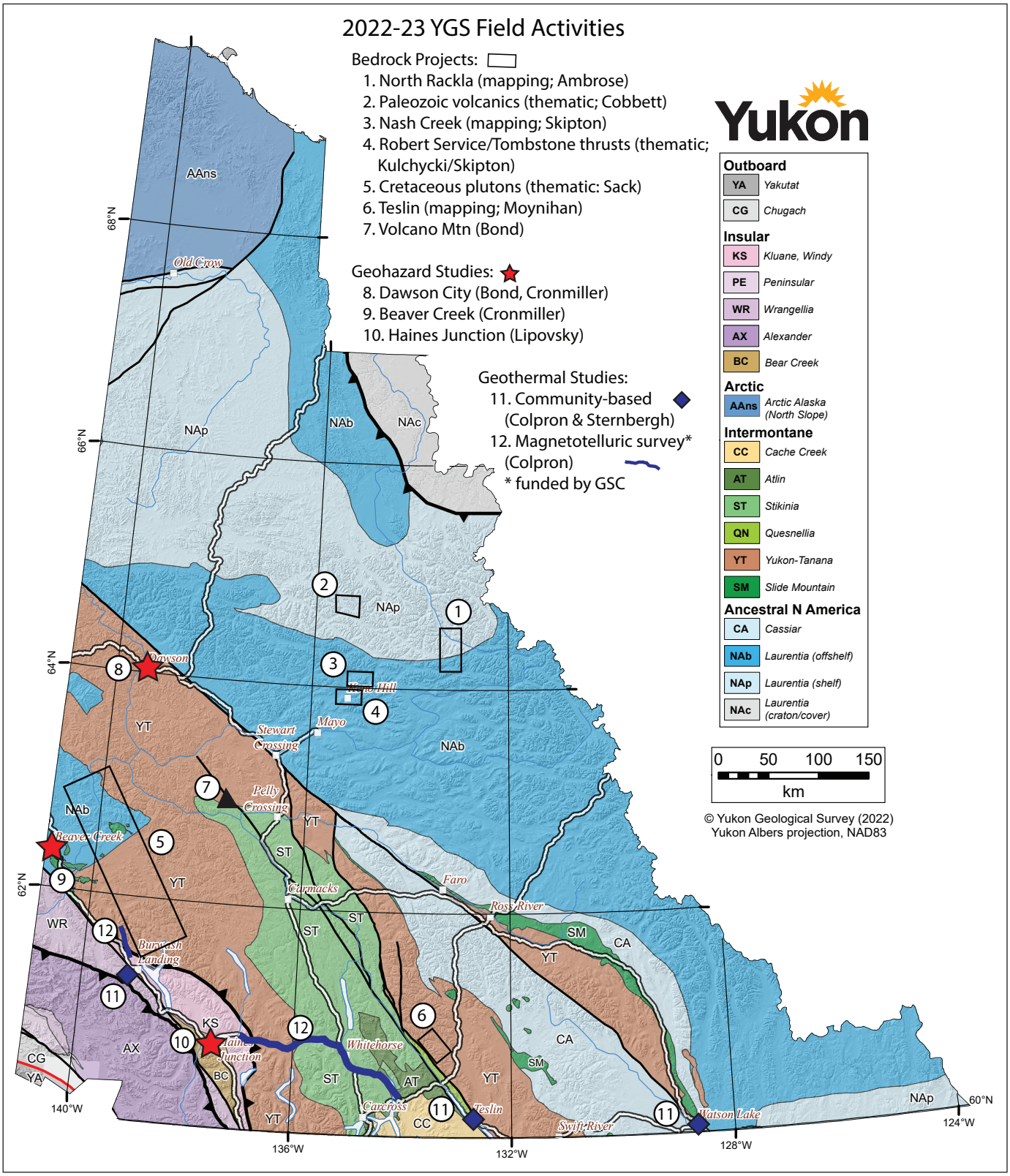

Figure 2. *Map showing locations of YGS' 2022 field activities.*

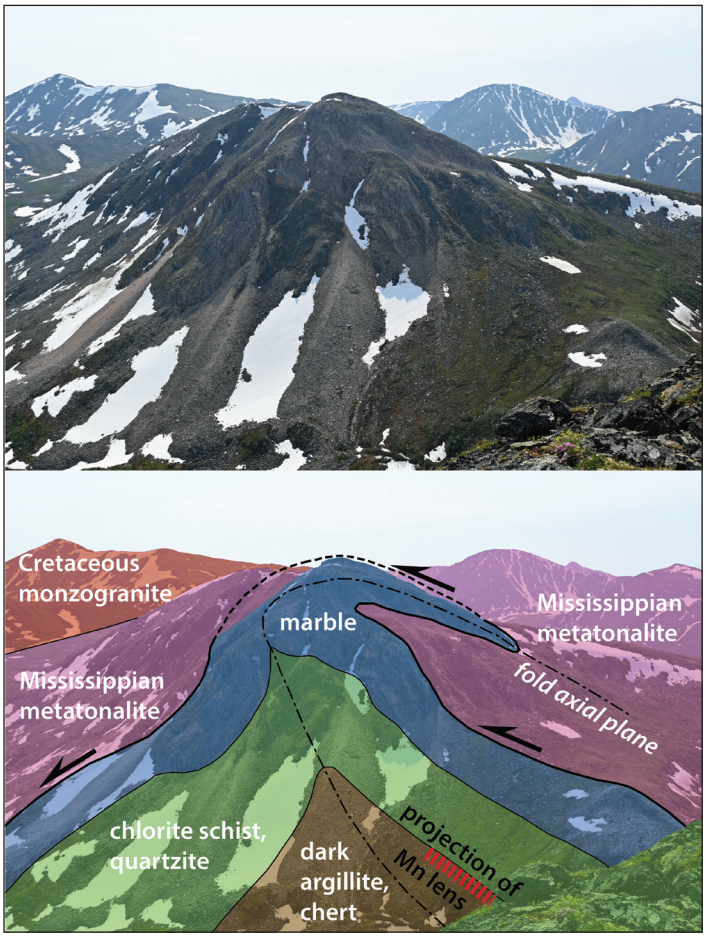

Figure 3. *View looking south at folded thrust fault near Evelyn Creek. Rocks of the Evelyn Creek succession are exposed in the footwall; hanging wall rocks are Mississippian metatonalite of the Simpson Range suite. All units are cut by Cretaceous granite (distant part of photo).*

Cobbett also documented a change in structural style across the study region, from flat-lying, openly-folded strata near Castle Mountain to tightly upright-folded rocks north of Hart River. More information on the geology of the Castle Mountain and McKay Hill areas is available in a recently-released Open File (Cobbett, 2022).

Late Cretaceous pluton metallogeny

Patrick Sack continued studies of late Cretaceous pluton metallogeny, though he had a shortened field season in 2022. He collected about a dozen samples along a transect in western Yukon north of Beaver Creek (Fig. 2), and has submitted them for whole-rock, isotope and geochronological analyses. This project links to the porphyry predictive mapping work done by Warwick Bullen (Bullen, 2021a), testing the veracity of the modelled prospectivity of plutons and providing further geochemical data to constrain the model.

Nash Creek map area

Diane Skipton continued investigations into the tectonic evolution of the southern Nash Creek area. This multi-disciplinary study integrates field mapping with geochronology and thermochronology. Collaborators include Alfredo Camacho (University of Manitoba), Jim Crowley (Boise State University), Kyle Larson (University of British Columbia-Okanagan) and Dawn Kellett (GSC). Unfortunately, extensive forest fires prevented access to the map area in July; however, Skipton did manage to get into the field area for two weeks in August, where she was able to advance mapping in the Davidson Range north of Keno (Fig. 2). As noted above, Skipton began maternity leave in December; she will be resuming work on this project in January 2024.

Robert Service and Tombstone thrusts

Skipton also spent time in the field with her graduate student Anya Kulchycki, whose MSc thesis focuses on documenting kinematics and timing of displacement of the Robert Service and Tombstone thrust faults in the Keno mining district. The project, co-supervised by Skipton and Larson, will integrate field data with microstructural and thermochronological methods to constrain the timing of ductile deformation.

North Rackla map area

Tyler Ambrose's field plan for 2022 was to wrap up his North Rackla project by extending map coverage to the base of the Windermere Supergroup. However, like Skipton, Ambrose's field season was shortened by factors beyond his control. Over the summer, he was able to complete three fly camps before he returned to Whitehorse (Fig. 2). In spite of a shortened season, he mapped a significant area, and he anticipates being able to complete map coverage with a week's fieldwork in 2023. Ambrose will focus on compiling his map and begin drafting the accompanying report over the winter.

Geothermal studies

YGS continued studies to characterize geothermal potential along the Denali, Tintina and Teslin faults in 2022. The study areas are located close to nearby communities (Burwash Landing, Watson Lake, Teslin and Haines Junction) and the affected First Nations are partnering on the projects. In addition to work near communities, regional geophysical data collection continued; this work is intended to image crustal features at a regional scale.

Funding for the geothermal studies described here was sourced primarily from NRCan (Emerging Renewable Power Program) and Yukon government (Our Clean Future). Additional contributions to individual projects are noted below. A number of contractors and researchers from universities and the Geological Survey of Canada are involved in different aspects of the geothermal studies described below. Their contributions are also noted below.

Burwash Landing

A number of field studies were carried out on the Denali fault system in the Burwash Landing area over the summer; collectively, they will support a better understanding of deformation and fault kinematics. Building on data collected in 2021 (Finley et *al.*, 2022), researchers from the University of Victoria continued acquisition of drone lidar data across the fault and collected kinematic information from outcrops. The group from Institut national de la recherche scientifique (INRS) collected outcrop data on fractures in the Duke River area that will provide a regional framework for analysis of fractures in core from drilling planned for 2023 (Chapman et *al.*, 2023). The fracture data from outcrop and core will help to characterize permeability in the region. Colpron joined colleagues from the United States Geological Survey (USGS) to examine exposures of the Denali fault and collect structural data to complement the kinematic analysis documented in an upcoming paper by J.S. Caine and colleagues. Colpron also visited outcrops north of Kluane Lake to collect samples of Kluane schist for physical rock property analysis; these data will help to better constrain interpretations of subsurface geology northeast of the Denali fault in geophysical models. Finally, YGS and GSC geologists installed shallow temperature loggers at more than 100 sites in the Duke River area. These instruments will collect near-surface temperature data for a year and will be retrieved in 2023.

Plans to drill a deep temperature gradient well near Duke River starting in spring 2022 were thwarted when YGS failed to find a qualified bidder to do the drilling. Over the summer, Colpron and Sarah Sternbergh amended the drill plan, splitting it into two phases. Phase 1 called for an eight-inch diameter well cased into bedrock, and Phase 2 called for a diamond drill to start at the bottom of the cased well and recover core to whatever depth could be achieved with available funds. Notional depths of 300 m for Phase 1 (based on an estimate of 200 m of overburden) and ~800 m for Phase 2 were targeted, recognizing that depth to bedrock was poorly constrained, and escalating fuel costs would significantly influence the final depth of the well.

Phase 1 drilling was completed in the fall, with Phase 2 planning and implementation to follow in 2023. Midnight Sun Drilling carried out the Phase 1 drilling using an RC rig, and Kluane Community Development Limited Partnership was contracted to provide drilling support services (e.g., provision of fuel, accommodation, road maintenance, etc.) The drill encountered bedrock at 49 m depth, and drilled a further 172 m into bedrock before casing and cementing the well to a depth of 221 m. A distributed temperature sensing fibre optic cable has been installed and temperature data will be collected at some point in 2023. Planning for Phase 2 will get underway shortly.

At the same time that work was underway to initiate drilling, geophysical data sets were interpreted to help characterize subsurface geology in the drill target area. Colpron worked with GSC colleagues Victoria Tschirhart and Jim Craven to interpret the magnetotelluric and EM data sets that were collected in 2020 and 2021 around the Duke River site (Tschirhart et *al.*, 2022). Their model confirmed the releasing bend previously interpreted along the Denali fault (Witter, 2020) and an associated conductor that could reflect a fluid pathway.

To complement the broadband seismographs deployed in 2020 in the Duke River area, two arrays of geophones

were deployed for a month along Duke River and Burwash Creek by researchers at the University of Calgary in fall 2022 (Fig. 4). Following retrieval of the geophones, a distributed acoustic sensing fiber optic cable was laid out across the Denali fault at Burwash Creek and connected to a seismic interrogator that will be collecting data until spring 2023. The intent of both the geophone arrays and the fibre optic cable is to collect data that could provide more detailed information about near-surface structures around the Denali fault and in the geothermal drill target area. Initial data from the broadband stations and geophones are being processed this winter.

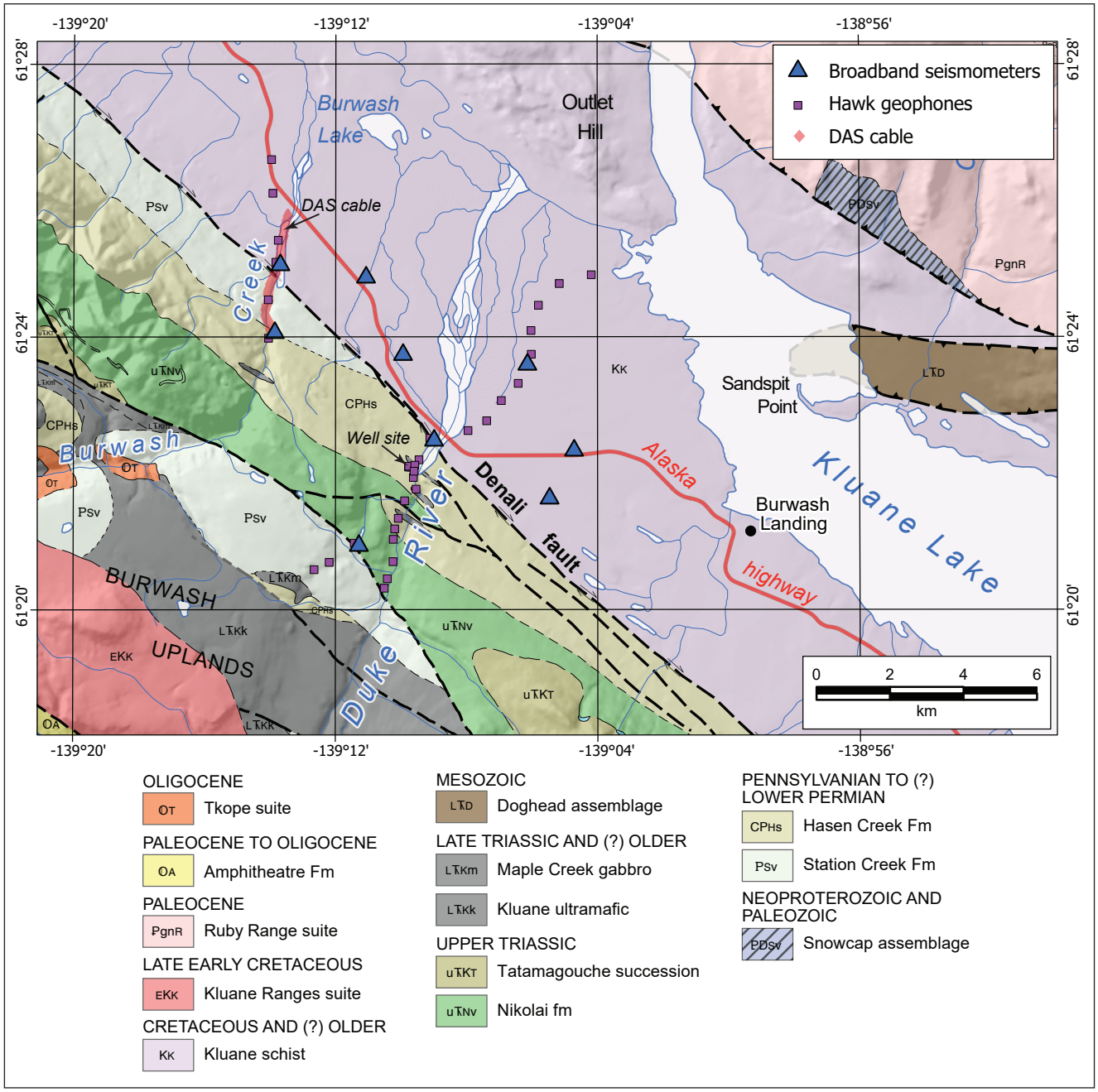

Figure 4. *Geological map of the Duke River area showing locations of seismic instruments (broadband seismometers, geophones and distributed acoustic sensing fiber optic cable) deployed by University of Calgary researchers. Location of the temperature gradient well site along the Duke River is also shown. Geology extracted from Yukon Geological Survey (2022a).*

Watson Lake

In the Watson Lake area, new gravity (Aurora Geosciences Ltd.), magnetotelluric (University of Alberta) and lidar (University of Victoria) data were integrated with geology and magnetics by Innovate Geothermal to generate a model of the subsurface geology across the study area. Collaborators on the Watson Lake project (YGS, GSC, University of Alberta, and Liard First Nation representatives) met in Edmonton in September to discuss the results of the project and consider next steps. The final report, (Witter, 2022) presents a model of the shallow crustal structure across the Tintina fault zone and highlights testable uncertainties about the geothermal potential of the area. At the time of writing, Liard First Nation is considering whether to pursue funds for a drill program to directly measure temperature gradient and test the geological model.

YGS and Liard First Nation (represented by Barkley Project Group) co-managed the Watson Lake geothermal study. The magnetotelluric survey was jointly funded by Crown Indigenous Relations and Northern Affairs Canada (through a Northern REACHE grant to Liard First Nation), the University of Alberta and YGS. Acquisition of lidar data that supported the interpretation of gravity and geologic data was covered by Northern REACHE funding.

Teslin

In the Teslin area, gravity data and detailed bathymetry of the lake in the study area were acquired in 2022 (Aurora Geosciences). In addition, data from a few audio-magnetotelluric sites were acquired (Quantec Geoscience) in September. Currently, Innovate Geothermal is integrating these data with existing magnetics and geology, to generate a 3D geological model of the Teslin fault that will guide future steps in the study. Plans for 2023 include the potential acquisition of an airborne EM survey (by GSC) to enhance the ground data.

The Quantec Geoscience contract was funded by GSC through their GEM-GeoNorth program.

Haines Junction

With the Watson Lake study completed and work wrapping up in Teslin next year, YGS has initiated a study in the Haines Junction area, applying the same suite of tools. In mid-November, Aurora Geosciences was contracted to start collecting gravity data. The bulk of the survey is expected to be completed over the winter, with the remainder of the area covered in summer 2023 when the ground is snow-free.

Regional geothermal investigations

In addition to site-specific studies near communities, the geothermal research program includes some regional-scale geophysical data collection to help characterize crustal structure. A series of 21 broadband seismometers were deployed in 2020 by University of Calgary researchers across southern Yukon from west of Burwash Landing to south of Watson Lake (Fig. 5). These instruments will be collecting earthquake data for a period of 3–4 years.

GSC is providing funds to complete magnetotelluric surveys along Yukon's major highway corridors (Fig. 5). Coverage will include those sections of highway that were not surveyed during Lithoprobe's SNORCLE transect. Data at sites along the Alaska Highway were acquired in 2021 and 2022; acquisition of data at the remaining proposed sites is planned for 2023. The contract for the magnetotelluric survey was managed by YGS and funded by the GSC through their GEM-GeoNorth program.

Seismic monitoring

In addition to collecting new seismic data to support geothermal studies, researchers from the University of Calgary have re-evaluated existing earthquake information from regional seismograph networks, including the USArray Transportable Array that was recently deployed across Alaska, Yukon and northern British Columbia. Using the USGS earthquake catalogue, Biegel *et al.* (2023) have relocated >5500 seismic events of magnitude >1.5 and greatly enhanced event clustering and depth of hypocentres. Their study has delineated a number of cryptic faults

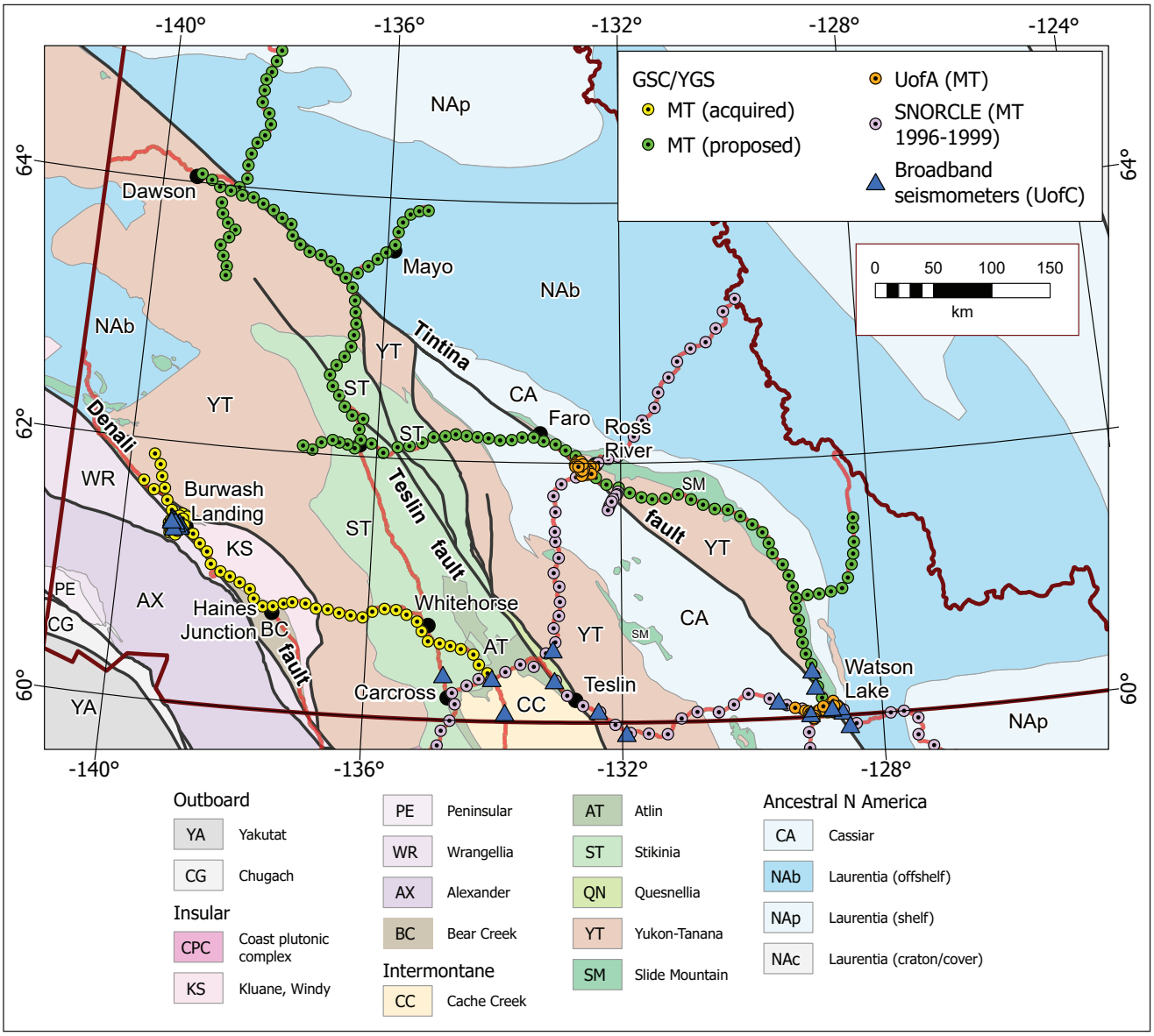

Figure 5. *Regional magnetotelluric transects and broadband seismometer network supporting geothermal research in southern Yukon. Terrane map extracted from Yukon Geological Survey (2022b).*

in the St. Elias Mountains that are related to the Denali fault system. A parallel study by Gosselin et *al.* (2023) provides an improved earthquake focal mechanisms catalogue that will inform further analysis of crustal stresses in southwestern Yukon. Both of these studies are presented in the accompanying Yukon Exploration and Geology volume.

Justin Emberley worked with Andrew Schaeffer (GSC-Pacific) to install a broadband seismic station on Yukon's North Slope at the Stokes Point DEW Line site. The station is a redeployment of a YGS-owned instrument that was moved from southeastern Yukon. This station, in conjunction with others located across northern Yukon and NWT, will help to better characterize seismicity in the Richardson Mountains and Beaufort Sea. It is part of a broader Canadian network of instruments deployed to monitor earthquakes and determine epicentre locations as part of GSC's Geohazards Program.

Surficial geology studies

Landslide monitoring

Landslide monitoring and research occupied a significant amount of YGS' Surficial Geologists' time in 2022, as numerous landslides impacted infrastructure. Higher-than-normal groundwater levels triggered slides in Whitehorse in late April and May, closing a major access route to the city for several weeks and resulting in the evacuation of some residents (Fig. 6). A remote YGS camera captured the flow of one of the Whitehorse landslides across Jeckell Street (www.facebook.com/YukonGeologicalSurvey/videos/). Over the summer, a landslide closed the Robert Campbell Highway near Little Salmon Lake, and in September, several active layer detachment slides caused by heavy rain closed the North Klondike Highway and stranded motorists. Jeff Bond, Panya Lipovsky and Derek Cronmiller worked with City of Whitehorse engineers and staff from Yukon's department of Highways and Public Works to assess slope stability and provide advice on when it was safe to clear debris. Such slides are expected to become increasingly more frequent as weather patterns change, and YGS anticipates that more of its resources will be dedicated to helping to monitor and predict such events.

Figure 6. *View looking south along Robert Service Way (Whitehorse) at debris from an April 30th 2022 landslide that closed the road for several weeks.*

In Dawson City, two potentially significant rock avalanches were the focus of attention by Cronmiller and Bond. A study commissioned by YGS in 2021 indicated the Moosehide Slide posed a level of risk that would be considered unacceptable in British Columbia (Yukon does not have a defined risk tolerance threshold for landslides). Consequently, YGS worked with contractors from BGC Engineering and installed a suite of near real-time instruments to monitor the head scarp (Fig. 7). The purpose of the array is to collect ground movement data over a period of two or more years to establish a baseline for movement rates and enable seasonal variations to be distinguished from movement rates that could indicate pending failure. Bond, Cronmiller and Lipovsky will work with BGC staff to monitor data as they are collected.

Figure 7. *BGC Engineering staff installing an extensometer on the Moosehide Slide in September, 2022.*

At the Sunnydale Slide, Cronmiller is co-supervising a student (Jackson Bodtker) who is studying the slide as part of an MSc thesis (Bodtker *et al.*, 2023). Lidar change detection analysis indicates the rock mass is moving, although the oldest lidar image is fairly recent, making it difficult to assess whether movement is accelerating. Bodtker is using older imagery (air photos, satellite images) to project movement rates back in time and he has collected samples for cosmogenic nuclide dating to quantify movement rate based on timing of exposure on the footwall. BGC has been contracted to model runout and associated wave displacement for Sunnydale, as flooding is considered the most significant hazard posed by this slide. In the meantime, reports of shallow failures on the cliff face above Yukon River have triggered plans by YGS to install some GPS instruments on the slide surface in the spring, to enable near-real time monitoring of movement.

The Dawson landslide working group, chaired by YGS, continues to share information with residents and liaise with municipal officials as they develop an emergency response plan.

Community mapping

YGS staff carried out community-based geohazard mapping and associated studies in three communities in 2022.

In Haines Junction, Lipovsky, Cronmiller and Moya Painter collaborated on a project to map and document geohazards and permafrost in and around the community. Lipovsky completed lidar analysis, then spent two weeks in the field with Painter mapping surficial geology. A final map is being prepared for release by spring 2023 (Lipovsky and Cronmiller, *in prep.*). Cronmiller drilled and installed thermistors in three new boreholes in 2022 to complement a borehole drilled in 2021 (Fig. 8). The borehole temperature data will be uploaded to YGS' permafrost database (https://service.yukon.ca/permafrost/) when data are downloaded from the loggers next summer. A final report for this project is planned for spring 2024, and will integrate mapping results, borehole data and profiles from an electrical resistivity tomography survey carried out in 2021 by Kryotek Arctic Innovation Inc.

Figure 8. *Derek Cronmiller installing a thermistor in a borehole. This one of four instrumented boreholes established in the Haines Junction area to monitor permafrost.*

Before joining YGS, Cronmiller mapped surficial geology in Teslin for Palmer Environmental. Palmer has granted YGS permission to include these data in a YGS geohazards map for Teslin. In 2022, Lipovsky and Painter carried out some fieldwork to expand the map area. Surficial geology information has been supplemented by a water well drilled by Yukon government's Water Resources Branch (as part of an aquifer mapping project). The well was logged by Lipovsky and the subsurface data will help inform geologic interpretations. Cronmiller plans further mapping in 2023, after which a final map will be prepared for release. As part of this project, Cronmiller installed an instrumented borehole; the temperature data will be uploaded to the permafrost database in 2023.

A surficial geology/geohazards mapping project initiated at Beaver Creek in 2021 was completed this year. In addition to mapping, three new boreholes were drilled and instrumented. The maps are currently undergoing review (Cronmiller, *in press*), and a final report is planned for spring 2023 (Cronmiller, *in prep.*).

In addition to the above projects, Panya Lipovsky worked to finalize the write-up of a four-year surficial mapping project in the greater Whitehorse area. Project outputs will include a digital Open File map (GIS product) of surficial geology with landslide and permafrost features embedded and an accompanying Open File Report (both *in prep.*). The report will include a derivative aggregate potential map that will help to address the city's shortage of aggregate resources.

Permafrost and glacier monitoring

Beyond the instrumented boreholes installed to support community mapping, Cronmiller drilled and installed thermistors in boreholes along the Alaska Highway, Dempster Highway, in the Eagle Plains area and by the Nordenskiold River near Carmacks. Temperature data from these boreholes will be added to the permafrost database in the new year. Plans are also underway to drill and instrument six deep (~10 m) boreholes later this winter in Mendenhall (1), Marsh Lake (1), Haines Junction (2) and Teslin (2), to further expand YGS' long-term permafrost monitoring network.

The Nordenskiold River borehole(s) supported the BSc research of Carolyn Hatton (Laurentian University), whose study is examining how degrading permafrost affects bank erosion and channel migration (Hatton *et al.*, 2023).

Over the summer, Painter and Cronmiller collected data from the Tweedsmuir glacier and Wheaton River valley glaciers, as part of a study to monitor the impact of receding glaciers on local watersheds (Fig. 9). The study involves both fieldwork and satellite image interpretation of about 20 glaciers in southern Yukon/northern British Columbia, recording retreat rates between 1986 and present. Details of the study are presented in the accompanying volume (Painter and Cronmiller, 2023).

Figure 9. *Derek Cronmiller documenting retreat of a glacier in the Wheaton Valley.*

Minerals-related activities

Industry Liaison

YGS Minerals Geology staff (Scott Casselman, Warwick Bullen, Yury Klyukin) visited ten exploration properties over the summer to view the local geology, learn about exploration results and engage with company geologists. Property visits included Sitka Gold's RC project, Snowline Gold's Rogue Project, and CMC Metal's Silver Hart property (Fig. 10). In addition to field visits, Casselman tracked news releases and contacted companies directly for updates on their activities. At the time of writing, exploration expenditures reported by companies working in the territory were just over $124M; up slightly from 2021 (just under $124M). Exploration and development highlights from all projects active in 2022 are presented in this volume (Casselman, 2023).

Figure 10. *Scott Casselman examining Manto-style Ag-Pb-Zn mineralization with company geologist at CMC Metals Ltd.'s Silver Hart property.*

The Core Library saw 51 days of use by 19 different users in 2022. While this is not a record for number of days of use, it is the largest number of users documented to date. Users included junior mining companies, prospectors, university researchers, colleagues from other geological surveys and a geothermal exploration company.

Following YGS's move to the H.S. Bostock Core Library in 2012, the survey spent two years moving the bulk of the drill core collection from the old core storage facility to the new core library. Core was catalogued and photographed so it could be captured in the Drill Core database (https://data.geology.gov.yk.ca/Drillholes/). A portion of the collection was left at the old facility, as space the Core Library is limited. In the spring, YGS received notice that the old facility would be torn down in the next few years, so Emberley began moving the remaining core over the summer. Just over 2500 boxes of core were moved, catalogued and photographed in 2022 (220 holes from 18 properties); roughly the same number of boxes remain to be moved in 2023.

Data compilation projects

Isotope data

As an offshoot to his Cretaceous porphyry study (described above), Sack has begun compiling whole-rock (Nd, Hf, Sr, Pb and O) and feldspar (Pb) isotope data, as well as S and Pb isotope data from sulphide deposits. Most of the data are sourced from geologic literature, with some new data generated from YGS samples. He is collaborating on this work with Ambrose.

Sack *et al.* (2022) used Pb isotope data to distinguish Late Cretaceous porphyry and epithermal systems in the Mount Nansen area; such studies have potential implications for exploration. Ambrose has been applying the isotope data to mineral occurrences in his North Rackla study area to constrain the timing of mineralization and potential metal sources. Silver-lead-zinc mineralization at the North Rackla, Val and Vera occurrences are interpreted to be Paleozoic in age, with the metals scavenged from the host stratigraphic units (Ambrose, *pers. comm.*, 2022).

The compiled isotope data were recently released by YGS and can be downloaded in a variety of formats (https://data.geology.gov.yk.ca/Compilation/37#InfoTab). Further applications of these data will continue to be explored.

Geochemical data from assessment reports

In the spring of 2022, Yury Klyukin initiated work on a new data compilation project. The project, modelled after British Columbia Geological Survey's Assessment Reports with digitized surface sediment geochemical data (http://webmap.em.gov.bc.ca/arssg/arssg_home_map.asp), involves extracting and compiling spatial and geochemical data from rock, soil, stream sediment, water and vegetation samples collected by mineral explorers and filed for assessment credit.

To date, Klyukin has extracted data from almost 300 publicly available assessment reports, including geochemical data for more than 225 000 soil, 74 000 rock, and 2200 stream sediment samples, primarily from the area around the Casino deposit. Many of the files required the use of optical character recognition software on scanned tables and .pdf files; however, more recent assessment reports include tabular data in digital form. Since joining YGS, Sarah Ellis has been assisting with data capture, focusing on new reports as they are submitted.

The next step in the project will be to build a spatial database to house the data.

Drill core scanning

Last winter, Fireweed Metals contacted YGS regarding plans to have their drill core scanned by a Calgary-based company (GeologicAI). The company had successfully applied for a grant under the federal government's Innovation Supercluster Initiative (https://www.scaleai.ca) to develop artificial intelligence to aid in the logging and interpretation of drill core. While the focus of the project was Fireweed's drill core at Macmillan Pass, GeologicAI was interested in scanning additional Yukon drill core and "training" it for other deposit types.

While this project wasn't something that was originally in YGS' work plan, the survey's Technical Advisory Committee had previously flagged core scanning technology as a potentially powerful tool for automated core logging. As a pilot project, this would provide high-resolution photos, XRF analyses, and lidar and hyperspectral images of the core and allow YGS to assess the benefits against the cost, should scanning be considered in the future. Emberley is lead on coordinating this project.

In spring 2022, GeologicAI scanned 2200 m of YGS core from 60 holes drilled on the Tom and Jason deposits. They focused on core from the Macmillan Pass area at the start of the field season in order to calibrate their instruments when they scanned Fireweed's core. In the fall, they returned to Whitehorse and scanned 3000 m of YGS core from the following deposits: Minto (12 holes), Kudz Ze Kayah (7 holes), Klaza (1 hole), Rusk (1 hole) and Cyprus (1 hole). At the time of writing GeologicAI was focused on processing Fireweed's core, but they anticipate by summer of 2023 they will have scanned files of YGS' core available for viewing. Access will likely be via a link on YGS' Drill Core database, with the files stored by GeologicAI.

MINFILE

With staff turnover and efforts focused on drill core scanning and moving, Minerals staff had less time than usual to work on the MINFILE database. Over the year, 400 occurrences were updated and 150 new occurrences were created (some are new occurrences; others were created by splitting out individual occurrences on a single property).

Thematic studies

Building on his previous work modelling porphyry potential in Yukon using weights of evidence (Bullen, 2021a), Warwick Bullen initiated a study using the random forest algorithm to assess the potential for Cu, Au, Mo and Ag porphyry systems. The algorithm is a supervised machine learning method which generates a prediction model using decision trees, with the predictions from each tree averaged to produce a final predictive model. The models were trained on known porphyry-style mineral occurrences ("present" points) and randomly generated "porphyry-absent" points. The density of absent points was determined from weights of evidence analyses.

Eleven "training layers" were used to predict prospective areas. Bullen used a lithology-based analysis developed by YGS (described in Bullen, 2022) to identify anomalous Au, Ag, Cu and Mo in catchment basins from stream sediment geochemical data. Geophysical layers (gravity, magnetics) and bedrock geology features (lithology, age, contacts, faults) were also used to train the data.

Prophyry-style mineralization was predicted to fishnets of differing cell sizes to allow for the generation of decreasing zones of prospectivity away from core areas (*i.e.*, areas of highest porphyry potential).

Preliminary results of his work were presented at the Geoscience Forum in November. As expected (and required), the model accurately predicted locations of known deposits and past producers; more significantly, it highlighted a number of areas with significant potential for previously undocumented porphyry mineralization. The latter make interesting exploration targets, as they have seen little or no exploration to date.

Bullen's random forest machine learning classification study will be written up over the course of the next year.

Land use planning

In June 2022, the Dawson Land Use Planning Commission released their Recommended Plan to the public. In September, Yukon and Tr'ondëk Hwëch'in governments launched public engagement on the plan. The engagement period closed in December.

Over the summer and fall, Bullen evaluated the recommended land management units against his assessment of mineral potential (Bullen, 2021b), and provided input to Yukon government's response. He examined the impact of the plan on highly to significantly prospective areas across the region: on mineral occurrences generally, and on critical minerals in particular. Bullen also determined the opportunity cost of permanent and interim land withdrawals as contemplated by the plan, and quantified the degree of value destruction, from a mineral exploration perspective, of the withdrawals.

The response to the recommended plan is expected to be released by spring, 2023.

Yukon Mineral Exploration Program

In 2022, YGS received 63 applications for funding under the Yukon Mineral Exploration Program (YMEP). This is the lowest number of applications seen in a decade. Applications were received for all four modules: Grassroots (6), Focused Regional (10), Target Evaluation (23) and Placer (24). Following the initial review, 45 applicants were offered funding. Wildfires and challenging market conditions caused a number of proponents to cancel their exploration plans in 2022, so funds were redistributed to projects that were not initially awarded grants. Ultimately, 42 projects were supported in 2022.

At the time of writing, it is anticipated that the Program will invest roughly $1.3M, and the total investment in exploration (*i.e.*, YMEP plus private funding) on YMEP-supported projects is forecast to be $3.8M.

In 2021, YGS added a questionnaire to the final reporting requirements for YMEP, asking recipients for data on where their exploration funds were being spent. The purpose of the questionnaire is to help track local economic impacts of the program. Results from the 2021 survey indicated that roughly 79% of YMEP project expenditures, which totalled $4.04M last year, stayed in the Yukon. Just over $2M was spent on local contractors for services such as drilling, air charters, camp support; almost $770K was spent on wages for Yukoners; and $323K was spent in the territory on supplies (e.g., groceries, fuel, hardware, etc.).

Highlights of 2022 YMEP-supported projects are presented in this volume (Ellis and Casselman, 2023).

Placer geology activities

During the 2022 field season, Sydney van Loon and Jeff Bond visited 85 placer operations (Fig. 11). Data collected on these visits will be compiled into the next placer activity report (2021–2023 Placer Industry Report), planned for release in spring 2024.

In May, van Loon and Bond attended the Gold Show in Dawson City, where they organized a series of presentations (in lieu of the cancelled 2021 Placer Forum) and distributed copies of the 2018–2020 Placer Industry Report. In November, van Loon organized the 10th annual Placer Forum. The one-day event included talks on 2022 industry activities and production statistics, wetlands classification and the application of drones to placer exploration and mine planning, among others. The 2022 Placer Forum was attended by more than 100 delegates.

Figure 11. *Jeff Bond visiting a placer operator on Scroggie Creek.*

Highlights of the 2022 placer season are presented in this volume (van Loon and Bond, 2023).

Thematic studies

Bond completed fieldwork on his study of placer potential in the Clear Creek district (Big and Josephine creeks area), where multiple glaciations have complicated placer exploration, but also locally reconcentrated gold. The study will be written up and released in 2023.

Outreach

As COVID-related restrictions on gatherings continued to lift in 2022, YGS outreach and public education activities ramped up. Leyla Weston organized or participated in numerous geoscience education events in 2022; two in particular are highlighted here as they are unique relative to the types of activities that she usually leads.

The first involved a field-based study of Volcano Mountain that involved representatives from Selkirk First Nation (SFN), YGS and Simon Fraser University (Fig. 12). Volcano Mountain is a basaltic cinder cone that was active periodically during the Holocene. It has not been directly dated, however, lava flows locally caused damming, and organic material recovered from the resulting ponds have yielded ages as young as 4200 BCE (Jackson and Stevens, 1992). The intent of

Figure 12. *Jeff Bond discussing Volcano Mountain geology with Selkirk First Nation Elder Roger Alfred (centre) and Lands & Resources Director Ellie Marcotte (right).*

this study is to determine the age of the most recent eruption by sampling a flow that overlies the youngest-dated flow and submitting it for cosmogenic nuclide dating. The project's appeal as an outreach activity is that the volcano has been active within the timeframe of SFN's oral history, and presented an opportunity to merge Traditional Knowledge with western science. SFN participants included Elder Roger Alfred, the Director of Lands and Resources Ellie Marcotte, and youth Keyshawn Sawyer.

The second event of note was the Great Yukon Shake-Out; an earthquake-awareness event organized by Yukon's Emergency Measures Organization (EMO). Held at Selkirk Elementary School, the event featured information on earthquake safety and involved students, staff and local media. Students had an opportunity to practice the "drop, cover and hold on" safety drill (Fig. 13) at the event, and Weston debuted YGS' new Raspberry Shake portable geophone. She ran an interactive demonstration that involved kids enthusiastically jumping in the gym and viewing the seismic response in real time on a graph projected on a screen.

Beyond these two unique events, Weston organized the usual array of interpretive hikes and school visits, and contributed to outreach activities at the Yukon Geoscience Forum. Over 400 students participated in the Discovery Day Camp during Mining Week 2022, and 600+ students attended the school tours during the Yukon Geoscience Forum. The Family Day event at the Forum reached over 300 people. Weston helped teachers enhance their geoscience curriculum with classroom visits and field trips for local schools, and she organized the annual Weekend on the Rocks at Tombstone Park, involving interpretive hikes and lectures.

In addition to educational events, Weston coordinated information-sharing with First Nation governments on YGS' program activities, inviting feedback on proposed studies and seeking input on their geoscience information needs. Recent flooding and the landslides that occurred in 2022 have raised awareness of landslide hazards in many communities, and growing interest in renewable energy has fueled discussions with a number of First Nation governments.

Figure 13. *Students at Selkirk Elementary School in Whitehorse practice an earthquake safety drill during the Great Yukon Shake-Out event.*

In July, Weston was invited to participate in Champagne and Aishihik First Nation's (CAFN) General Assembly. This was a great opportunity for her to connect in-person with many CAFN citizens and their government representatives and highlight YGS program activities within their Traditional Territory. Weston also brought some of her most popular activities that are engaging for both children and adults alike.

Summary

Although 2022 posed many challenges that impacted YGS' activities (e.g., wildfires, landslides, floods), staff were able to advance field projects and deliver services to industry, Yukon communities, and First Nation governments. New maps and reports resulting from the activities described above will be released in 2023. Publications can be found online at https://data.geology.gov.yk.ca and downloaded free of charge.

Looking forward, YGS will continue providing geoscience information to the public, and welcomes feedback on how its data are delivered. Staff are always happy to engage in discussions on project ideas or to visit sites of interest to clients.

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