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**GEOLOGICAL SURVEY OF CANADA
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Survey of Canada, Calgary**

C. Jiang, L.R. Snowdon, R. Robinson, and O.H. Ardakani

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Summary: This report briefly describes highlights of the history and function of the Organic Geochemistry and Petrology group and its laboratories at the Geological Survey of Canada, Calgary. In addition to the current fossil-fuel-focused, especially petroleum-oriented analytical and research activities, the laboratory analytical capabilities and research expertise have been and could be readily applied to solving environmental issues related to organic contamination of air, water and soil, especially from petroleum hydrocarbons.

1. Background of the Organic Geochemistry and Petrology section at the GSC-Calgary

The Organic Geochemistry and Petrology (OGPet) section, to be named as Energy & Environment Organic Geochemistry section at the Geological Survey of Canada, Calgary (GSC-Calgary) has a long history of supporting government departments and regulatory agencies in their policy- and decision-making as well as industrial and academic activities related to the exploration, production and utilization of fossil fuels such as oil, gas and coal. It was renamed from the previous Energy and Environment Subdivision that embraced two separate research groups at the GSC-Calgary in the 1980s: Organic Geochemistry and Organic Petrology.

The Organic Geochemistry group was conceived in 1969 by Bob McCrossan who received permission to hire a full time chemist, Lloyd Snowdon who later obtained a PhD in organic geochemistry from Rice University in Houston and became a highly respected, globally recognized organic geochemist. One of the original justifications for the establishment of the Organic Geochemistry group (and associated laboratory) at the GSC-Calgary was that there were about 700 oil companies operating in Calgary in the late 1960s, but only foreign controlled major corporations had any organic geochemistry capability. Most companies had geologists and geophysicists but none of the medium and small sized (mostly Canadian) companies employed organic geochemists. The organic geochemistry lab was set up at GSC-Calgary to deal with the serious competitive disadvantage faced by the Canadian companies through producing survey scale (basin-wide) data sets for many of the sedimentary basins in Canada and working with companies to help interpret results and provide input to their much smaller scale play models. The analytical and interpretive capability in organic geochemistry played an important role in assisting the petroleum industry with carrying out research to ensure that they were at the cutting edge of the discipline.

In 1972, the Organic Geochemistry group was joined by the first PhD research scientist in organic geochemistry, Trevor Powell, who was trained in the UK and left a job in Australia to come to Calgary. Roger Macqueen and Jack McMillan were the initial managers of the research group until management responsibilities were assumed by Trevor Powell who then left the GSC in 1983 for a high ranked management position at the Australian Geological Survey Organization (now Geosciences Australia). With the winding down of the geology elements in the Coal Section at GSC-Calgary during the 1980s, the Organic Petrology elements of the Coal section were then merged with the Organic Geochemistry group with the addition of Fariborz Goodarzi, Wolfgang Kalkreuth and Steve Creaney to the team, and together became the Energy and Environment Subdivision (EES). Dr. Goodarzi shifted much of his research focus away from organic petrology to tracking toxic trace element dispersion from coal fired power generation (fly ash) and mineral mining and processing operations prior to his retirement. Dr. Creaney left the GSC to pursue a career in industry and Dr. Kalkreuth was laid off during the downsizing of the Federal government in the 1990s largely due to the reduced emphasis in coal petrology. The group was later named the Organic Geochemistry and Petrology (OGPet) section.

Martin Fowler, Lavern Stasiuk, Maowen Li, Mark Obermajer and Hamed Sanei joined the OGPet group at GSC-Calgary in the late 1980s and 1990s. Lloyd Snowdon and Fari Goodarzi retired in the early 2000s, and then Martin Fowler, Lavern Stasiuk and Maowen Li resigned from the GSC to pursue other opportunities in the private sector around 2010. With mounting pressure and demand from large government programs such as GEM (Geo-mapping for Energy and Mines) and GNES (Geoscience for New Energy Supply) along with a strong demand from the industry and regulation agencies for local geochemical expertise, Dennis Jiang, Andy Mort and Omid Haeri Ardakani were hired to maintain and expand the organic geochemical and petrographic capabilities at GSC-Calgary during 2012-2013. As of 2018, the GSC-Calgary OGPet section has six scientists and four technologists as shown in Table 1.

Table 1. The current organic Geochemistry and petrology staff at the GSC-Calgary

GSC-Calgary OGPet Staff member	Role	Expertise/Skills
Omid Haeri Ardakani	Research Scientist	<i>Inorganic and organic petrology:</i> (1) fluid inclusion petrography and microthermometry characterization of diagenetic fluids for their composition and temperature; (2) Cathodoluminescence (CL) microscopy of sedimentary carbonate and siliciclastic rocks for their diagenetic history; (3) White and fluorescence light organic matter microscopy of rock samples and recent sediments, reflectance measurement, maceral count in shale and coal samples; (4) Transmitted light petrography and fluorescence microscopy of all rock types (igneous, metamorphic, and sedimentary) (5) Geochemistry of trace metal elements in geologic and environmental samples
Dennis Jiang	Research Scientist	<i>Organic geochemistry:</i> (1) organic geochemical analysis and interpretation of hydrocarbons from oil, water, rock and sediments; (2) characterization of hydrocarbon source and reservoir rocks; (3) characterization of heavy oil and oilsands for their production and utilization; (4) petroleum hydrocarbons, PAHs and other organic pollutants in water and sediments from rivers, lakes and oceans
Andy Mort	Research Scientist	<i>Organic geochemistry:</i> (1) organic geochemical analysis and interpretation of hydrocarbons from oil, water, rock and sediments; (2) characterization of hydrocarbon source and reservoir rocks; (3) basin modeling of petroleum hydrocarbon resources
Mark Obermajer	Physical Scientist	<i>Organic geochemistry & database:</i> Database management and publication of bulk and molecular results of geochemical analysis and petrographic observations
Julito Reyes	Physical Scientist	<i>Organic petrology:</i> (1) qualitative and quantitative microscopic observation of organic macerals and reflectance measurement; (2) pyrolysis of OM-containing rock and sediments
Hamed Sanei (<i>on leave</i>)	Research Scientist	<i>Organic Petrology:</i> (1) Qualitative and quantitative microscopic observation of organic matter and their relationship to rock matrix; (2) Role of organic matter in soil and recent sediments
Marina Milovic	Lab Technician	Hydrocarbon sample preparation, and GC-FID and GC-MS analysis of hydrocarbon fractions
Rachel Robinson	Lab Technician	GC, High Resolution GC-MS, GC-MS-MS, GCxGC-MS analysis of hydrocarbon fractions, and lab operations
Rick Vandenberg	Lab Technician	Rock-Eval and XRF analysis of geological and environmental samples
Pat Webster	Lab Technician	Sample and data management, as well as rock sample preparation

2. Contributions of organic geochemistry and petrology: Fossil fuel and environment

The OGPet section at GSC-Calgary has a long history of serving Canada through cooperation with government departments and agencies, other divisions in the GSC, universities, and many oil companies mostly based in Calgary (Appendix A). The initial focus of the group was on ensuring that baseline data were available for many active petroleum exploration areas to help attract investment to the oil and gas industry in Canada and to carry out world class fundamental research to ensure that Canada and Canadians had access to the global advances made in the subject areas. The organic geochemistry group began by generating baseline data using drill cuttings for gas composition and total organic carbon (TOC) content analyses, mainly from the Arctic Islands. The National Energy Board (NEB) put regulations in place whereby canned cuttings were collected at frontier well sites and were provided to the GSC geochemistry group for destructive analysis. Exploration groups were also required to provide crude oil samples to the GSC-Calgary. Subsequently, the Canada-Newfoundland Offshore Petroleum Board (CNOPB) and Canada-Nova Scotia Offshore Petroleum Board (CNSOPB) put similar regulations in place, and so offshore east coast samples of cuttings and oils were also added to the GSC-Calgary geochemistry archive. These regulatory efforts evolved into the GSC National Oil Library that is currently held in the geochemistry repository and hosts >5000 crude oil samples. In return, GSC-Calgary provided analytical results back to the regulatory agencies as public documents through scholarly publications and open file reports. In order to deliver this baseline data to the regulatory agencies (and the people of Canada), the laboratory was provided with sufficient A-base operating, capital equipment and salary funds to acquire and operate a state-of-the-art facility and to carry out fundamental research and methods adaptation and development to ensure that the facility remained up to date. The current zero base-funding model provides salaries and capital equipment, but it precludes delivering baseline data without a fee for service payment from other government agencies and universities.

In addition to government and academic support, the OGPet staff also worked closely with geologists and geophysicists in the industry that were active players in the Arctic Islands, Beaufort-Mackenzie Basin and Mackenzie Corridor regions in addition to east and west coast offshore areas. While accessible to the industry partners, the archived samples and the generated results from the frontier areas have also been intensively utilized for NRCan research programs

such as the Geo-mapping for Energy and Minerals (GEM 1 and 2) and Geosciences for New Energy Supply (GNES) during the past years.

In addition to the work on frontier and offshore hydrocarbon discoveries and resource evaluation, the OGPet section also provided significant amounts of analytical service and interpretative expertise on the petroleum systems and coal deposits in Western Canada sedimentary basins during the 1980s-2000s. This resulted in a large number of GSC open file reports and peer-reviewed journal publications that provided guidance for the fossil fuel industry to optimize their exploration and production activities. For example, the “Blue Book” series of open file reports on the oil and gas endowment of essentially all Canadian sedimentary basins benefitted from the input of organic geochemists based in the Calgary laboratory. In addition to domestic activities, the highly regarded research expertise and advanced analytical facilities in organic geochemistry and petrology have resulted in the OGPet section being engaged in collaboration with numerous foreign research institutions and universities in the past, as indicated in Appendix A.

While the focus of OGPet section at GSC-Calgary has been mainly on providing analytical and research expertise critical to advancing fossil exploration and production, important studies have also been carried out dealing with environmental issues. This includes studies by Goodarzi and Sanei in the 1990s and early 2000s on characterizing fly ashes from various coal power plants, and mercury, arsenic and other metal element distribution in various river/lake sediments and their relationship to sedimentary organic matter. Collaborative work has also been carried out between the OGPet section and other GSC divisions and government departments such as Agriculture Canada on lake sediments and farm soil samples (Appendix A). Organic geochemistry expertise was provided to the Royal Canadian Mounted Police with respect to an investigation of oil spilled into Rainbow Lake, Alberta and to the Department of National Defence with regard to the remediation of a diesel fuel spill where a DND vehicle crashed and dispersed fuel into a marshy area. Analytical and interpretive expertise were provided to the Department of the Environment with regard to the Nestucca Barge spill (Sebastian Brothers Ocean Towing) off the coast of Vancouver Island. A subdivision specialist was named as an expert witness and the group provided an analytical report in preparation for legal action on behalf of the Government of Canada. Follow up laboratory work documented the

persistence of organic compounds in nearshore sediment samples obtained by Environment Canada.

In another environmental case, the Calgary geochemistry group was asked to provide expertise in a case where it was suspected that polychlorinated biphenyls (PCBs) and related dioxins and other toxic contaminants were being diluted in diesel fuel that was being imported into eastern Canada from the U.S. The lab was also asked to develop a screening protocol that could detect these compounds in real time so that trucks could be held at the border until it could be verified that their cargo was not contaminated. Two separate analytical protocols were developed and made available within 24 hours. This was possible because of the existence of suitable standard materials within the lab and the latent skill set of one of the researchers in the group.

The Calgary geochemistry group worked in cooperation with Waterloo University on a significant project to observe the rates and distances of dispersal of creosote in near surface aquifers. Calgary developed and provided analytical methods and data to a research project being run on Camp Borden, a military base in Ontario. Creosote was intentionally introduced into an already contaminated aquifer and the resulting plume monitored with over 300 downstream wells. The Calgary laboratory tracked both creosote compounds and putative metabolites obtained from test wells over several years. The significance of the results was sufficient for the U.S. Department of the Environment to fund the project for a two year extension after the original funding obtained by the University of Waterloo had run out.

GSC Calgary geochemists were also requested by Environment Canada to provide expertise on organic substances in the environment in relation to the EPA priority substances list. Similarly, GSC Calgary geochemists provided insights to an Inland Waters research group of Environment Canada regarding the observation of polyaromatic hydrocarbons (PAH) in Lake Hazen sediments (Ellesmere Island). Lake Hazen had been selected to be a “pristine” baseline because of its remote location (81°40'N 72°58'W to 81°56'N 68°55'W) and when PAH were observed in the lake sediments, the GSC Calgary group was able to provide evidence that these compounds were, in fact, naturally occurring and associated with eroding coal seams crossed by a stream flowing into the lake.

The analytical laboratories have been an important part of the OGPet section right from its conception. The labs were structured and funded such that analytical services and data were

provided to all GSC divisions as required, basin scale databases were constructed and maintained and made publicly available, and world class research projects were carried out and published by the scientists in leading international journals. At various times, large capital equipment budgets were available and equipment was maintained and operated as closely as possible at maximum capacity by a staff of up to seven technologists plus hands-on scientists. In addition, the archival of regulated sample sets of drill cores, cuttings and hydrocarbon fluids from the frontiers at the GSC-Calgary meant that samples and analytical results were generally available to address some of the important science questions that were being posed by the global geoscience and natural resources community.

3. Current geochemical and petrographic analytical facilities and research applications

The OGPet laboratories at the GSC-Calgary are equipped with state-of-the-art analytical instruments for bulk and molecular characterization of soluble organic matter, especially petroleum hydrocarbons in (1) crude oil; (2) source and reservoir rocks; (3) water from petroleum well drilling and production; (4) water and sediments from rivers, lakes, oceans and shallow subsurface. Advanced microscopic facilities with both white and ultraviolet light as well as laser sources are also available for petrographic investigation of diagenesis and rock mineral composition, for characterization and quantification solid organic matter, for evaluation of thermal maturity and history, and for characterization of diagenetic/mineralizing fluids in geological samples in particular and environmental sediment samples as well. Table 2 presents a list of the facilities and their current applications at the OGPet laboratories in GSC-Calgary.

As the OGPet laboratories are part of the GSC's Science Laboratory Network (SLN), operations of the labs are locally managed but at the direction of the SLN Coordinator located at GSC-Ottawa. SLN has benefited from large annual capital budgets from programs such as GEM and TGI in an effort to ensure that GSC labs, including OGPet, can continue to offer advanced innovative geoscience research. Analytical work requests from GSC's research projects are handled through SLN's Laboratory Study Agreement (LSA) system. Each LSA, initiated by both a project scientist and a lab proponent, needs approvals by the local lab supervisor, the project manager and the SLN manager before the requested analytical services can be commenced in the labs. For service requests from external clients including Provincial and Territorial Governments, the SLN policy remains that the required analytical work is in alignment with a research project

Table 2. Facilities and current applications in the Organic Geochemistry and Petrology Laboratories

Labs	Facilities	Current applications
Rock Sample Prep Lab	<ul style="list-style-type: none"> (1) LECO GPX200 polishers (2) Buehler polisher table (3) Westward drill press (4) Retsch RS200 vibratory disc mills 	<p><i>Rock sample preparation for organic geochemical analysis and petrographic observation:</i></p> <ul style="list-style-type: none"> (1) Sample crushing and grinding for Rock-Eval pyrolysis and solvent extraction; (2) Pellet pressing and polishing for reflectance measurement and organic maceral characterization
Wet Chemistry Preparation Lab	<ul style="list-style-type: none"> (1) Soxhlet extractors (2) Open chromatographic columns (3) API density/gravity meter (4) Crude oil distillation apparatus 	<p><i>Hydrocarbon sample preparation:</i></p> <ul style="list-style-type: none"> (1) Soxhlet extraction of petroleum source and reservoir rock samples; (2) Solvent extraction of production water samples for hydrocarbons; (3) Open column chromatography separation of crude oil and rock extracts for Saturated-Aromatic-Resin-Asphaltene (SARA) fractions; (4) Florisil SPE column fractionation of crude oil for total hydrocarbon fractions
Trace Organic Preparation Lab	<ul style="list-style-type: none"> (1) Trace organic prep facility (2) High efficiency Soxhlet extractors 	<p><i>Solvent extraction of environmental samples such as water and sediment from rivers, lakes and oceans</i></p> <ul style="list-style-type: none"> (1) Soxhlet extraction of recent sediment and soil samples for organics; (2) Solvent extraction of environmental water samples for hydrocarbons; (3) Open column chromatography separation of extracts for Saturated-Aromatic-Resin-Asphaltene (SARA) fractions;
GC and GC-MS Lab	<ul style="list-style-type: none"> (1) Agilent 7890A GC–FID (2 systems) (2) OI Analytical Purge & Trap –Agilent 7890 GC–FID (3) Agilent 7890 GC–5973 MSD 	<p><i>Hydrocarbon compositional analysis:</i></p> <ul style="list-style-type: none"> (1) Saturated fraction GC-FID analysis; (2) Whole oil/extract GC-FID analysis; (3) Total hydrocarbon GC-MS analysis; (4) Aromatic hydrocarbon fraction GC-MS analysis; (5) Crude oil Gasoline range GC analysis;
Advanced GC-MS Lab	<ul style="list-style-type: none"> (1) Agilent 7000C GC–TSQ–MS (2) LECO Pegasus GCxGC–TOF-MS (3) Agilent 7200 GC–qTOF–MS 	<p><i>High sensitivity & resolution hydrocarbon compositional analysis:</i></p> <ul style="list-style-type: none"> (1) GC-MS analysis of saturated biomarkers using GC-TSQ-MS; (2) GC-MRM-MS analysis of saturated and total hydrocarbon fractions for biomarkers using GC-TSQ-MS; (3) High resolution GC-MS/MS analysis of saturated and total hydrocarbons using GC-qTOF-MS; (4) High resolution GC-MS analysis of saturated, aromatic and total hydrocarbon fractions using GC-qTOF-MS for biomarker characterization; (5) Compositional fingerprinting of whole oil and total hydrocarbons using GCxGC-TOFMS

Table 2. (Continued)

Labs	Facilities	Current applications
Py-GC Lab	(1) Frontier EGA/PY 3030D and Agilent 7890A GC– 5975C FID/MSD	<i>Direct compositional fingerprinting of volatile and semi-volatile organic matter from solid samples:</i> (1) Online GC analysis of thermally desorbed hydrocarbons and other volatile organic matter released before 350°C; (2) Online GC analysis of flash pyrolysates from rock, sediment and organic materials heated at 500 to 850°C; (3) Compositional kinetics of hydrocarbon generation;
Rock-Eval Lab	(1) HAWK Pyrolyzer, Wildcat Technologies (2) Rock-Eval 6 pyrolyzer, Vinci Technologies	<i>Bulk analysis of property of organic matter in rock, sediment and soil samples:</i> (1) S1, S2, S3, S4 and S5 peaks, as well as HI, OI, TOC%, Tmax (°C) parameters on source rock, environmental sediment and agricultural soil samples; (2) Total carbonate content determination (3) Bulk hydrocarbon generation kinetics
Pyrolysis Lab	(1) Parr high pressure and high temperature reactor vessels (250 and 500 mL size) (2 sets) (2) Swagelok plug & cap mini reactors (30 mL volume)	<i>Hydrous and anhydrous pyrolysis</i> (1) Pyrolysis rock and sediment samples at 290 to 350°C for days to weeks to simulate hydrocarbon generation; (2) Pyrolysis of other organic materials at high temperature and pressure;
Microscopic Petrography Lab	(1) Zeiss Axioimager II microscope with Diskus-Fossil (2 systems) (2) Zeiss Axioscope A1 (2 systems)	<i>Microscopic observation of sedimentary organic matter, rock/sediment mineral matrix and geo-fluids:</i> (1) Reflectance measurement, and white and florescence light characterization of organic macerals in sedimentary rocks; (2) Matrix characterization of diagenetic phases using Cathodeluminescence (CL); (3) Fluid inclusion petrography (white and fluorescence light) and micro-thermometry characterizing the temperature and chemistry of diagenetic and mineralizing fluids for thermal history/burial history, diagenesis, ore geology, and hydrocarbon migration and charge studies
micro-Spectral Lab Lab	(1) ThermoFisher micro-FTIR (2) Renishaw micro-Raman	<i>Microscopic scale spectral characterization of matrix and organic matter:</i> (1) Raman identification, mapping and quantification of rock matrix minerals, solid organic matter, and fluid inclusion; (2) FT-IR spectral characterization of rock matrix minerals and organic matter

being carried out at the GSC, and the analytical results can be utilized by GSC research staff for scientific publications and disseminations after a confidential period agreed upon by both parties (usually 1 year). It also should be noted that all external requests have to be accompanied with a scientific justification from the lab proponent or a local project scientist, and to be approved by the SLN Coordinator, SLN Director and the Director General. The justification needs to show clearly that the analytical results can be integrated into current research projects or that it is beneficial to the Canadian public interest to carry out the analytical work at the GSC, and that the analytical service provided is not competing against service providers in the private sector. Analytical services for other Federal Government Departments can be approved at the SLN Director level. Current prices for analyses are available upon request.

With the increased alignment of the SLN's functions with the NRCan's science and technology (S&T) mission of being "to build a sustainable Canadian resource advantage through S&T excellence", the research activities and laboratory services at the OGPet over the past decade or so have been mainly centered on projects under various research programs being executed across all divisions of the GSC. These projects include:

1) Canada-Nunavut Geoscience Office Program

- Govt. of Nunavut (David Mate; S00150-NU62)
- Canada-Nunavut Geoscience Office (Serge Basso; 340200-CNGO)

2) Energy Geoscience Program

- PERD FOG Program (Keith Dewing; 331405-NU62)
- Tools for EIA for Metal Mining (Alexandre Desbarats; 341303-NL2J)
- Coal & Oil Resources and Environment Sustainability (Martine Savard; 341304-NL2J)

3) Environmental Geoscience Program

- Shale Gas–Ground Water (Denis Lavoie; 341307-NL2J)
- Tools for EIA for Metal Mining (Alexandre Desbarats; 341303-NL2J)

- Coal & Oil Resources and Environment Sustainability (Martine Savard; 341304-NL2J)
- EIA in the Northern Environment (Sharon Smith; 341302-NL2J)
- Metal Mining: Northern Baselines (Michael Parsons; 341309-NL2J)
- Shale Gas–NB Aquifers (Denis Lavoie; 341310-NL2J)

4) Geo-mapping for Energy and Minerals (GEM) Program

- GEM Coordination (Alain Leclair; 340411-NU62)
- Hudson Bay/Foxe sedimentary basin (Sonya Dehler; 340436-NU62)
- Petroleum Systems of the Eastern Arctic (Sonya Dehler; 340435-NU62)
- Petroleum Systems of the Western Arctic (Carl Ozyer; 340434-NU62)
- Yukon Sedimentary Basins (Carl Ozyer; 340432-NU62)
- Mackenzie Delta Corridor (Carl Ozyer; 340433-NU62)
- GEM II-Mackenzie Corridor (Carl Ozyer; 340540-NU62)
- GEM II-Shield to Selwyn North-Central Transect (Carl Ozyer; 340542-NU62)
- GEM II-Hudson/Ungava Region (Rejean Couture; 340510-NU62)
- GEM II-Western Arctic-Beaufort-N. Yukon (Carl Ozyer; 340530-NU62)
- GEM II-Stratigraphy of Petroleum Basins (Rejean Couture; 340514-NU62)
- GEM II-Hydrocarbon Source Rocks (Rejean Couture; 340515-NU62)
- GEM II-Coppermine River (Carl Ozyer; 340546-NU62)
- GEM II-Baffin-Hudson Ungava High Resolution Bathymetry (Lila Chebab; 340517-NU62)
- GEM II-Sverdrup Basin-Stratigraphy/Petroleum Systems and Mineral Potential (Carl Ozyer; 340533-NU62)
- GEM II-High Arctic Large Igneous Provinces (Carl Ozyer; 340532-NU62)
- GEM II-Pearry Terrane, North Ellesmere (Carl Ozyer; 340534-NU62)
- GEM II-Geo-Transect (Glen Stockmal; 340544-NU62)

5) Geosciences for New Energy Supply (GNES) Program

- GNES–Shale resource assessment (Zhuoheng Chen; 331404-NU63)

- GNES–Shale reservoir characterization (Hamed Sanei; 331403-NU63)

6) Targeted Geoscience Initiative (TGI) Program

- Tectonic influence on Gold (Kathleen Lauziere; 340348-NU61)

4. Future Applications

Although the majority of research projects and analytical services in the OGPet section have been associated with petroleum and coal, the current analytical instrumentation capabilities for compositional fingerprinting of soluble organic matter and microscopic observation of insoluble organic matter can be readily applied to many environmental issues. Various pieces of pyrolysis equipment operated in either a stand-alone or instrument coupled mode provides the ability to analyze complex mixtures of very high molecular weight materials including kerogen, the NSO fraction, asphaltene, extra-heavy oil (e.g., bitumen) and humic materials. Similarly, this equipment is useful for simulating geological processes yielding crude oil from source rocks and following the thermal evolution of coal and other organic matter types during geological burial and exposure to geothermal stress.

The occurrence of various types of organic matter in water and sediments can be determined using both bulk and compositional geochemical techniques as well as optical spectroscopic procedures. This will help to elucidate the sources of organic contaminants in the environment, either natural or anthropogenic. The commissioning of the newly built Trace Organics Lab at GSC-Calgary will be especially beneficial to the group's capability in environmental geochemical research in the following areas:

- Hydrocarbon (and salt) contamination by flowback water from hydraulic fracturing operations during unconventional well drilling and completion. An investigation of the hydrocarbons (and the various minerals and metal elements) in the flowback water will not only help industry and regulators to determine the best method of waste water management but also provide critical information for determining the efficiency of artificial fracturing practice in enhancing hydrocarbon recovery from shale and tight reservoirs.

- The occurrence of petroleum hydrocarbons, especially PAHs in major rivers, lakes and ground waters from regions where industrial extraction of fossil fuels are active. Areas with large scale oilsand and heavy production via SAGD and open pit mining is one major targets for this type of research. Another one will be the shale gas/oil drilling and completion sites where management of drilling mud and flowback water from hydraulic fracturing and other operations may be a challenge.
- Soil contamination from crude oil at historic well sites and along oil pipelines. A geochemical investigation of the hydrocarbon properties of soil samples collected from the surroundings of well drilling and high-risk sites along the pipelines can help to identify the occurrence of oil contamination from improper disposal of oil-based-drilling mud and utility/operation fuel, from well-testing or production crude flow at well sites, and potential oil spills from pipelines. This will provide information essential to the subsequent land remediation and management.
- Hydrocarbon occurrence in seawater associated with natural oil seeps. A positive detection of natural hydrocarbons in sea water may indicate potential subsurface oil generation, migration, reservoir destruction, or a combination of these processes, and will act as a lead for future offshore exploration and development as well as establishing a baseline background prior to any commercial exploitation.
- Occurrence of various hydrocarbons and metals like nickel and vanadium in urban storm water related to asphalt road paving. Asphalt has been widely used in road paving material, and can be a significant source of toxic chemicals such as polyaromatic hydrocarbons, and the elements nickel and vanadium in surface water and groundwater.
- Bulk and compositional characterization of organic matter in lake water and sediments and their relationship to various toxic metals sourced from mining activities.
- Organic matter in sediments from putatively pristine lakes as indicators of climate and environmental change.

Appendix A: Past and current OGPet lab service users and project collaborators

Government Agencies & Departments

1. Geological Survey of Canada-Atlantic
2. Geological Survey of Canada-Quebec
3. Geological Survey of Canada-Ottawa
4. Canada-Newfoundland Offshore Petroleum Board
5. Canada-Nova Scotia Offshore Petroleum Board
6. Canada-Nunavut Geoscience Office
7. Agriculture Canada
8. Fisheries and Oceans Canada
9. Environment Canada
10. Royal Canadian Mounted Police
11. Department of Indian and Northern Affairs
12. Department of National Defence Canada
13. Canadian International Development Agency
14. National Research Council (IRAP)

15. Alberta Geological Survey
16. Alberta Research Council (Alberta Innovates Technologies)
17. BC Geosciences
18. Manitoba Geological Survey
19. National Energy Board
20. Nova Scotia Department of Energy
21. Nunavut Department of Economic Development and Transportation,
22. NWT Geological Survey
23. Ontario Geological Survey
24. Quebec Ministry of Natural Resources
25. Saskatchewan Geological Survey
26. Yukon Geological Survey

27. China Geological Survey, China
28. Chinese Academy of Sciences, China
29. Geological and Nuclear Sciences (GNS), New Zealand
30. Geological Survey of Denmark and Greenland, Denmark
31. Geosciences Australia, Australia
32. International Committee for Coal and Organic Petrology (ICCP)
33. IFP (French Institute of Petroleum) Energies Nouvelles, France
34. Japan Oil, Gas and Metals National Corporation (JOGMEC), Japan
35. Korea Institute of Geoscience and Mineral Resources (KIGAM), South Korea
36. North Dakota Geological Survey, USA
37. United States Geological Survey, USA

Educational Institutions

1. Acadia University
2. Brock University
3. Dalhousie University
4. Laurentian University
5. McGill University
6. Memorial University
7. Queen's University
8. St. Mary's University
9. University of Alberta
10. University of British Columbia
11. University of Calgary
12. University of Manitoba
13. University of McGill
14. University of Victoria
15. University of Waterloo
16. Western University

17. Memorial University
18. Aarhus University, Denmark
19. Ben-Gurion University of the Negev, Israel
20. China University of Geosciences, China
21. China University of Petroleum, China
22. Curtin University, Australia
23. Southwestern Petroleum University, China
24. Technical University of Crete, Greece
25. Yangtze University, China
26. Ocean Drilling Program International Consortium

Industry

1. AEC International
2. AGAT Laboratories Ltd
3. Alberta Energy Company
4. Alconsult International
5. Anadarko Petroleum
6. Apache Canada
7. Apex Engineering Inc.
8. Applied Petroleum Technology (Canada) Ltd
9. ARC Resources
10. Birchcliff Energy
11. Birch Mountain Resources Ltd
12. BP Canada
13. Canadian Natural Resources Ltd. (CNRL) Canadian Occidental Petroleum
14. CBM Solutions Ltd.
15. Chevron Canada Ltd
16. ConocoPhillips Canada
17. Core Laboratories

18. Devon Canada
19. Dome Petroleum
20. EOG Resources
21. EnCana Corporation
22. Esso Canada
23. Gulf Canada Resources Ltd.
24. Gushor Inc.
25. Hunt Oil Company
26. Husky Energy
27. Hycal Energy Research Laboratories Ltd.
28. Imperial Resources Ltd
29. International Frontier Resources Corporation
30. Japex
31. Junex Inc. (Quebec)
32. MGM Energy Corp.
33. Murphy Oil Co. Ltd
34. Nexen Inc.
35. Northcliff Resources Ltd.
36. Northern Cross Yukon Ltd.
37. Northrock Resources Ltd.
38. Oilsand Quest Ltd.
39. PanArctic Oils Ltd.
40. PanCanadian Petroleum Ltd.
41. Paramount Resources Ltd.
42. Parker Solutions Inc.
43. Pengrowth Corporation
44. PetroBank Energy and Resources Ltd.
45. PetroChina
46. PetroCanada
47. PetroCanada International Assistance Corporation

48. Schlumberger Canada
49. Shell Canada
50. Sherritt International
51. SinoPec
52. Source-Eval Ltd.
53. StatOil
54. Stealth Ventures Ltd.
55. Suncor Energy
56. Talisman Energy
57. TerraTek-Schlumberger
58. Tiger Resources
59. Total Canada
60. Tourmaline Oil Corp
61. Trident Explorations Ltd.
62. Tundra Oil & Gas Ltd.
63. Wascana Energy Inc.