University of Calgary

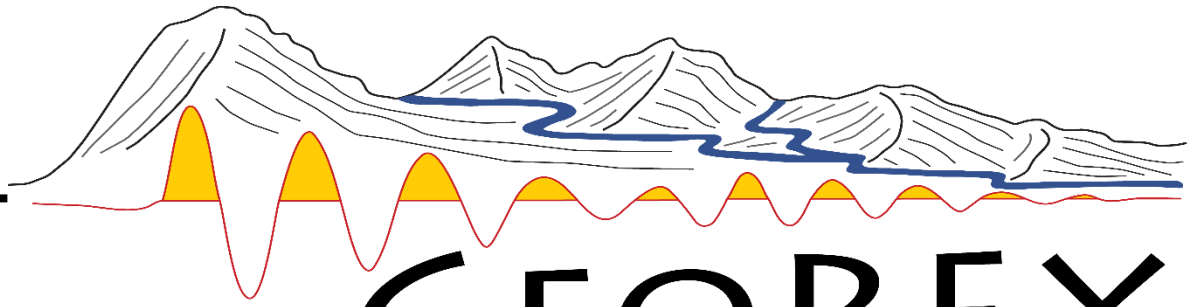
Department of Geoscience

Geoscience Research Exchange

April 7th, 2017

MacEwan Ballroom

Abstract Book and Program



GEOREX

GEOSCIENCE RESEARCH EXCHANGE

A message from the organizers

Welcome to the sixth annual Geoscience Research Exchange (GeoREX) at the University of Calgary! We are proud to present an extensive line up of presentations and posters this year, covering a wide variety of topics in earth sciences including Hydrogeology, Petroleum Geology and Geophysics, Clastic Sedimentology, and Paleontology and Carbonate Sedimentology. We'd also like to thank our keynote speakers: Hugh Abercrombie, Paul MacKay, and (as the final Friday Afternoon Talk Series presenter of the 2016-2017 academic year) Akbar Sohrabi.

GeoREX was initially introduced as a low pressure environment for both undergraduate and graduate students to communicate their research and ideas with other earth science students, supervisors, faculty, and industry members. From this idea, GeoREX has grown into an annual symposium that seeks to instill a culture of sharing and collaboration within the department of Geoscience and between the students of the University of Calgary and Mount Royal University. Sharing our research in such a multidisciplinary environment provides us all with an opportunity to explore new ideas and seek out new collaborative efforts, all while gaining critical experience in communicating the results of our research. We hope to see this become a longstanding tradition for the students of the University of Calgary and Mount Royal University.

Finally, we would like to express our gratitude for the financial support from Imperial, Teck, Torc, PS GeoData, Matrix Solutions Inc., Parkinson Alberta, and the Department of Geoscience. Without their support this event would not be possible.

Welcome to GeoREX 2017, we hope you enjoy your day!

Sincerely,

The GeoREX organizing committee: Daniel Alonso-Torres, Marie-Pier Boivin, Carly Doig, Chloe Duong, Lauren Madronich, Wyatt Petryshen, Dylan Riley, and Dane Synnott.

PS – If you are interested in getting involved with GeoREX next year, please speak to one of us throughout the day or express your interest by sending an email to georex@ucalgary.ca

GeoREX 2017 Schedule

8:00 AM **Sponsor Registration and Morning Coffee**

8:30 AM Doors Open to Audience

8:50 AM Welcome from the GeoREX Committee

9:00 AM ***Keynote Speaker: Hugh Abercrombie***

9:30 AM Assessing and mapping groundwater vulnerability to bacteria in Alberta
Tamara Van Staden, BSc

9:45 AM Conditioning the geostatistical simulation of Paskapoo formation with lithologs, paleo-current statistics, and pumping test for stochastic regional groundwater mapping
Amir Niazi, PhD

10:00 AM Nutrient distribution between different compartments of a wastewater effluent impacted river
Nadine Taube, PhD

10:15 AM Improved resolution in depth imaging through reflection static corrections derived from model-based moveout
Dennis Ellison, MSc

10:30 AM **Poster Session/Coffee Break**

11:00 AM Carbon sequestration and groundwater dynamics at Carbon Management Canada Field Research Station near Brooks, Alberta
Louise Rush, BSc

11:15 AM Comparison of novel techniques to establish baseline subsurface gas chemistry and isotopes at a gas injection field site
Terri Cheung, MSc

11:30 AM Assessment of fluid residence time in reservoirs – case study of radiolysis effects in crude oils from China and Norway
Jing Zhao, MSc

11:45 AM Petroleum potential evaluation of geochemical sweet spot of Mississippian Banff Formation, Alberta, Canada
Yihua Liu, BSc

12:00 PM **Lunch Break**

1:00 PM ***Keynote Speaker: Paul MacKay***
The relationship of the Canadian Oilsands to the Rocky Mountain Fold and Thrust Belt

1:30 PM Experimental stimulation of partitioning of oil into the water column during a submarine oil spill
Aprami Jaggi, PhD

1:45 PM Sediment distribution along point bars of the Red Deer River with insights for mapping the McMurray Formation, Alberta, Canada
Scott Norlin, BSc

2:00 PM Delineating and interpreting sand fairway in the McMurray Formation, Athabasca Oil Sands Region, Alberta
Harrison Martin, MSc

2:15 PM Implications for the tectonic initiation of the Laurentian passive margin from U-Pb detrital zircon ages
Lauren Madronich, MSc

2:30 PM **Poster Session/Coffee Break**

3:00 PM Do strontium isotopes hold the key to dinosaur migration?
David Terrill, PhD

3:15 PM High temperature origin of an early Permian bivalve-dominated reef, Sverdrup Basin, Northwest Ellesmere Island, Arctic Canada
Breanne Rathgeber, BSc

3:30 PM Facies evolution and environmental significance of Pennsylvanian-Early Permian shelf cycles in the Sverdrup Basin, Arctic Canada
Nikita Fernandes, MSc

3:45 PM Abundance and stratigraphic distribution of lingulid brachiopods during the mid-Permian (Guadalupian-Lopingian) mass extinction in the Sverdrup Basin, Arctic Canada
Reisa San Pedro, BSc

4:00 PM ***Keynote Speaker: Akbar Sohrabi***
What caused the Late Ordovician Mass Extinction? What can brachiopods tell us?

4:40 PM **Prizes and Closing Remarks**

Poster Presentations

Daniel Alonso-Torres, MSc	Late Paleozoic to Triassic arc magmatism north of the Sverdrup Basin in the Canadian Arctic: evidence from detrital zircon U-Pb geochronology
Laura Cruickshank, MSc	Chemistry and structure of tetragonal garnets
Inayat Dhaliwal, MSc	The structure and chemistry of some lead-apatite minerals
Manuele Lazzarotto, PhD	Tectonometamorphic investigations in the western Flin Flon-Snow Lake greenstone belt, Manitoba
Peyman Mohammadmoradi, PhD	Experimental and numerical visualization of two-phase saturation maps in a rough fracture
Dillon Newitt, MSc	Sedimentology, sequence stratigraphy and reservoir characterization of the 'Wilrich', Spirit River Formation, west-central Alberta
Colin Padget, MSc	Upper mantle and lower crustal xenolith from southeast Yukon Territory
Wyatt Petryshen, BSc	On the path of discovery: the controversy and science behind Chicxulub crater
Jeffrey Salvador, MSc	Crystal chemistry and structure of anomalous birefringent cubic uvarovite garnet, ideally $Ca_3Cr_2Si_3O_{12}$

Keynote Speaker: Hugh Abercrombie

Groundwater Hydrochemistry and Significance, North Athabasca Oil Sands Region

Hugh J. Abercrombie, Ph.D., P. Geol
Matrix Solution Inc., Calgary AB

Groundwater compositions are publicly available for Devonian through Holocene rocks in the North Athabasca Oil Sands (NAOS) region. In the NAOS region, the Athabasca River forms a significant regional hydrogeological divide. West of the River, flow is up-dip whereas to the east, flow is westward towards the River from recharge regions along the Devonian subcrop edge and downwards through Quaternary cover.

Groundwater hydrochemistry varies systematically from Recent to Devonian age rocks. Surficial and near-surface aquifers are recharged directly from surface and are characteristically enriched in calcium, magnesium and bicarbonate, transitioning to sodium, calcium and sulphate dominated compositions where oxidation of Clearwater shale has occurred. The salinity of groundwater in surficial and Quaternary aquifers is low and stands in contrast to the compositions of groundwaters in Cretaceous rocks, particularly the basal water sand aquifer of the Lower McMurray Formation. Within the McMurray Formation, salinities increase to several thousand milligrams per litre total dissolved solids (TDS) and water compositions are typically calcium-sodium-bicarbonate to sodium-calcium-bicarbonate-chloride and sodium-chloride-bicarbonate types. The basal water sands aquifer lies directly on Devonian rocks of the Waterways Formation and its composition reflects contributions from lateral flow within Cretaceous rocks as well as vertical flow up and out of the Devonian.

Three distinct water types are recognized in Devonian aquifer systems and these can be directly linked to the mineralogy of the aquifer systems. Characteristics of these water types are as follows:

> **Type 1** Devonian groundwaters occur within the Waterways Formation and have contributed to elevating the groundwater salinities in the Cretaceous basal water sands aquifer. Type 1 groundwaters are defined as belonging to the sodium-bicarbonate hydrochemical facies and reflect interaction with carbonate minerals calcite and dolomite, and contain variable amounts of chloride and low sulphate concentrations.
>
> **Type 2** Devonian groundwaters have higher salinities than Type 1, but are typically less than about 12,000 mg/L TDS. These groundwaters belong to the sodium-sulphate hydrochemical facies and are typically found within the Keg River ramp and reef where they indicate interaction with carbonate and sulphate minerals calcite, dolomite and gypsum. They generally contain low concentrations of chloride and bicarbonate, the latter reflecting equilibration with calcite/dolomite.

Type 3 Devonian groundwaters are the most recognizable Devonian groundwater type and are characterized by compositions within sodium-chloride hydrochemical facies. Type 3 Na-Cl groundwaters occur in Prairie Evaporite Formation aquifers and in discharge areas proximal to the Athabasca River. Type 3 Devonian groundwaters have a large range in salinities, from less than 10,000 mg/L to as high as 350,000 mg/L, but characteristically show molar Na/Cl ratios near 1 indicating that halite dissolution is the dominant control on solute chemistry, even at high dilution. Type 3 groundwaters indicate halite dissolution; no residual evaporite brines are recognized east of the Athabasca River.

Although it would seem possible that mixtures of all three Devonian groundwater types should occur, publicly available data show that Type 1-3 and Type 2-3 intermediate groundwater compositions are dominant with few instances of Type 1-2 mixtures and few if any ternary mixtures of all Devonian water types. It is suggested that the intermediate water types are more reflective of the flow path mineralogy rather than large scale mixing of different flow systems, except in regional discharge areas.

The distribution and composition of groundwater types in the NAOS region east of the Athabasca River reflects the groundwater flow regimes and mineralogy of Devonian through Recent sediments. The trends are similar to the evolution of groundwaters in other areas such as the Michigan Basin in southern Ontario where near-surface bicarbonate-dominated compositions give way with depth to sulphate-dominated groundwaters of intermediate salinity and eventually to chloride-dominated brines indicative of interaction with halite in deep evaporate formations. The flow system east of the Athabasca River is fundamentally different than the system west of the river and in deeper regions of the Alberta Basin where there has been no or little influx of meteorically derived fluids. This condition has persisted for tens of millions of years and may be the fundamental control on the localization of highly biodegraded and water-washed bitumens of the Athabasca Oil Sands region.

Keynote Speaker: Paul MacKay

The relationship of the Canadian Oilsands to the Rocky Mountain Fold and Thrust Belt

Paul A. MacKay
Shale Petroleum Ltd, Calgary AB

The Western Canadian Thrust System is dependent on multiple factors to create failure conditions. Two of the main requirements for failure are a significant differential stress and fluid pressure. The differential stress acts as the driving force creating contraction as a result of plate collisions in the hinterland (to the west). The fluid pressure is the trigger mechanism that shifts the conditions into and out of failure. As fluid pressure build up the system shifts into failure conditions. Failure opens the system to allow fluids to move, thereby reducing the fluid pressure and returning the system back into stable conditions. One of the principal fluids to form in this scenario are hydrocarbons. The productions of hydrocarbons become an added complexity in the system, due to phase changes controlled by pressure and temperature variations.

As this system advances the fluids are flushed to the Foreland Basin and migrate. These migrations can be traced to the Oilsands, approximately 800 kilometres of lateral fluid migration. Temperature data from oil fields reveal that the major migration in the south is in the Upper Devonian Nisku Formation but is charged from the overlying Exshaw Formation, suggestive of first downward migration of fluid and then lateral migration.

In central Alberta, the fluids generated out of the Upper Cretaceous Seconds Specks Formation did not advance to the Oilsands but was trapped in a series of oil wet fracture systems that eventually formed the basis for the large oilfields within the Cardium and Viking Formations. South of the Peace River Arch the oil moved principally out of the Nordegg Formation and charged the northern portion of the Oilsands.

Recognition of the role of sustained fluid pressure as a trigger mechanism challenges some of the assumptions of Critical Taper Theory, timing of thrust development and the role of fractures as not only a response to stress but also as the principal conduit for fluid migration over great distances.

Keynote Speaker: Akbar Sohrabi

What caused the Late Ordovician Mass Extinction? What can brachiopods tell us?

Akbar Sohrabi, Ph.D.
University of Calgary, Calgary AB

The Late Ordovician mass extinction was one of the five mass extinctions in the Phanerozoic. Several possible causes have been documented. According to the scientific community, the Late Ordovician mass extinction was most likely caused by a period of glaciation which included two phases: a lowering of sea level followed by a rise in sea-level. Brachiopods (one of the major and widespread groups of marine life during the Ordovician Period) indicate diversity changes from pre-extinction to extinction times.

GeoREX
Presentations

Assessing and mapping groundwater vulnerability to bacteria in Alberta

***Tamara Van Staden*[1]*, Ed Cey*[1]*, Cathy Ryan*[1]*, Sylvia Checkley*[1]*, Jesse Invik*[1]
1 – University of Calgary, Calgary, Alberta, Canada
email correspondence: tamara94@shaw.ca

Aquifer vulnerability index methods are commonly used for assessing groundwater vulnerability to surface contaminants, however, the methods have primarily been developed for dissolved contaminants. Microbial contaminants have unique characteristics that result in different transport behavior in the subsurface, and thus different tools need to be designed. Key vulnerability indicators specific to microbial sources and subsurface transport mechanisms were identified in this study and incorporated into a model using an ArcGIS framework to create provincial-scale maps of groundwater vulnerability, specific to E. coli, in Alberta for the year 2012. Examples of these indicators include: soil type, percentage of organic matter, hydrogeologic properties, depth to aquifer, and meteorological conditions. These indicators were combined from individual GIS layers to create an intrinsic vulnerability map, demonstrating where aquifers were more vulnerable to bacterial contamination if a source became present. Maps were created for the growing season and cold season, and attempts were made to validate the model with E. coli detection data. The results of these statistics were not significant enough for this model to be used for predictive purposes, but this could be caused by the presence or lack of risk (i.e., source of contaminants), as opposed to real differences in aquifer vulnerability. This project helped inform which parameters should be considered when making a vulnerability map for bacterial contaminants, most notably temporal parameters such as precipitation and soil moisture. The developed map provided insights as to where shallow aquifers in Alberta are intrinsically vulnerable to bacterial contamination.

Conditioning the geostatistical simulation of Paskapoo formation with lithologs, paleo-current statistics and pumping tests for stochastic regional groundwater modeling

***Amir Niazi*[1]*, Laurence Bentley*[1]*, Masaki Hayashi*[1]**
1 – University of Calgary, Calgary, Alberta, Canada
email correspondence: aniazi@ucalgary.ca

In the conventional modeling approach, a single hydrogeological model is constructed based on a single geological model and the uncertainty in geological heterogeneity is not explicitly taken into account. In contrast, Monte-Carlo analysis (MCA) is a method to account for the uncertainty associated with heterogeneity of local geology in groundwater models. In MCA, a suite of stochastic representations of the geology is generated by geostatistical simulation. In this presentation, we present a Markov chain method to generate and condition a suite of stochastic representations of the highly heterogeneous and non-stationary fluvial bedrock aquifer Paskapoo formation. All available information, including paleo-current statistics, sand fraction, lithologs and pumping tests, are used to generate the simulations.

In this methodology a lithologic model is constructed and conditioned with hard data using transition probability geostatistics. Subsequently, a segment of the simulation around a pumping well was used to generate a numerical groundwater flow model. A single well pumping test was modelled using the flow model, and hydraulic conductivity and specific storage of sand channels and mudstone were estimated by using an inverse model. The original simulated lithology model was updated to match the pumping test results by locally deforming the lithology distribution using the probability perturbation method and again iteratively performing the inverse parameter estimation. This loop was executed until our optimization function was minimized and our prior knowledge about hydraulic properties of the hydrofacies was satisfied.

By using this method, we constrain the uncertainty in the lithologic model and obtain estimates of local hydraulic properties of the hydrofacies (sandstone and mudstone) in the aquifer which later can be used to calibrate a regional groundwater model.

Nutrient distribution between different compartments of a wastewater effluent impacted river

***Nadine Taube*[1]**, *Jianxun He*[1], *Cathy Ryan*[1], *Caterina Valeo*[2]
1 – University of Calgary, Calgary, Alberta, Canada
2 – University of Victoria, Victoria, British Columbia, Canada
email correspondence: nmtaube@ucalgary.ca

The understanding of in-stream nutrient storage and nutrient export in river systems is important in establishing nutrient loading criteria to reduce excessive aquatic biomass growth and the risk of eutrophication. Eutrophication studies on lentic environments often focus on one nutrient, one river compartment, or are restricted to small stream environments. To understand the nutrient dynamics in the river and assess the impact of wastewater treatment plant (WWTP) effluent on nutrient storage and export, we combined nutrient measurements in river sediment, surface water, hyporheic water, and aquatic biomass to quantify nutrient export and storage from a river reach impacted by WWTP effluent. In the 25km long river reach, 98% of total nitrogen (N) and phosphorus (P) mass (g/m2) was stored in the sediment, where it can support algal and macrophyte growth. The export of nutrients from the river each by sediment, hyporheic water, and biomass is negligible in comparison to water column transport. The water column exports 70-80% of WWTP effluent nutrients. N/P ratios in the different pools suggest that the water column is severely P limited but sediment and hyporheic water pools have a tendency towards co-limitation and N limitation as does the biomass. Most of the P is stored right downstream of the major WWTP. In the rest of the reach N is retained at a higher rate relative to P. Interactions between the different pools suggest that multiple nutrient pools should be considered to establish nutrient conditions and limitations. In conclusion, nutrient analysis in multiple pools in the river can add valuable insight into nutrient dynamics and nutrient limitation.

Improved resolution in depth imaging through reflection static corrections derived from model-based moveout

***Dennis Ellison*[1]**, *Greg Cameron*[1], *Kris Innanen*[1]
1 – University of Calgary, Calgary, Alberta, Canada
email correspondence: ellisondk@gmail.com

When seismic data are used to image the subsurface, assumptions and calculations are made about the near-surface to overcome the uncertainty of the velocities of the low-velocity layer. A near-surface velocity model is generated to calculate a time shift that is used to correct for velocity anomalies in the near-surface for time migration.

Reflection statics are calculated because often the lack of detailed near-surface information leads to inaccuracies. A normal moveout (NMO) velocity field is picked and applied to stack the data in preparation for the reflection statics calculations. NMO is a two-term equation based on the assumption that the moveout can be approximated by a hyperbola. However, the accuracy of this assumption is valid when the moveout on data is near-hyperbolic and deviates when the moveout is more complicated. A few scenarios of non-hyperbolic moveout are when the topography isn't flat, strong lateral heterogeneity of velocity is present, and when there are variations in the seismic weathering thickness and velocities.

Raytracing in depth migration has overcome many of the issues with the assumptions in time migration. Foothills datasets and other geologically complex environments compel us to look for ways to overcome these assumptions as they are violated. Using the depth migration velocity model, we apply the offset dependent traveltime summation as the moveout correction for reflection static calculations in depth imaging.

Carbon sequestration and groundwater dynamics at Carbon Management Canada Field Research Station near Brooks, Alberta

Louise Rush[1]
1 – University of Calgary, Calgary, Alberta, Canada
email correspondence: lvrush@ucalgary.ca

Anthropogenic activity has raised atmospheric carbon dioxide (CO_2) concentrations to an alarming level. A way to mitigate these emissions is a method called carbon sequestration, also known as carbon capture and geologic storage. This strategy consists of injecting CO_2 into the ground in a supercritical state in order to be stored. The Carbon Management Canada Research Institutes' Containment and Monitoring Institute Field Research Site (CMC CaMI FRS) is a site proposed for carbon sequestration. The CMC CaMI FRS is located southwest of Brooks in central-southeast Alberta and injection will commence in late spring of 2017. A vital consideration is whether the CO_2 will leak after injection. CO_2 plumes will naturally diffuse outward and upward. Literature predicts upward diffusion of the CO_2 gas plumes along cracked cement linings of old, abandoned wells dotted throughout the site, as well as through the bimodally-spaced fracture network present in the 27 m-thick glacial till surficial deposit.

In order to determine if the site is suitable for carbon sequestration, it is important to research chemical and physical background characteristics of the subsurface. Multiple types of field analysis, including a groundwater survey consisting of water table surface measurements, supplied the data for creating various water table contour maps. Modeling softwares used to create these maps were Grapher 8 and Surfer. Mapping the groundwater flow dynamics of the CMC CaMI FRS is required for larger studies because it provides insight into groundwater and soil gas flow configuration within the vadose zone.

Comparison of novel techniques to establish baseline subsurface gas chemistry and isotopes at a gas injection field site

***Terri Cheung*[1]*, Bernhard Mayer*[1]*, Beth Parker*[2]*, Don Lawton*[3]**
1 – University of Calgary, Calgary, Alberta, Canada
2- Univerisity of Guelph, Guelph, Ontario, Canada
3 – CMC Research Institutes Inc., Calgary, Alberta, Canada
email correspondence: bmayer@ucalgary.ca

Geological storage of CO2 and hydraulic fracturing associated with shale gas development have the potential to cause mobilization of entrapped gases and subsequent leakage into shallow groundwater. To detect gas migration and determine impacts from anthropogenic activities, a scientifically reliable baseline assessment of subsurface gas distributions is required. This study has the objective of developing depth-resolved chemical and isotopic baseline assessments of the shallow groundwater in an area where potential gas migration will be investigated in the future.
CMC Research Institutes Inc. (CMC) has established a multi-disciplinary field research site dedicated to advancing state-of-the-science approaches for monitoring gas migration. The subsurface gas samples analyzed was obtained during the drilling of the site boreholes and water samples collected after groundwater monitoring infrastructure was installed. The site is comprised of one 300m deep gas injection well, two 350m deep monitoring wells, a 65m deep domestic water well and a depth-discrete multi-level WestbayTM system with 26 sampling ports distributed throughout the uppermost 106 m. C isotope ratio depth-profiles for methane were determined in the uppermost silty sandstone/ coal bedrock using rock core, cuttings and dissolved gas samples. The C isotope ratios and trends were consistent between all methods and reveal δ13CCH4 values for the upper 106 m range naturally from -85‰ to -65‰, indicating a biogenic origin of the methane. Aqueous geochemistry data suggest that the shallow aquifer could be at favourable redox conditions for in-situ methanogenesis. The outcome of this research will be an unprecedented depthresolved baseline characterization of the shallow groundwater.

Assessment of fluid residence time in reservoirs – case study of radiolysis effects in crude oils from China and Norway

***Jing Zhao*[1]**, *Haiping Huang*[1], *Lloyd Snowdon*[1], *Steve Larter*[1]
1 – University of Calgary, Calgary, Alberta, Canada
email correspondence: jing.zhao@ucalgary.ca

Fluid residence time in a trap is a key factor in many petroleum systems evaluation, basin modeling and carbon storage studies. It will not only provide constraints for basin modeling but also contribute an alternative approach to caprock efficiencies evaluations for carbon storage and oil charge studies. However, dating of fluid flow events in petroleum systems is currently based on indirect methods, and direct assessment of hydrocarbon charge and residence time from analysis of crude-oil is not feasible. The study of my thesis aims at investigating the radiolysis effects and mechanisms, identifying a hydrocarbon-related potential proxy system, and thus, to develop a new precise analytical method to permit functional dating of reservoirs by organic geochemical proxies with realistic reservoir gamma ray doses.

High-dose and low-dose gamma ray irradiation experiments were designed and conducted on the selected crude oil samples from Chinese Tarim Basin, North Sea and Barents Sea, which aim to find novel radiation damage products and discover potential radiolysis marker candidates as well as analytical methods to quantitate them. After irradiation, the majority of GC-MS monitored compounds were destroyed at different rates. The rates are dependent on the original concentration, compound class, molecular size and the oil matrix. Important compounds were selected and abundances and distributions were analyzed. The dating proxies were determined and preliminary dating concepts of the reservoir filling were developed. In an ideal scenario, knowing the irradiation dose and the reservoir radiation dose rate from analysis of samples would enable the calculation of reservoir residence age.

Petroleum potential evaluation of geochemical sweet spot of Mississippian Banff Formation, Alberta, Canada

***Yihau Liu*[1]**, *Milovan Fustic*[1], *Steve Larter*[1], *Chunqing (Dennis) Jiang*[2], *Omid Ardakani*[2], *Jagos Radovic*[1]
1 – University of Calgary, Calgary, Alberta, Canada
2 – Geological Survey of Canada, Calgary, Alberta, Canada
email correspondence: mfustic@ucalgary.ca

The previous regional study revealed a localized, but up to 100m thick, organic rich interval within the Mississippian Banff Formation. Since previous researchers consider the poorly studied Banff Formation as neither a source rock nor a reservoir, this research contains detailed multidisciplinary characterization of two short cores collected in the 1950s, and petroleum potential evaluation, including:

(i) detailed core description including facies analysis and environment interpretation;
(ii) interval correlation using geophysical logs;
(iii) detailed mineralogical and petrological analysis using thin sections and scanning electron microscopy (SEM);
(iv) source rock evaluation using RockEval of drill cuttings (from publicly available data) and core samples, as well as qualitative organic petrography (fluorescence);
(v) hydrocarbon molecular composition analysis using gas chromatography-mass spectrometry.

Data shows a carbonate dominant lithology with noticeable siliceous fragments; evidence of multistage dolomitization and silica precipitation; initial porosity reduction and limited secondary porosity formation. Although RockEval results suggest source rock potential, SEM and organic petrography evidence of oil migration through pores and microfractures suggest reservoir potential. Variable properties in two cores and their correlation with logs suggests that documented characteristics are widespread in the area. Heterogeneity is related to carbonate slope sedimentology, with sporadic, likely wind transported siliciclastic fragments, and is coupled by post-depositional changes. Although on occasion contradictory to each other, all results clearly show that the studied interval has both source and reservoir potential that deserves further quantitative studies. Furthermore, presented concept suggest the need for revisiting Western Canadian Sedimentary Basin (WCSB) petroleum systems with a focus on intraformational organic-rich units.

Experimental simulation of partitioning of oil into the water column during a submarine oil spill

***Aprami Jaggi*[1]**, *Ryan Snowdon*[1], *Jagos Radovic*[1], *Steven Larter*[1], *Thomas Oldenburg*[1]
1 – University of Calgary, Calgary, Alberta, Canada
email correspondence: aprami.jaggi@ucalgary.ca

The traditional methods for determining partitioning behavior of organic species into water following petroleum spillage, fail to accurately model the conditions of high pressure, low temperature and dissolved gas found in submarine oil spill scenarios. To experimentally simulate the partition behavior of water-soluble oil components using live oils (methane-charged) with saline waters under subsurface oil spill conditions, a unique, customized oil-water partitioning device was developed. The partitioning behavior of low- molecular weight species was determined along the depth of the water column over a range of pressure (2–15MPa) and temperature (4–20°C) reflecting water depths between 200m and 1500m. Within these investigated ranges, the partitioning of BTEX compounds showed a 'salting-out' effect with the increase in pressure with 'live oils', resulting in lower BTEX partitioning into the water phase. In addition, BTEX compounds partitioning also showed an increase proportionally with the increase in temperature, and inversely with increase in alkylation.

To understand the effect of dispersants on the partitioning of oil constituents, the system was run under similar conditions with the addition of dispersant at 1:1000 dispersant to oil ratio. The addition of dispersants increased the extent of BTEX partitioning from the oil to water – the increase was high at near surface conditions, while it was within the experimental error limits at higher pressure conditions.

This data will aid in near-field and far-field distribution modeling of the environmental fate of crude oil components of interest and assist in the prediction of component migration pathways from potential oil spills.

Sediment distribution along point bars of the Red Deer River with insights for mapping the McMurray Formation, Alberta, Canada

***Scott Norlin*[1]*, Stephen Hubbard*[1]*, Paul Durkin*[1]**
1 – University of Calgary, Alberta, Canada
email correspondence: smnorlin@shaw.ca

Many studies have attempted to understand the deposits of meandering river point bars, focusing on factors such as grain size distribution and depositional architecture. These studies have led to the development of point bar facies models, with predictive grain-size distribution trends as a key area of focus. However, development of oil sands reservoirs in northeastern Alberta is particularly sensitive to lithologic heterogeneity within fluvially dominated stratigraphy. The refining of fluvial facies models for the purpose of developing enhanced predictions of reservoir heterogeneity could have particularly important implications for characterizing and mapping Alberta's oil sands reservoirs. Mudstone is particularly prevalent in the deposits of confined meanderbelts due to the propensity for down-valley point bar translation, which results in widespread: (1) mudstone deposition within counter point bars; and (2) erosion of sand at the heads of point bars. The stratigraphic product of confined meanderbelt processes is dominated by inclined heterolithic strata, which is a sub-optimal reservoir target. Through the study of point bars in a modern river (Red Deer River, Alberta, Canada), as well as well log correlation and core analysis (Lower Cretaceous McMurray Formation), the development of a facies model to account for sand distribution in confined meanderbelts is developed.

Delineating and interpreting sand fairways in the McMurray formation, Athabasca Oil Sands Region, Alberta

***Harrison Martin*[1]*, Cynthia Hagstrom*[1,2]*, Sean Horner*[1]*, Stephen Hubbard*[1]**
1 – University of Calgary, Calgary, Alberta, Canada
2 – Nexen CNOOC Ltd, Calgary, Alberta, Canada
email correspondence: harrison.martin@ucalgary.ca

A large-scale, north-trending valley form is delineated in the Early Cretaceous McMurray Formation at the southeast-through-central portions of the Athabasca Oil Sands Region (AOSR) of northeastern Alberta and northwestern Saskatchewan, Canada. This sand fairway contains a significant proportion of the region's high-quality bitumen resource. Its distribution is mapped based on the presence or absense of regional stratigraphic markers (commonly referred to as the 'upper' McMurray Fm): the regional markers were presumably erosionally removed during valley incision ("A-Valley" of Hein and Cotterill, 2006). Well logs, core descriptions, and 3D seismic imagery (where available; ex. Hubbard et al., 2011) are integrated for an area >10,000km2, bounded to the east by the 'bitumen edge' where much of the McMurray Formation dips below the regional oil-water contact. In this study, the composite valley fill is examined from T70-8W4 to T87-12W4, where it is of variable width (10s of km) and thickness (10s to >100 m). Maps of its distribution and character, including sedimentological, ichnological, and component sedimentary body parameters, are presented from the ~170 km long north-south oriented transect. Morphologic interpretation suggests a meanderbelt dominated by mobile channels, with numerous attributes analogous to characteristics consistent with fluvial processes (e.g., evidence for down-valley translation of point bars, counter point bars, large scale upwards-fining point bar deposits, etc). Evidence suggests that the valley fill comprises one or more stacked channel successions, depending on paleogeographic position. This valley form is believed to be one of the stratigraphically-latest components of the McMurray Formation succession and represents a basis for comparing various previously defined depositional models developed across this portion of the AOSR.

Implications for the tectonic initiation of the Laurentian passive margin from U-Pb detrital zircon ages

***Lauren Madronich*[1]**

1 – University of Calgary, Calgary, Alberta, Canada

email correspondence: lauren.madronich@ucalgary.ca

It is well-established that active rift processes occurred throughout the Cryogenian with an ample record of magmatism in the form volcanic rocks and detrital zircons. This occurred ~100 Ma before the Cambrian initiation of the passive margin as evident from thermal subsidence models and the subsequence tectonic quiescence during the deposition of major Paleozoic carbonate successions. There is a limited record of Cambrian magmatism in the form of volcanic rocks, however, the sedimentary record hosts young magmatic grains. Samples of Cambrian sandstones provide a more-complete record of renewed magmatism along the Laurentian margin. New U-Pb detrital zircon ages support tectonic models that distinguish Cryogenian rifting and final passive margin initiation as two discrete events

Do strontium isotopes hold the key to dinosaur migration?

***David Terrill*[1]**

1 – University of Calgary, Calgary, Alberta, Canada

email correspondence: dfterril@ucalgary.ca

Stable isotope geochemistry is a rapidly growing field with applications in hydrogeology, climatology, stratigraphy, and paleontology among others. Isotope systems of interest are numerous, including (but not limited to) oxygen, carbon, nitrogen, sulfur, and strontium. Strontium is a common isotope system used in paleontology due to the relative ease with which it replaces calcium in carbonates and apatites. It can be found in marine fossils such as brachiopods and conodonts, as well as in the bones and teeth of marine and terrestrial vertebrates. In terrestrial ecosystems, the strontium isotope values vary regionally, depending largely on the bedrock and upstream geology of a given area, as strontium enters the environment through the weathering of these rocks. Archaeologists have used this fact to study human migration and movement by analyzing the strontium contained in tooth enamel and tying the results to the values found in plant and animal fossils in different regions. While the method has proven quite successful for archaeological studies, this technique has seen very little application to broader topics in paleontology.

For this study, strontium isotope ratios are being analyzed from a variety of terrestrial vertebrate fossils. Freshwater fish and crocodile teeth and scales have been analyzed to determine the natural variability of strontium isotope ratios in a single locality, and to characterize a locality in Cretaceous Alberta. These values will then be compared to dinosaur teeth in a preliminary attempt to determine if dinosaurs were migratory.

High temperature origin of an early Permian bivalve-dominated reef, Sverdrup Basin, Northwest Ellesmere Island, Arctic Canada

***Breanne Rathgeber*[1]**
1 – University of Calgary, Calgary, Alberta, Canada
email correspondence: bjrathge@ucalgary.ca

Bivalves are typically scarce in skeletal-microbial mud mounds found in the Sverdrup Basin, Arctic Canada, yet a particular buildup in the Lower Permian Nansen Formation is uniquely dominated by large bivalves. The bivalves are cemented together via multiple generations of isopachous cement creating a bivalve cementstone. Petrographic analysis provided information of the nature of the bivalves with an overlying phylloid-algal dominated bank, categorizing the samples into nine microfacies which are arranged in a number of high-frequency (~400 Kyr) cycles. Stable isotope analysis of the marine cement yielded results consistent with a high temperature origin of 40-50°C. The presence of the bivalve cementstone raises many questions about the origin of the buildup, about what type of potentially stressed environments could harbour dominant bivalves and little or no other organisms. Possible modern analogues for this unique setting include CO2 vents, methane seeps, black smokers, “Lost City” hydrothermal fields, and saline brine pools or springs, the latter perhaps providing the best explanation of the available data.

Facies evolution and environmental significance of Pennsylvanian-Early Permian shelf cycles in the Sverdrup Basin, Arctic Canada

***Nikita Fernandes*[1]**
1 – University of Calgary, Calgary, Alberta, Canada
email correspondence: nkfernan@ucalgary.ca

Cyclic shelf deposits in the Sverdrup Basin are Late Pennsylvanian to Early Permian in age. These deposits, referred to as cyclothems, are 5th order cycles of recessive-resistant couplets thought to result from glacioeustatic fluctuations driven by the waxing and waning of Late Paleozoic Gondwana glaciers. A maximum glacioeustatic fluctuation of 120 m is estimated during the time interval of the samples studied. Cyclothems from the Nansen and Belcher Channel formations are examined in three sections from Ellesmere and Axel Heiberg islands in the Sverdrup Basin of the Arctic. The three sections are represented by thirteen microfacies indicating a shallow shelf depositional environment that varies from section to section. Through microfacies analysis, a shallowing upward trend is evident in all three sections with distal outer shelf facies shallowing to inner shelf facies. Weathering profiles in the field are thought to closely parallel microfacies analysis, however the two are not always consistent with each other. Facies transitions between microfacies are more gradual than expected even though sharp contacts are observed in the field. An overall shallowing upward trend is characteristic of individual cyclothems, however in most cases these trends are interrupted by higher order fluctuations (6th and 7th order). Lastly, bathymetric interpretation estimates indicate 35-40 m fluctuations in cyclothems that are < 10 m thick. Taking compaction and dissolution into account, these cyclothems lack evidence relating to the 120 m maximum fluctuation previously interpreted.

Abundance and stratigraphic distribution of lingulid brachiopods during the mid-Permian (Guadalupian-Lopingian) mass extinction in the Sverdrup Basin, Arctic Canada

***Reisa San Pedro*[1],**
1 – University of Calgary, Calgary, Alberta, Canada
email correspondence: rjsanped@ucalgary.ca

Northwestern Pangea experienced a marine facies shift from a rich carbonate- to impoverished spicule-dominated fauna from the early Sakmarian (early Permian) to the end Permian. This transition is captured in the strata of an approximately 2000km^2 study area with regionally exposed middle and late Permian carbonate and siliciclastic deposits of Ellesmere Island in the Sverdrup Basin, Canadian Arctic. Although brachiopods are abundant within the Permian formations in the Sverdrup Basin, this is the first study to focus on the distribution of phosphatic brachiopods (PB) in this area during the middle and late Permian. This study documents the abundance, average size, mode of preservation, degree of weathering, and diagenetic alteration of phosphatic brachiopods using petrographic analysis of 288 thin sections. Most phosphatic brachiopods were identified as small, curved, rectangular or thin elongated shells; most are preserved as broken fragments with varying degrees of compact dissolution from grains in the surrounding matrix. Phosphatic brachiopods range from very rare (1-2 fragments per thin section) to very abundant (>80% PB fragments per thin section); they range in size from 100um to >2000um. Intensively silicified calcitic brachiopods were found adjacent to less silicified phosphatic brachiopods suggesting phosphatic brachiopods exhibit greater resistance to diagenetic alteration than calcitic brachiopods. Construction of two stratigraphic cross sections through the study area provided evidence that PB concentrations occur in shell lags near unconformities separating Capitanian and Wuchiapingian lithologies. The pattern of PB abundance in the Gudalupian-Lopingian boundary is consistent with the presence of opportunistic taxa that flourished following the decrease in biodiversity caused by ocean anoxia.

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Late Paleozoic to Triassic arc magmatism north of the Sverdrup Basin in the Canadian Arctic: evidence from detrital zircon U-Pb geochronology

***Daniel Alonso-Torres*[1]**, *Benoit Beauchamp*[1], *Bernard Guest*[1], *Thomas Hadlari*[2], *William Matthews*[1]
1 – University of Calgary, Calgary, Alberta, Canada
2 – Geological Survey of Canada, Calgary, Alberta, Canada
email correspondence: dalonsot@ucalgary.ca

Tectonic reconstructions of the Arctic during the Paleozoic and Mesozoic have been a major subject of debate in recent years. The Permian emergence of a landmass north of the Sverdrup Basin in the Canadian Arctic led to the onset of northerly derived detritus and followed volcanism and basin inversion pulses that began in the latest Carboniferous. However, the mechanisms for these events and the Paleozoic to Mesozoic paleogeography of this region remain controversial.

New LA-ICP-MS detrital zircon U-Pb geochronology data of upper Paleozoic to Lower Triassic units of the Sverdrup Basin help constrain the nature of this northern landmass and its effects on the adjacent basin. Permian to earliest Triassic strata of the northern margin of the Sverdrup Basin contain abundant zircons derived from Ellesmerian bodies (355–420 Ma), Timanian basement (500–700 Ma), and additional Permian syn-depositional sources (250 – 300 Ma). This signature differs from coeval strata in the southern margin, which are dominated by Ellesmerian and Caledonian aged zircons (420–480 Ma).

The detrital zircon signatures of the studied units in the northern margin of the Sverdrup Basin record continuous magmatism within the northern landmass from latest Carboniferous (ca. 300 Ma) to at least earliest Triassic time (ca. 250 Ma). These results are indicative of ongoing subduction and development of a magmatic arc off the northern margin of the Sverdrup Basin. The proposed onset of subduction in latest Carboniferous time provides an explanation for the shift in stress regimes in the Sverdrup Basin that led to basin inversion and volcanism episodes. Therefore, the data in here presented suggests that the tectonic history of the Canadian Arctic during this time was controlled by an active margin regime, contrasting with previously accepted reconstructions and thus furthering our understanding of the tectonic evolution of the Arctic.

Chemistry and structure of tetragonal garnets

Laura Cruickshank[1], *Sytle Antao[1]*
1 – University of Calgary, Calgary, Alberta, Canada
email correspondence: lacruick@ucalgary.ca

Most garnets exhibit cubic symmetry, but exceptions with tetragonal symmetry have been reported. Henritermierite is a rare Mn^{3+}-bearing hydrogarnet, ideally $Ca_3Mn_2[(SiO_4)_2(O_4H_4)_1]_{\Sigma3}$, with only two known occurrences. It has been reported with tetragonal symmetry and space group $I4_1/acd$. The tetragonal symmetry has been previously attributed to Jahn-Teller distortion of the octahedral Mn^{3+} cation. (OH,F)-bearing spessartine is a pyralspite-group garnet, ideally $Mn_3Al_2[(SiO_4)_2(O_4H_4,F_4)_1]_{\Sigma3}$, and has been reported with either cubic or tetragonal symmetry and space group $Ia\bar{3}d$ and $I4_1/acd$, respectively. It has been reported that the cause of the tetragonal symmetry is ordering of (OH,F) groups or atoms. This study focuses on the crystal structure and chemical analyses of henritermierite and (OH,F)-bearing spessartine garnets using electron probe microanalysis (EPMA) and synchrotron high-resolution powder X-ray diffraction (HRPXRD) data. EPMA gave near end-member compositions of $Ca_{2.97}\{Mn_{1.95}Al_{0.04}Fe_{0.03}\}_{\Sigma2.02}[(SiO_4)_{2.00}(O_4H_4)_{1.00}]_{\Sigma3}$ and $(Mn_{2.82}Fe^{2+}_{0.14}Ca_{0.04})_{\Sigma3}\{Al_{1.95}Fe^{3+}_{0.05}\}_{\Sigma2}[(SiO_4)_{2.60}(O_4H_4)_{0.28}(F_4)_{0.12}]_{\Sigma3}$ for henritermierite and spessartine, respectively.

The structure and chemistry of some lead-apatite minerals

***Inayat Dhaliwal*[1]*, Sytle Antao*[1]**

1 – University of Calgary, Calgary, Alberta, Canada

email correspondence: idhaliwa@ucalgary.ca

This study is based on some lead-apatite minerals, including pyromorphite, Pb5(PO4)3Cl, mimetite, Pb5(AsO4)3Cl, and vanadinite, Pb5(VO4)3Cl. Emphasis is placed on their crystal structure and chemistry. The lead-apatite minerals belong to the hexagonal space group P63/m. In pyromorphite, mimetite, and vanadinite the XO4 tetrahedra is occupied by P5+, As5+, and V5+ cations, respectively. Based on their general formula, Pb5(XO4)3Cl, the variations in size of these cations result in different O-X-O angles and X-O bond distances in each mineral, thus influencing their unit-cell dimensions. Three samples of pyromorphite were studied, of which two are from China and one is from Ontario. Our mimetite sample is also from China and our vanadinite sample is from Morocco. To examine the structural trends among these samples, high-resolution powder X-ray diffraction (HRPXRD) results and electron-probe microanalysis (EPMA) analyses were used. Several structural trends were observed and explained in this study.

Tectonometamorphic investigations in the western Flin Flon-Snow Lake greenstone belt, Manitoba

Manuele Lazzarotto[1], *Dave Pattison*[1], *Simon Gagne*[2]
1 – University of Calgary, Calgary, Alberta, Canada
2 – Manitoba Geological Survey, Winnipeg, Manitoba, Canada
email correspondence: manuele.lazzarotto@ucalgary.ca

The Flin Flon-Snow Lake greenstone belt is part of a tectonic collage situated in west-central Manitoba. It consists of accreted terranes comprising metamorphosed ocean floor and island-arc assemblages that are unconformably overlain by sedimentary rocks and intruded by successor-arc plutons. The study areas consist of blocks bound by faults and major shear zones, within which both regional and contact metamorphism are observed. The regional metamorphic grade generally increases northwards across the Flin Flon-Snow Lake greenstone belt from prehnite-pumpellyite facies rocks in the south, to amphibolite facies rocks in the north. This general pattern is locally disrupted by faults and plutons. Rocks in contact metamorphic aureoles around plutons record proximal amphibolite facies conditions. Late shear zones overprint the margins of the plutons and the contact aureoles. A preliminary metamorphic map of the area is presented, together with isograd maps for fault-bounded blocks in the Schist Lake region, and for the contact aureole of the Lynx Lake pluton. Phase equilibria modelling of the rock sequence of the this contact aureole suggest equilibration pressures around 3-4.5 kbar. Displacement of isograds along faults, kinematic indicators and relative timing of movement on the shear zones indicate that vertical and strike-slip movements played an important role in the tectonometamorphic evolution of the region. Relationships and timing of metamorphism and structures suggest that peak metamorphic conditions, may have been attained during an early stage in the tectonometamorphic evolution of the Schist Lake area.

Experimental and numerical visualization of two-phase saturation maps in a rough fracture

***Peyman Mohammadmoradi*[1]*, Apostolos Kantzas*[1]**
1 – University of Calgary, Calgary, Alberta, Canada
email correspondence: seyedpeyman.mohammad@ucalgary.ca

A multi-phase pore morphological workflow is utilized to simulate fluid displacement scenarios in a rough-walled three-dimensional fracture geometry captured by x-ray microtomography. The imaging resolution is 27 µm which allows for proper construction of fracture surfaces and fluid occupancies after the segmentation of the scanned rock sample. The adapted quasi-static model extracts the pore space statistics by applying the expanding sphere concept and conducts the pore-level capillary dominant displacements assuming multiple predefined filling criteria associated with each scenario. Due to the voxel-based nature of the pore morphological algorithm, it can precisely find the pore-level fluid configurations satisfying the Young-Laplace equation. As the inlet pressure varies, capillary pressure, relative permeabilities, fluid saturations, and interfacial areas are automatically predicted. It also simply deals with tight pore throats and arbitrarily complicated geometry of solid surfaces. Here, the experimental flooding sequences are simulated and the saturation maps are compared with the experimental observations during both drainage and imbibition processes. The pore-level mechanisms which directly affect the performance of the process such fluid bypassing, preferential least resistive flow paths and snap-off of the non-wetting fluid are then demonstrated in both numerical and experimental visualizations. According to the results, the fluid occupancy is a strong function of the fracture geometry, saturations, mineralogy and the wetting characteristics of the rock.

Sedimentology, sequence stratigraphy and reservoir characterization of the 'Wilrich', Spirit River Formation, west-central Alberta

Dillon Newitt[1], *Per Pedersen*[1]
1 – University of Calgary, Calgary, Alberta, Canada
email correspondence: djnewitt@ucalgary.ca

Progradational, wave dominated shorelines form laterally extensive, laterally continuous sandstones reservoirs, which often have sweet spots that are not revealed by net sandstone maps and cross sections. The study area (T46 to 57 and R14 to 22 W5) is located within the Alberta Deep Basin in west-central Alberta. The petroleum industry referred 'Wilrich', is a wave dominated, mainly progradational, slightly aggradational, shallow marine deltaic shoreline succession that prograded northward along the foreland basin axis following a maximum transgression of the Moosebar Sea. Lateral changes in composition, sedimentary processes and trace fossil assemblages are documented in cores, together with identification of key sequence stratigraphic surfaces. Based on cored wells, sedimentary facies and stratigraphic surfaces were picked and correlated between wells based on the geophysical well log response, showing subtle variations in facies thicknesses, which together with the identification of sequence stratigraphic surfaces allows for the subdivision of the 'Wilrich' sandstone sheet into several parasequence sets. The sandstone sheet formed as laterally northward accreting shorelines, with major marine flooding surfaces separating the sandstone sheet into several parasequence sets. The progradational 'Wilrich' is the older and geographically southern parasequence sets of the Spirit River Formation clastic wedge. The 'Wilrich' is an emerging highly economic liquids rich tight sandstone play hosting a continuous hydrocarbon accumulation. This study integrates along shore variation in shore normal facies architecture, sedimentary facies, grain texture and unconventional reservoir property measurements to identify potentially higher reservoir quality zones, sweet spots.

Upper mantle and lower crustal xenoliths from southeast Yukon Territory

***Colin Padget*[1]*, Dave Pattison*[1]*, David Moynihan*[2]
1 – University of Calgary, Calgary, Alberta, Canada
2 – Yukon Geological Survey, Whitehorse, Yukon, Canada
email correspondence: colin.padget@ucalgary.ca

Xenoliths of spinel-bearing lherzolite and granulite facies paragneiss were recovered from basaltic dykes that intrude Neoproterozoic-Palaeozoic metasedimentary rocks in the upper Hyland River region of southeast Yukon Territory. The dykes are typically 1-5 metres in diameter and commonly exhibit columnar jointing along their margins. The age of the dykes is poorly constrained, but they post-date Early Cretaceous regional metamorphism and deformation. Whole rock geochemical data indicates the dykes are nepheline-normative alkali basalts, and they plot within the basanite field on a TAS diagram. The xenoliths occur as discrete subrounded to subangular fragments up to 8 cm in maximum dimension. The lherzolite samples, which consist of equidimensional crystals of olivine (~Fo90), orthopyroxene (Mg# of ~0.90), clinopyroxene (Mg# of 0.88-0.90), brown spinel (Mg# of ~0.76; Cr# of ~0.1), and Fe-Ni sulphide, exhibit smoothly curved grain boundaries. Orthopyroxene locally contains fine exsolution lamellae. Preliminary results from analyses of 18 mineral pairs using the Fe-Mg olivine-spinel thermometer provide temperatures of 807 ± 65°C (2), 819 ± 65°C (2), and 832 ± 66°C (2) at pressures of 10, 15, and 20 kbar, respectively. Granulite facies paragneiss samples contain K-feldspar, quartz, sillimanite, graphite, and 1-8 mm rounded domains that consist of patchy, symplectic intergrowths of feldspar and orthopyroxene. These domains are interpreted as pseudomorphs (after Grt?) and may record post-peak metamorphic decompression. The aim of this project is to provide an estimate of pressure and temperature conditions of the xenoliths, which may help inform our understanding of the nature of the upper mantle and lower crust in this region of the northern Canadian Cordillera.

On the path of discovery: the controversy and science behind Chicxulub crater

***Wyatt Petryshen*[1]**
1 – University of Calgary, Calgary, Alberta, Canada
email correspondence: wyatt.petryshen@ucalgary.ca

"On the Path of Discovery" is a historical case study aimed at illustrating the nature of science in geology. In 2010, a scientific consensus was published in the Journal of Science stating that the driving force behind the Cretaceous-Paleogene mass extinction was the Chicxulub bolide impact. Our understanding and interpretation of hypervelocity impact products, geophysical data, and core samples wasn't all that clear in the 1980's. This case study tracks how the reevaluation of evidence, over the course of time, allowed us to gain new insights into the processes we thought we understood. This improved understanding enabled us to adjudicate between previously contentious hypotheses on the mechanism behind the Cretaceous-Paleogene Mass Extinction, be it from volcanoes to interstellar clouds of charged particles.
The process of science is often characterized by the "scientific method", a method of hypothetical deductive reasoning. However, this is often only a pale likeness of the scientific process. The aim in exploring the nature of science is to debunk the "myth-conceptions" often taught, and to better help in assessing the reliability of scientific claims. This case study highlights the certain aspects of science like our ability to test new scientific claims, and how scientific discoveries are often tentative in nature. In essence, the creation of historical case studies can portray the real progression of science, not an idealized pattern of reasoning (1).

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Crystal chemistry and structure of anomalous birefringent cubic uvarovite garnet, ideally $Ca_3Cr_2Si_3O_{12}$

Jeffrey Salvador[1], *Sytle Antao*[1]
1 – University of Calgary, Calgary, Alberta, Canada
email correspondence: jjsalvad@gmail.com

Extensive research on the anomalous birefringence phenomenon of the garnet group of minerals still continues to be the focus and interest of many geoscientists today. Previous studies from over a century of investigations attribute the occurrence of optical anisotropy mostly, but not limited to, cation ordering on the dodecahedral {X} and octahedral [Y] sites, lattice mismatch at compositional boundaries caused by strain, and from the presence of hydrous components within the tetrahedral (Z) site. However, the origin remains debatable and is still unclear. Uvarovite, a rare mantle-derived garnet, ideally, Ca3Cr2Si3O12, is the least studied silicate end-member species. Under crossed-polarized light, this beautiful emerald-green mineral displays distinct birefringence of 0.001-0.006 with some crystals exhibiting additional anisotropic features revealing a sectored 'bowtie' structure with well-defined extinction positions. Birefringent uvarovites from Finland, California, Russia, and Switzerland are the focus of this study. Using electron probe microanalysis (EPMA) and synchrotron high-resolution powder X-ray diffraction (HRPXRD) further reveals the correlation of the anomalous birefringence in relation to crystal chemistry and structure. Our results are consistent with other anisotropic garnets analyzed with EPMA and HRPXRD, further supporting the cause of anomalous birefringence in uvarovite garnets, as derived from strain closely related to crystals containing the existence of secondary cubic uvarovite phases consisting of slight variations in chemical compositions.

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