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GEOSCIENCE RESEARCH EXCHANGE

ABSTRACTBOOK

April 6, 2018 · MacEwan Hall B

GEOREX

ucalgary.ca/georex

A message from the organizers

Welcome to the seventh 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 geosciences including hydrogeology, geochemistry, geophysics, petroleum geology, clastic sedimentology, tectonics, metamorphic petrology, and paleontology. We would also like to thank our keynote speakers Richard Simms and Paul Hoffman, as well as FATS speakers Tiera Naber and Emily Ellefson.

Over the years, GeoREX has grown into annual symposium that seeks to instill a culture of sharing and collaboration within the Department of Geoscience. 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 GeoREX become a longstanding tradition for the students of the University of Calgary.

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

Welcome to GeoREX 2018, we hope you enjoy this experience!

Sincerely,

The GeoREX Committee

Dane Synnott, Dylan Riley, Wyatt Petryshen, Tania Lyons, Chloe Duong

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

PROGRAM SCHEDULE

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Keynote

COSIA Regional Groundwater Solutions Project for the Southern Athabasca Oil Sands – Predictive Simulations on Long Term Usability of Major Aquifers

Richard Simms, MASc
Matrix Solutions Inc.

Introduction

The Canada's Oil Sands Innovation Alliance (COSIA) Regional Groundwater Solutions (RGS) project was established to evaluate the potential range of change in aquifer pressures resulting from groundwater withdrawals and disposal associated with future in situ bitumen production within the Southern Athabasca Oil Sands (SAOS) region. In 2016, Matrix Solutions Inc. took the existing RGS groundwater model, updated it, and performed the computationally intensive coupled steady-state and transient calibration using PEST software. Using the updated numerical model, three potential water forecasts were developed and simulated to explore uncertainty in the future growth of in-situ oil sands production within the SAOS region. These scenarios were identified as Status Quo, Medium Growth, and High Growth scenarios.

Summary

Predictive scenarios covered a period of 62 years from 2013 to 2075. The timing of peak change in hydraulic heads varied spatially but in general occurred between 2030 and 2040 when industry water demand was projected to be highest. Effects were evaluated relative to a benchmark of 50% reduction to aquifer available head, which is aligned with the criterion laid out for non-saline water use within the Alberta Conservation and Allocation Policy for Oilfield Injection. Although this criterion does not apply to saline aquifers, it serves as a useful reference for evaluating impacts on pressures in all aquifers.

For the Empress Channel, Lower Grand Rapids, Clearwater A, Clearwater B, and Basal McMurray Sand aquifers, all three predictive scenarios have resulted in a maximum simulated change in available head of less than 50% for more than 99% of respective aquifer area over the predictive simulation period. Areas where more than a predicted 50% reduction in available head were found to occur close to operations, where best practices and compliance with existing provincial regulations should preclude such an occurrence or would otherwise require corrective action to remedy.

In addition to the operational uncertainty assessed through Status Quo, Medium Growth, and High Growth scenarios, the uncertainty in calibrated parameters was quantified using the Null Space Monte Carlo (NSMC) methodology on the Medium Growth predictive scenario. A total of 300 realizations with independent parameter sets were used in this effort. Results from this exercise demonstrated, that the operational uncertainty as to the rate of future project development and the associated water requirements is likely the greatest uncertainty on potential future cumulative effects.

Predictive analysis demonstrates the aquifers within the SAOS regional would not experience unacceptable pressure reductions due to oil sands water production under any of the three potential/hypothetical future development scenarios. In other words, there is sufficient groundwater available to support future growth of the SAGD oil sands without adverse impacts on the sustainability of water resources.

Acknowledgements

COSIA Regional Groundwater Solutions Project Participants

Mike Brewster, Devon Canada

Louis-Charles Boutin, Matrix Solutions Inc.

Richard Simms, Matrix Solutions Inc.

Paul Martin, Matrix Solutions Inc.

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Danielle Kondla Memorial Keynote

The "end of the beginning" in the history of life on Earth

Paul F. Hoffman
University of Victoria

Planktonic cyanobacteria are important primary producers and nitrogen fixers in the modern ocean. Relaxed molecular clocks suggest that they radiated from freshwater ancestors of Cryogenian age (717-635 Ma), when the world ocean was covered by kilometer-thick 'sea glaciers' during Snowball Earth epochs lasting 57 and 15 Myr, separated by a 10 Myr ice-free interlude. They evolved from benthic filamentous forms, through adaptations favouring unicellularity and small cell size. They are abundant also in modern polar freshwater ecosystems, including supraglacial cryoconite holes and ponds, glacial meltwater streams, and meromictic ice-capped lakes. In contrast, they are notably rare or absent in the polar oceans. This distribution suggests that their success in polar freshwater habitats is not due to cold-tolerance but to tolerance of oligotrophy (nutrient starvation). In the nutrient-rich polar oceans, they cannot compete with diatoms. During Snowball Earth epochs, the total area of oligotrophic freshwater habitats greatly expanded. Cryoconite holes and ponds dotted the equatorial sublimation zone of the sea glacier, encompassing 12% of global surface area. Climate modeling suggests that a further 6-24% was bare land, on which dry valleys were occupied by meromictic (salinity-stratified) ice-capped lakes. The first Snowball Earth epoch gave cyanobacteria 57 million years to press their advantage. When it ended, the former supraglacial meltwater inhabitants, along with coastal lacustrine populations, found themselves in the meltwater lid of the global ocean. Surface waters warmed rapidly, to their benefit, and salinification was gradual over tens of kyrs, because whole-ocean mixing was retarded by the stable density stratification. The evolving planktonic cyanobacterial clades were soon pushed away from nutrient-rich coastal waters, but found permanent homes for which they were pre-adapted in the oligotrophic ocean gyres. Sterane biomarkers in ancient kerogens and oils suggest that eukaryotic primary producers and multicellular heterotrophs also first rose to prominance during the inter-Snowball Cryogenian interlude. In the history of life, Snowball Earth was "not the end, not even the beginning of the end, but perhaps just the end of the beginning" (W.L.S. Churchill, 1942).

Friday Afternoon Talk Series

Land to sea: undergraduate Arctic fieldwork and research

Tiera Naber and Emily Ellefson

What does it mean to be a student pursuing field work in the Canadian Arctic, whether it be on land or on the sea? How does a student even hear about, let alone take part in these types of opportunities? This talk helps to answer these questions, as it encompasses the aspects of travelling, field operations and field work from two undergraduate students, Tiera Naber and Emily Ellefson, working for the Geological Survey of Canada and the University of Calgary, respectively. In addition to assisting others in their research, curiosity and questions in the field led us to undergraduate research projects in order to better understand the geologic history of the high Arctic. Tiera's portion of the talk will focus on the Arctic fieldwork that took place on land in the 2016 and 2017 field seasons on northern Ellesmere Island, as well as her undergraduate thesis work on the volcanics located at Hansen Point, northern Ellesmere Island. These volcanics are a part of the High Arctic Large Igneous Province (HALIP) and may be an on-land extension of the poorly understood Alpha Ridge. Emily's portion of the talk will focus on sample collection and life onboard the icebreaker the CCGS Amundsen. In addition, she will also briefly talk about her undergraduate research on Permian-Triassic palynology of Svalbard and how pollen and spores can help us better understand terrestrial recovery after the extinction.

Is the rate of fugitive methane gas migration around Alberta's energy wells adequately estimated?

Jason M. Abboud, M. Cathryn Ryan
University of Calgary

Recent methane emission reduction efforts by the IPCC, and the Governments of Canada and Alberta make the assessment of fugitive emission sources important. Fugitive methane emissions around petroleum wells have been recognized by industry and regulators in Alberta since the early 1990s, but have proven problematic to remediate. Methane emissions are classified based on their expression at ground surface as either i) Surface Casing Vent Flow (SCVF), where methane migration from the subsurface occurs via outermost casing, or ii) Gas Migration (GM), where methane gas is observed at ground surface outside of the outermost casing and/or cement sheath. SCVF and GM must be tested for at certain points in a well's lifetime and/or at abandonment.

This work critically evaluates the degree to which methane migration is understood around Alberta's energy wells by considering the fraction of these wells that have required GM testing by regulation either during their lifetime or at abandonment.

An estimated 3.8% of Alberta's wells have required GM testing with 90 days of drilling - specifically those that were drilled in the defined 'Required Testing Area' (RTA) near Lloydminster. GM was observed in 3,574 unique wells, or an estimated 2,670 wells outside the RTA (where GM testing is not required).

All wells require SCVF testing upon abandonment, and although 61% of wells have had SCVF measurement reported, poor correlation between SCVF and GM occurrence was found in the provincial database.

It is concluded that GM rates around Alberta's energy wells are not well known under current regulations.

Toward characterizing baseline vadose zone gas conditions at Carbon Management Canada's Containment and Monitoring Institute, near Brooks, AB

Dylan Riley, BSc, MSc Candidate, GIT
University of Calgary, Applied Geochemistry Group

Gas migration (GM) from leaking energy wells and deep geological carbon storage sites must be understood, quantified and minimized for reducing atmospheric greenhouse gases concentrations to mitigate anthropogenic climate change. Currently, GM and leakage is a poorly constrained problem in Alberta, and likely other energy jurisdictions, with gas fluxes from various energy infrastructure likely being significantly underestimated. Carbon Management Canada's Containment and Monitoring Institute (CaMI) near Brooks, AB is designed to address these and other challenges from a leak and plume characterization perspective. However, prior to analyzing for leaks, characterizing the associated plumes and migration pathways due to experimental carbon injection and controlled methane release tests, the baseline vadose zone gas conditions need to be first understood. Otherwise, it is impossible to know, what conditions are naturally inherent to the area, and what conditions can be attributed to the experiments. This talk focuses on the soil gas data acquisition methodologies, gas composition analysis procedures, data analysis, and results. Discussion will focus on the challenges with using geostatistical methods for interpolation of the baseline distribution of CO_2 and CH_4 at the CaMI site. Specifically, stationarity of the data, clustering of the data, and sparseness of the data, and their corresponding maps generated using the ArcGIS program will be addressed. The, resulting baseline interpolated and non-interpolated CO_2 and CH_4 concentration distributions maps will be presented, highlighting elevated methane concentrations around wells and also show typical seasonal CO_2 levels for a semi-arid mixed grassland prairie system over the CaMI site.

Interpreting flow pathways of diurnal Elbow River water contributors during summer flow

Nicole Jensen[1], Cathy Ryan[1], Éowyn Campbell[1]
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The Elbow River is characterized by a diurnal flow cycle that persists throughout the summer and into October, controlled by snowmelt run-off, storm events, and evapotranspiration. Understanding the flow pathways of these river-dominating water sources is important for evaluating water quality and flood mitigation techniques. These river inputs can be quantified using δD, δ18O, and ions with each water source having a different signature. This study focuses on the influence of snowmelt and storm events and their interactions with the river-connected alluvial aquifer (RCAA) during the rising and falling limbs of the Little Elbow River and Big Elbow River, Alberta, during the summer months of 2016 and 2017. Water samples were collected automatically during 24- or 36-hour windows from May to September, and geochemical data was correlated to discharge. This correlation was greatest for EC and δD and highest during events with moderate precipitation influence. A goodness to fit of a daily sine curve displayed increasing correlation for SO42- and Mg2+ during increased precipitation influence. All other factors exhibited weak to no correlation and were not influenced by diurnal river cycling. Peak flow time of day was inconsistent, indicating that the source of dominant discharge contribution varied. This analysis suggests that snowmelt water is creating a pressure pulse through the RCAA while storm events contribute more directly to the rivers. This developed model provides insight to the summer flow pathways of the water entering the rivers and suggests that snowmelt is the dominant recharge source for baseflow.

Groundwater contributions to fall and winter streamflow in the Canadian Rocky Mountains

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Mountain headwaters play a crucial role in supplying water resources to downstream communities and ecosystems. Sustainable management of these resources requires an understanding of hydrologic processes in alpine environments. Fall and winter streamflows in the Canadian Rocky Mountains are largely sustained by groundwater discharge, making streamflow records a useful tool for studying hydrogeologic processes. Numerous previous studies have demonstrated the existence of relationships between streamflow recession behavior and the subsurface characteristics of hillslopes draining to streams. They have suggested that alpine landforms such as talus slopes, moraines, and rock glaciers are important sites of groundwater storage, and often consist of higher conductivity material overlying less permeable sediment or fractured bedrock. Bedrock topography at the base of these landforms has also been identified as a control on groundwater flow. In this study, fall and winter recessions in 19 streams in the Rocky Mountains were analyzed to evaluate different conceptual models of subsurface flow in alpine environments. Preliminary results demonstrate that recessions in different watersheds display common patterns, such as two distinct stages of seasonal streamflow recession. Semi-logarithmic plots of fall and winter streamflow show that discharge decreases in two linear segments in most rivers. This analysis will guide ongoing work using numerical groundwater flow models to investigate the relationships between the two-part recessions observed in mountain streams, and conductivity distributions and bedrock topography in alpine landforms. Results from this study will provide insight into the hydrogeologic processes that sustain fall and winter low flows in mountain environments and downstream communities.

Alternative Vectors for Carbon Storage (AVECS)

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Focus on environmental remediation is increasing, as many countries consider climate change, caused by anthropogenic CO_2 emissions, as a top concern. While current carbon sequestration methods are effective, they are costly and globally inaccessible. AVECS aims to develop a cost-effective method which stores atmospheric carbon in the subsurface as an inert solute. Biodegradation-resistant organic species are common in oils and provide molecular structure templates which AVECS adapts as a guide to convert biologically derived carbon-rich material into non-biodegradable and water-soluble molecules for storage in polluted shallow aquifers.

We used Fourier transform ion cyclotron resonance mass spectrometry to distinguish the molecular composition of resistant organics in biodegraded oils. The resistant species in the oils comprised sulfur bearing, C_{20}, C_{30} and C_{40} molecules with up to 13 double bond or ring equivalents. Possible chemical structures that satisfy these characteristics are sulfurized steroids, hopanoids and carotenoids. These species were likely sulfurized during diagenesis which elevated biodegradation resistance.

We modified organic lipid molecules by using sulfur incorporation reactions at ambient temperatures. After several days, molecules were sulfurized and biodegradation potential was measured using EPI Suite and ChemAxon software tools. Future work will be to improve water solubility using oxidation reactions and to expand modification experiments with biomass.

Studying the Structure of the Rocky Mountain Trench with Earthquakes

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The Rocky Mountain trench within the Canadian Rocky Mountains has a complex and unknown fault structure. Elevated heat flow values at Canoe Reach geothermal field within the trench suggest the presence of a heat source close to the surface. This study will investigate the structure of the fault to understand its influence on the heat transfer towards the surface.

The University of Calgary and a geothermal company have deployed 10 seismometers in the trench around the Canoe Reach geothermal field near Valemount, BC. Using signals from local earthquakes recorded on these instruments will help determine the structure of the fault within this portion of the trench. This presentation will include results from testing various methods for automatically detecting local earthquakes and identify which method is most appropriate for the Canoe Reach dataset. The first of these methods compares the ratio of long- to short-term energy of the seismic signals. This method identifies peaks in this ratio, which significantly increases when an earthquake is recorded. Another method is to sum signal energy for many seismometers, which also increases for recorded earthquakes. A third method detects changes in the kurtosis, a measure of the tail of a distribution, of the signal to identify arrivals. Future work will extend automated picking of arrival times to locating the earthquakes and determining their focal mechanisms. These earthquakes events will be compiled into an earthquake catalogue that will help better understand tectonic development of the Rocky Mountain trench and its connection to a geothermal system.

Developing a nonlinear relative location methodology for seismic events

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Understanding fault structures and their associated tectonic regimes are important areas of study in earthquake seismology, but the first step is locating faults. Accurate event locations are needed to locate faults. There are many location methods for earthquake events, but relative location methods, particularly joint hypocenter determination applications, show particular promise at regional or microseismic scales because of their ability to relocate earthquake clusters more precisely.

This research focuses on new relative location techniques. By augmenting datasets with new techniques for event correlations, including receiver-side cross-correlations, this methodology sorts earthquake events into correlated multiplets, multiple events that share similar source characteristics. These novel data processing techniques can improve existing location methods, but can also be applied to new methods. By jointly relocating these clusters and applying numerical methods, this research will develop a new nonlinear relative location method that will provide more general non-linear solutions to the problem than widely applied linearized solutions. The numerical methods will include efficient, massively parallel Markov chain Monte Carlo algorithms. The goal of this research is to carry-out a large-scale study of the uncertainty associated with regional and microseismic event locations and compare this new nonlinear method to the original catalog locations and other methods of relocation. This research will have both industry and global applications as precise event locations are needed in fields such as microseismic reservoir monitoring, induced seismicity monitoring, understanding fault mechanics, and many other fields.

The Influences of Structural Highlands on Channel Stacking and Reservoir Quality, Atlas Member, Saskatchewan

Shanelle Bjorndahl, Per Pedersen, Mike Blair

The Atlas Member is the uppermost unit of the Cantuar Formation in Southwest Saskatchewan, deposited during the Lower Cretaceous in an overall transgression. Locally, the sub-Cretaceous Unconformity incises into the Upper Jurassic Success and Roseray formations (J.E. Christopher, 1997). During deposition of the Atlas Member, the topography of the unconformity was variable, including the Swift Current highlands and intervening incised valley systems. Incised valley systems were infilled with complex fluvial sediments of the Cantuar Formation which are up to 85 meters thick (Figure 1) (Leckie et al. 1997). The fluvial sandstone reservoir of the Atlas Member is composed of stacked channels of commonly feldspathic litharenite that overlie the Swift Current highlands or are present at the top of the incised valley system. The purpose of this study is to compare the reservoir quality of the Atlas Member where it overlies the Swift Current highlands versus locations where it is present within the incised valley system.

Analyzing the fluvial reservoir heterogeneity and quality is conducted by evaluating channel stacking patterns (depositionally controlled) and fluid content (post-depositionally controlled) to determine the effects of structural highlands on channel reservoirs. Oil and water saturations are compared between Atlas channel sands: (1) within the incised valley system; and; (2) overlying the Swift Current highlands. Cross-sections constrain channel body architecture and geometry to determine the effects of differential compaction on deposition.

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Lithofacies determination in the Southern West Shale Basin of the Duvernay Formation: Creation, Characterization and Correlation

Blair Cann, Larry Lines

The goal of this study is to propose a set of lithofacies in the Duvernay Formation that will accurately characterize lithological variation at core and thin section scales, and correlate with conventional well logs and basic source rock data. A sedimentological assessment of seven wells within the Duvernay Formation has been undertaken and the resultant data has been used to define the proposed lithofacies. Care was taken to ensure that the lithofacies determined in this study relate to sizable inherent subdivisions seen in the core. This methodology was chosen to improve the likelihood that the lithofacies would correlate with responses of conventional well logs and source rock data allowing for future extrapolation.

Colour is successfully utilized as one of the primary lithofacies characteristics within the planar laminated mudstones of the Duvernay Formation. These planar laminated mudstones comprise the dominant reservoir in the Formation. This use of colour as a primary lithofacies characteristic has resulted in a substantial degree of correlatability with conventional well logs and source rock data. It is proposed that these lithofacies also display a predictable and logical progression of environmental change within the Duvernay Formation.

Further study will provide insight into the determined non-primary lithofacies characteristics, and the relationships that exist between the lithofacies and geochemical data, elastic properties, and proposed dynamic brittleness determination methods. Comparison of this data with data from the Northern West Shale Basin, as well as the East Shale Basin, may occur alongside an examination of the sequence stratigraphic cycles that appear to govern the natural subdivisions that were observed during core analysis.

Banff Formation – Geology Behind Scenic Outcrops

Guanyu Zhang, Milovan Fustic, Gerald Osborn, Jagos Radovic, and Chris Debuhr

The Lower Carboniferous Banff Formation of Western Canada Sedimentary Basin (WCSB) is a widespread and up to 800 m thick succession deposited on the cratonic platform in the northwestern margin of ancestral North America. Outcrop observations suggest that the Banff Formation is less resistant to erosion than underling and overlying units.

This project includes slope measurements using Digital Elevation Models (DEM) and ArcMap Spatial Analytics tools, as well as a number of analysis of selected outcrop samples from Canyon Creek and Lac des Arcs including: RockEval, Gas Chromatography – Mass-Spectrometry (GCMS), Raman Spectrometry, Scanning Electron Microscopy (SEM), XRD, XRF, and nano-scale geomechanics.

Results, integrated and interpreted in contexts of sedimentology and geomorphology suggests the strong impact of various lithologies and dispersed organic matter on differential erodibility of Banff Formation outcrops.

Refining the provenance of the Nanaimo Basin, British Columbia, Canada by LA-ICP-MS depth profiling

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The Late Cretaceous latitude of the western terranes in the North American Cordillera is contentious. Paleomagnetic and paleobotanical estimates of large Late Cretaceous to Cenozoic displacements are difficult to reconcile with geological estimates based on offsets along faults in the western Cordillera. Recent detrital zircon dating of Nanaimo Group strata are consistent with derivation from the Mojave-Sonoran region and support a southerly paleogeographic position. However, derivation from the Lemhi sub-basin of Idaho cannot be ruled out. High U/Th rims on some detrital zircons from the Nanaimo Basin are interpreted to record one or more metamorphic events that affected the sediment source area and may further constrain the provenance interpretation.

LA-ICP-MS depth-profiling was used to date <10 µm rims found on ~30-40% of zircon grains in 6 samples from Maastrichtian formations. 240 grains from each sample were depth profiled. Depth-profiling reveals that 78% of high U/Th rims (n=213) grew between 95 and 71 Ma (mode 87 Ma). The high U/Th rims become younger with decreasing depositional age and are between 7-10 Ma older than the maximum depositional age of the sample. Rims were found predominantly on cores yielding Proterozoic dates but also on Mesozoic and Archean cores.

If the high U/Th rims are indicative of metamorphism in the source area, then the timing of rim growth can be used to distinguish between potential northern and southern source areas. Our results suggest the source area underwent metamorphism between 95 and 71 Ma. The timing of metamorphism of the Lemhi sub-basin is constrained by Lu-Hf Garnet dates to be approximately between 110 and 85 Ma and thermochronology indicates the basin was cooling by 83 Ma. Metamorphic rim growth in the source area for the Nanaimo Basin sediments post-dates cooling in the Lemhi sub-basin by ~12 m.y. and derivation from this region in unlikely. The timing of rim growth overlaps with metamorphism of the POR schists of southern California (95 to 50 Ma) and is consistent with the period of flat-slab subduction in the Mojave-Sonoran region (90 to 70 Ma). Our observations support the paleomagnetic estimates for the Late Cretaceous latitude of the basin and derivation of Maastrichtian Nanaimo Group sediments from the Mojave-Sonoran Region.

Evidence for two phases of Rodinian rift-related magmatism in Cambrian rocks of western Laurentia

Madronich, Lauren, University of Calgary, lauren.madronich@ucalgary.ca
Matthews, William, University of Calgary

An understanding of the breakup of Rodinia along the western margin of Laurentia is hindered by a limited record of rift-related magmatic rocks. Previous work identified two main periods of magmatism associated with periods of crustal thinning: (1) Cryogenian magmatism synchronous with deposition of the Windermere Supergroup and (2) late Ediacaran and Cambrian magmatism associated with initiation of the Laurentian passive margin. Detrital zircons from 23 samples of basal Sauk sequence sandstones and a tuff along the Laurentian margin from central British Columbia, Canada to New Mexico, USA provide an additional record of rift-related magmatism.

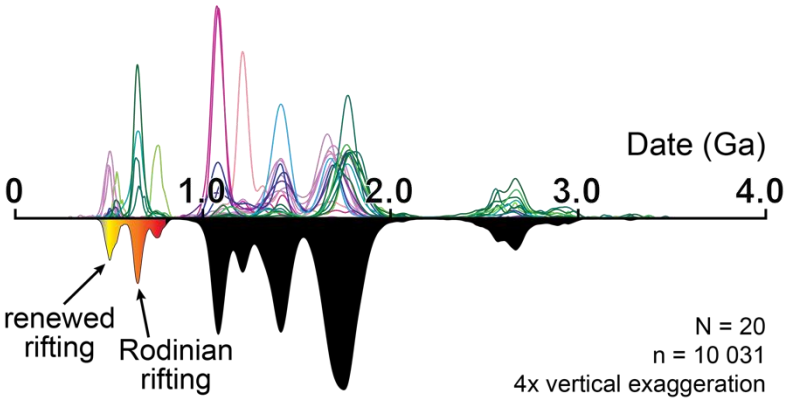

Figure 1. Overlain normalized probability density plots (PDP) of U-Pb zircons for samples of Cambrian rocks yielding grains less than 800 Ma. The PDP for all is reflected below, showing two dominant peaks of 506 and 656 Ma. Curves for northern samples from British Columbia and Alberta are green; Utah and Colorado are blue; southwestern US are pink and purple.

Over 600 zircon grains from each sample of basal Sauk sequence sandstones were measured to identify Neoproterozoic and Cambrian grains. These grains were re-ablated to reduce the uncertainty of the dates and to measure trace-element compositions. Samples from strata in Canada contain grains yielding dates of 780 Ma through 525 Ma (Figure 1; green curves). Trace-element compositions of the 780 to 600 Ma populations are consistent with mafic source rocks while the 580 to 525 Ma populations derive from sources with mixed compositions. In samples from the southwestern USA, Cryogenian age populations are much less prevalent and have compositions indicative of mafic to intermediate source rocks. Late Ediacaran to Cambrian grains are much more abundant in the south end of the study area and have mixed trace element chemistries (Figure 1; pink and purple curves).

The new U-Pb detrital zircon age and trace element data show spatial and temporal trends that enrich our understanding of the timing and mode of magmatism along the margin. A lull in magmatism between 640 and 580 Ma clearly separates Windermere events from those associated with the formation of the Paleozoic passive margin. Magmatism is dominantly mafic during the initial phase of crustal thinning during Cryogenian time. The second phase of magmatism, associated with latest Neoproterozoic to Cambrian initiation of the passive margin, is synchronous throughout the study area and exhibits mixed chemistry.

A comparison of observed and thermodynamically predicted phase equilibria and mineral compositions in mafic granulites

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Recently published activity–composition relations parameterized for minerals in upper amphibolite- and granulite-facies intermediate and basic rocks have expanded our ability to interpret petrological evolution of these important components of the lower continental crust. If such petrological modelling is to be reliable, the abundances and compositions of phases calculated at the interpreted conditions of metamorphic equilibration should be close to those in the sample under study. Petrological modelling was applied to six upper amphibolite- and granulite-facies rocks that formed in different tectonic environments and reached different peak metamorphic pressure–temperature (P-T) conditions. Whilst phase assemblages matching those observed in each sample can generally be calculated at P-T conditions that approximate those of peak metamorphism, consistent discrepancies were observed between the calculated and observed compositions of amphibole and clinopyroxene. These include: the Al/Si ratio, Ca content, and A-site K/Na ratio in hornblende; and the Fe and Mg content of clinopyroxene. These significant mismatches question the reliability of P-T estimates made using mineral composition constraints when conducting petrological modelling for high-temperature metabasites.

Comparative fracture characterization from geological media, Cretaceous Mannville Group, Livingstone Falls, Southwest Alberta

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Fractures and fracture networks are key outlets for migration of hydrothermal fluids, water and contaminants in groundwater systems, and oil and gas in petroleum reservoirs. Comprehensive analysis of natural fracture network geometry is an essential step in the realistic modeling and characterization of reservoir targets as fractures can provide preferential flow pathways, impact wellbore stability, and influence hydraulically induced fractures. This study highlights the complexity of natural fracture networks in heterogeneous reservoirs. Furthermore, the results provide guidelines for accurate fracture model generation and fractured reservoir characterization.

Mechanical discontinuities within Earth's crust are essential in understanding reservoir properties such as petroleum storage and extraction, contaminant transport and fluid flow. These structures govern the flow regimes that arise in the subsurface by acting as preferential flow pathways for subsurface fluids. Exposed bedding pavements of the Cretaceous Mannville Group along Livingstone River in southwestern Alberta were the focus of this study as they provided detailed multi-dimensional fracture network data in a heterogeneous reservoir analog. At the study site, the lower Cretaceous succession consists of a complex interfingering of marine and non-marine siliciclastic and volcanic sediments deposited during several transgressive and regressive cycles (Leckie and Burden, 2001). The Mannville Group was deposited across the Cordilleran-derived clastic wedge of the foreland basin and record the first basin-wide sedimentation (Hayes, B.J.R., Christopher, J.E., and Rosenthal, R.L., 1994) that correlates with the Blairmore Groups westward.

This study highlights both traditional and modern technological field methods to analyze fracture networks which can provide key data for subsurface reservoir models. Based on the two methods, modern techniques, with the aid of UAV's, are more accurate and efficient on a macro scale because it can correct sampling bias's compared to traditional field methods. However, traditional field techniques can help define finer details such as fractures found in outcrop too minor for drone footage to capture. By analyzing the results, a combination of both techniques provides the best models.

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Depositional Environment of the Permian Johnston and Ranger Canyon Formations near Banff, AB

Simon Wiebe

This research on the Lower Permian Johnston Canyon and mid-Permian Ranger Canyon formations in the Sundance Canyon and Tunnel Mountain localities near Banff, AB is focused on characterizing the environmental conditions present during deposition. These formations are characterized by the presence of especially large siliceous sponge spicules and little else in terms of macrofossils, raising questions about what conditions may have been present to promote the dominance of a sponge community. Methods used to explore this topic include conodont biostratigraphy, scanning electron microscopy (SEM), δO^{18} thermal ionization mass spectrometry (TIMS) analysis of conodont apatite, and whole rock x-ray fluorescence (XRF) and total organic carbon (TOC) analysis. The formations have been interpreted as being deposited on a continental shelf to slope setting, in an environment of high productivity. This setting was fed by cool, nutrient-rich upwelling waters from the Slide Mountain Ocean, which was linked to the Panthalassic Ocean. High dissolved oxygen levels prevailed, and were only interrupted by a short euxinic interval above the mid-Permian unconformity separating the Johnston from the Ranger Canyon formation. Conodonts retrieved from these units include Mesogondolella hendersoni, M. monstra, M. dentiseparata, Sweetognathus obliquidentatis, S. anceps, S. binodosus, S. merrilli, and Hindeodus spp. Productive samples tend to contain only a single genus in the Sundance Canyon locality, which may indicate eutrophic oceanic conditions. Further study will help to expand understanding on the climate and paleogeography in the area in order to fully characterize the depositional environment.

Characterization of the Canoe Reach geothermal field using ambient noise seismology

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The Canoe Reach geothermal field in Valemount, British Columbia is in the process of being developed into Canada's first geothermal power plant. Due to the subsurface complexity and lack of geophysical surveys, the structure of the crust is not well understood. Traditional seismology typically produces this data, but this method has several limitations such as uneven sampling from passive sources and limited depth resolution from active sources. Ambient noise seismology overcomes these constraints by using the homogeneous vibrations of the Earth instead. The University of Calgary and a local geothermal company deployed ten seismometers around Valemount in July, 2017. The stations are spaced from ~5 to ~43 km apart and cover an ~18 by ~43 km area. Cross-correlating the raw recorded waveforms enhances coherent signals between instrument pairs. Resulting signals show Rayleigh waves, a type of surface wave, traveling between each instrument pair within the ambient noise at a consistent speed of ~3.5 km/s. Future work will include measuring group and phase velocities from these Rayleigh waves, inverting for shear wave velocities, and creating a crustal structure map. This study will also identify whether the development of the geothermal field leads to any changes in crustal structure. Since ambient noise has been widely used in large, regional structure surveys, this project will show that this method can be used in exploration and time-lapse monitoring projects as well.

Depositional controls on organic-rich facies in a Cenomanian-Turonian mudstone succession

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The mechanisms for distributing large volumes of fine-grained sediment hundreds of kilometers across low – gradient epicontinental seas are still poorly understood. Additionally, the three dimensional facies variability in fine-grained sedimentary rocks are not well documented in comparison to their coarser-grained siliciclastic and carbonate counterparts. In order to understand the distribution of potential reservoir-facies fairways the processes that control their deposition must be known. This study aims to describe the sedimentary structures of the organic-rich Second White Specks Formation in detail in order to identify the processes responsible for the deposition of this succession.

The Second White Specks Formation is an organic-rich, mixed siliciclastic/carbonate succession. Detailed descriptions of grain size, mineralogy, cement type, and sedimentary structures will be conducted at the cm scale from core; and at the mm scale from thin sections collected at selected intervals. The bedforms for the coarser-grained siltstone and sandstone beds can easily be identified from core; however, the lamina-sets in the mudstone facies require thin section analysis to discern subtle structures and grain-size. Both the coarser-grained and finer-grained fractions need to be described to gain a comprehensive understanding of the depositional processes for the entire system.

Results from this study will contribute to assessing the hypothesis that the organic-rich microfacies in the interval of interest were deposited in relatively shallow-water, under dynamic and dysoxic to oxic conditions, rather than in a quiescent, anoxic, relatively deep water environment as suggested by traditional models for organic-rich mudstone deposition.

Phase Equilibrium of Clinopyroxene Amphiboles From Three Valley Gap, British Columbia

Tezla Hayduk

A unique outcrop of garnet-clinopyroxene amphibolite boudins is located along the Trans-Canada Highway near Three Valley Gap, British Columbia. It was originally described in 1977 and is the only occurrence of granulite-facies rocks on the highway in an area with evidence of Mesozoic aged metamorphism. The Theriak-Domino program (Capitani and Petrakakis, vers. 01.08.09) calculated the first isochemical phase diagram section, or pseudosection of these rocks. The diagram shows the theoretical phase equilibria of the boudins over a range of P-T and a(H2O). Observations of the thin sections agree with mineralogy calculated in the phase diagram (hornblende, plagioclase, clinopyroxene and quartz). Using the Thermocalc 3.33 program, P-T lines from the geothermometers: hornblendeplagioclase, hornblende-garnet, and clinopyroxene-garnet were plotted against the clinopyroxenegarnet-plagioclase-quartz geobarometer P's and T's. The intersection of these P-T lines yield 7-9kbar and 680-850^{o}C. This is a very broad range of estimated pressures and temperatures. These updated pressure and temperature estimates come both from the inverse modeling with the geothermometers and geobarometers and forward modeling from the pseudosection.

Prehnite-pumpellyite– to amphibolite-facies metamorphism in the Athapapuskow Lake area, west-central Manitoba (parts of NTS 63K12, 13)

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The Athapapuskow Lake area is part of a tectonic collage situated in the Flin Flon greenstone belt, 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 area consists of blocks bound by faults and major shear zones, within which both regional and contact metamorphism are observed. The regional metamorphic grade generally increases northward across the Flin Flon greenstone belt from prehnite-pumpellyite–facies rocks in the south, through to amphibolite-facies rocks in the north. Rocks in contact metamorphic aureoles around plutons record amphibolite-facies conditions. Late shear zones disrupt the regional metamorphic grade and overprint contact aureoles. A preliminary map of metamorphic-mineral assemblages and isograds of the area is presented. Isograds that were identified include actinolite-in, prehnite- and pumpellyite-out, hornblende-in, oligoclase-in, actinolite-out, chlorite-out and garnet-in. Two spatially important isograds are the hornblende-in and chlorite-out isograds. These have been demonstrated to be associated with major fluid release that can have implication for the generation of orogenic gold deposits. Isochemical phase diagram modelling of equilibration conditions of the rocks indicates that, in the Athapapuskow Lake area, for both contact and regional metamorphic sequences, the hornblende-in isograd occurs at pressures of 3.7–4.2 kbar and temperatures around 450°C, whereas the chlorite-out isograd yields similar pressures but higher temperatures (500–550°C).

Investigations of the structural and thermal interface between the Purcell Anticlinorium and the Kootenay Arc

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The Purcell Anticlinorium (PA), is a Mesozoic (Cordilleran) regional structure composed Mesoproterozoic- lower Paleozoic strata that are of ancestral North American affinity. These rocks have been metamorphosed at low grades within the biotite and chlorite zones. Mica cooling ages are as old as Mesoproterozoic in this domain. The Kootenay Arc (KA), which lies just west of the PA, is an arcuate salient involving highly deformed marginal rocks of North American affinity, as well as arc related rocks accreted during Cordilleran orogenesis, and reaches sillimanite grade. Mica cooling ages are in the range 100-50 Ma in the KA. This project seeks to understand the transitional structural, metamorphic and thermochronological interface between these two structural domains.

Argillaceous rocks within the Belt-Purcell Supergroup in the PA preserve bedding (S_0) and a penetrative slatey cleavage (S_{1PA}) whose dips fall within a range of 15-30 ° from that of S_0. The absence of S_{1PA} within overlying Windermere rocks indicates that the development of this cleavage occurred prior to the Neoproterozoic. Biotite and chlorite porphyroblasts in this domain postdate cleavage development. Within the Kootenay Arc, the dominant rock fabrics (S_1 and S_2) are associated with two Cordilleran deformation events: Middle Jurassic (D_1), and early Cretaceous (D_2). The D_1 deformation is characterised by a penetrative S_1 schistosity (S_{1KA}) in rocks of low metamorphic grade. These were overprinted by D_2, which is characterised by an S2 (S_{2KA}) schistosity that is axial planar to F_2 folds. D_2 deformation was accompanied by Barrovian regional metamorphism, whose low margin (chlorite/biotite zone) extends eastward into the PA.

A westward transect in the northern portion of the field area crosses the transition between the PA, in which S_0 and S_{1PA} (Mesoproterozoic) are the dominant structures, and the KA, in which S_{1KA} is deformed by S_{2KA} (both Mesozoic). The first indication of Mesozoic structural modification of the Mesoproterozoic PA structures is a crenulation of S_{1PA} that occurs in the rocks of the Aldridge formation near Kimberley, BC. The crenulations increase in intensity westward, resulting in a crenulation cleavage that evolves further into a full-blown schistosity (S_{2KA}) that is characteristic of the KA. This structural transition serves as evidence for the impingement of Mesozoic deformation signatures on the western margin of the Purcell Anticlinorium. Large scale folding of the Purcell Anticlinorium appears to be related to D_2. When plotted on a stereonet, fold axes defined by S_0 and S_{1PA} are roughly coincident with the cluster of lineations that are attributed to the crenulation of S_{1PA}, and which are contained within S_{2KA} in the KA.

Artificial Intelligence in SAGD Reservoir Development – Case Study from Christina Lake

Zheyu Shen, Darren Kodrat, and Milovan Fustic

The tremendous amount of reservoir characterization and production data becomes impossible for individuals and teams to process, compare, and analyze in a reservoir geology context.

Description of a post-steam core and interpretation of a suite of petrophysical logs including Residual Saturation Tool (RST) and time-lapse temperature logs, from an observational well from a producing oil-sands reservoir are used to identify reservoir flow units. A free open source machine learning tool (Python) is used to process data and create a training set which is subsequently used to predict the top of steam chamber, the top of conductively heated zones, and intervals with insitu generated gas.

Although results show unexpected amount of noise in produced curves the qualitative comparison with field data shows that the main objectives are achieved. Developed method and workflow can be applied in other SAGD development cases.

Petroleum Migration – Case Study from Lower Carboniferous Banff Formation

Jianuo Wang, Milovan Fustic, Yihua Liu, and Chris Debuhr

The Lower Carboniferous Banff Formation of Western Canada Sedimentary Basin (WCSB) is a widespread and up to 800 m thick succession deposited on the cratonic platform in the northwestern margin of ancestral North America. Recent work on selected cores from West-Central Alberta reveals the co-occurrence of low reflectance alginate, indicative of immature organic matter, and both solid bitumen (migrabitumen) and fluid light hydrocarbon residue (FHR) indicative of migrated oil. Furthermore geochemical (biomarker) analysis shows two distinct organic facies: marine and carbonate sourced.

To better understand source and migration phenomena one dimensional basin modeling (Genesis, ZetaWare^{TM}), SEM, and grain and bulk density (on 1.5 x 2 inch core samples) porosity and permeability measurements have been conducted.

Results, integrated in geological context suggests that: (i) micro- and nano-scale fractures and vuggy, intercrystalline, and/or intergranular porosity within tight rock are only partially occupied by oil; (i) the oil is not generated insitu (not self-sourced) but had likely migrated from the East where hot-spot locally matured the underlying Exshaw Formation; (iii) the co-existence of migrabiutmen and FHR suggests petroleum geochromatography; (iv) irregular nature of fractures that follows crystal and/or grain contacts are more likely indicative of stress changes related to uplift then tectonic stresses; (v) the mechanism of migration remains enigmatic, but invasive percolation have been favored; (vi) the widely accepted belief that petroleum migrates via narrow migration paths comprised of porous carrier beds or paths is challenged by the presence of Exshaw sourced oil in examined Banff Formation tight carbonates.

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