BCGS
BC Geophysical Society

Geophysics applications to environmental, civil and mining engineering studies; Dennis Woods, Ph.D., P.Eng., Discovery Int'l Geophysics Inc.; Director, BC Geophysical Society

Over the past half century and more, applied geophysics has been instrumental in creating wealth and comfort for society vis-à-vis critical scientific input for petroleum and mineral exploration. Indeed, our science can arguably lay claim to the greatest increase in the quality of life in history and from that, the greatest advancement of human existence in the arts, entertainment, health, leisure, etc.

But the advancements have not come without problems, serious problems in some cases. However, when these problems are of a geological nature or at least have a "geological" component, then applied geophysics also has an important role to play in recognizing, defining, investigating, understanding and ultimately solving these problems. Other geo-disciplines have a role to play, but it is geophysics, by its very definition - the study of the interior of the earth by physical means - that plays a central role.

Today's symposium is all about "geological" problem solving using applied geophysics. We discuss a wide variety of problems and an even wider gamut of cutting-edge geophysical techniques to help solve the problems.

Bio: *Dennis Woods is a principal in Discovery International Geophysics Inc., a full-service geophysical contractor and consultancy, specializing in electromagnetics, induced polarization and resistivity. The company is particularly focused on innovative techniques and scientific research to improve the application of geophysics to the discovery of new mineral resources.*

Dennis has a long career in mineral exploration geophysics, which has included a tenured position as Assistant Professor of Applied Geophysics at the Department of Geological Sciences, Queen's University in the 80's, and Chief Geophysicist of Granges Inc. (later Vista Gold Corp) in the 90's. He has been a consultant thorough most of his career, and has founded a variety of geophysical contracting companies in Canada, USA and China.

From Bulletin 121 to Brumadinho: The Increasing Frequency & Severity of Tailings Facility Failures: Navigating the Decade 2020-2029; David Chambers, Center for Science in Public Participation

In 2011 (Chambers & Higman) the authors published the results of their research into worldwide tailings dam failures. This research, which involved developing the most complete list of tailings dam failures publically available (www.worldminetailingsfailures.org), showed the rate of tailings dam failures over the period 1940-2010 was relatively constant. There are two immediate implications of this finding. First, efforts to implement regulatory, engineering, and operating changes to lower the rate of tailings dam failures are not having the desired effect. Second, because the rate is staying the same, and the number of mines is increasing, the number of failures is also rising. In 2017 we (Bowker & Chambers) updated our data to include the half-decade from 2010-2014. We segregated the data into several different categories in accordance with observed impact, and noted that the failure rate remained essentially the same for the most important Serious and Very Serious failures. We also found a correlation between the production of copper ore, an analog often used for metal production in general, and the number of failures. We now have data for next half-decade, 2015-2019, and will show how this new data relates not only to the trends observed in previous decades, but also how it compares to the predictions we made for this time period, and what we predict for the next decade if significant changes to present practices for the design, construction, operation, and closure of tailings dams are not made.

Bio: *David Chambers is the president of the Center for Science in Public Participation, a non-profit corporation. He has 40 years of experience in mineral exploration and development – 15 years of technical and management experience in the mineral exploration industry, and for the past 25+ years he has served as an advisor on the environmental effects of mining projects both nationally and internationally.*

David has Professional Engineering Degree in physics from the Colorado School of Mines, a Master of Science Degree in geophysics from the University of California at Berkeley, and is a registered professional geophysicist in California (# GP 972). Dr. Chambers received his Ph.D. in environmental planning from Berkeley. His recent research focuses on tailings dam failures, and the intersection of science and technology with public policy and natural resource management.

Safe design of tailings dams: how geophysics can help; Harvey McLeod, P.Eng., P.Geo., FEIC, Klohn Crippen Berger

Tailings dam designs have evolved over the years from simple upstream placement, to engineered complex structures. The principles of soil mechanics, upon which the designs are based upon, was developed in the 1930s to 1950s with rapid advancement, and knowledge of building dams, taking place after the second world war. Engineered tailings dams, which respect the principles of soil mechanics, started in the 1960s and continues to evolve. The types of tailings, the types of tailings dams, and the slow evolution of thickening and filtering technologies, present the designer with a wide range of options for design. Recent tailings dam failures highlight the requirement to understand the geotechnical properties of the dam foundations and the dam materials. Geophysics is a valuable tool for collecting spatial data and case examples of the application and use of seismic and resistivity surveys are shown to identify anomalies and to interpret the density and types of soils. Seismic cone penetration testing with pore pressure measurements (SCPTu) is a valuable tool for assessing upstream tailings dams. Monitoring technologies which are used to detect changes in the dam performance continue to be developed and improved with the key parameters being pore pressure and deformation. Continued development of geophysical investigation/monitoring technologies and the application of sound soil mechanic principals, with integration of water management and geochemistry, form the basis for design, operation and closure of safe tailings dams.

Bio: *Harvey McLeod is a geotechnical engineer with 45 years of experience in all aspects of tailings dams. He has a degree in geological engineering from the University of British Columbia and a Masters of Soil Mechanics from Imperial College, London, UK. Harvey has worked on hundreds of tailings dams in all types of physical, climatic and social conditions in over 30 countries. He has been active with the International Commission on Large Dams (ICOLD) for 20 years and is currently Chair of the Subcommittee on Tailings Dams. Harvey supported the British Columbia Ministry of Energy and Mines with the Chief Inspector's investigation into the Mount Polley tailings dam failure and was Chair of the Subcommittee on redrafting the tailings dam regulations. Harvey also chaired the Engineers & Geoscientists of BC's production of the Guideline on Dam Foundation Characterization, which was a recommendation of the Panel Report on Mount Polley. In 2016, he presented the RM Hardy Keynote Lecture at the annual Canadian Geotechnical Conference in Vancouver.*

The Gamut of Tailings Dam Geophysics; Graham Parkinson, Klohn Crippen Berger

For initial tailings facility site selection and alternatives assessments, a range of potential sites need to be compared. Tailings sites often initially have limited access, so geophysics is typically the first investigative technique used. Each of the subsequent design stages rely on increasingly detailed understanding of the characteristics of tailings dam foundations. During operations, the emerging internal properties of embankments and impoundments that develop during dam raising rise are also key inputs to the required stability assessments. At facility closure, conditions change again, and the performance of both the embankments and tailings consolidation behaviour continue to be important. Examples are presented from across the full range of geophysical methods which show site investigation objectives changing throughout the entire life cycle of tailings facilities. Geophysical techniques used at various stages from design, operations and closure are presented. Factors that limit the application of geophysics are examined in the hope that better use can be made of the full potential of geophysics.

Bio: *As a consultant in the mining industry with Klohn Crippen Berger (KCB) for the last 25 years, Graham has a wide variety of experience in the mine development, engineering, geophysical, and environmental sectors. Graham has bachelor's degrees in physics and geophysics from UBC and U of A. As Senior Geophysicist at KCB, one of his responsibilities is the assessment of proposed and existing tailing dams and dam sites, and investigations for the remediation of dam deficiencies. KCB also uses geophysics extensively on hydrogeological and environmental assessments of tailings dams and other dam structures. Graham's 35 years experience in geophysics is drawn from the engineering, exploration, and oil / gas sectors and includes airborne, marine, surface, borehole and push cone surveys; seismic, radar, radiometrics, magnetics, IP, streaming potential, electromagnetic, multi-electrode resistivity, INSAR and other studies.*

Failure is not an option: tailings dam investigations with geophysics and the Mount Polley review; Doug McConnell, P.Eng., P.Geoph., DMT Geosciences

The publicly available Expert Review Panel, Report on Mount Polley Tailings Storage Facility Breach, highlighted "the need to improve the geological, geomorphological , hydrogeological and possibly seismotectonic understanding of sites proposed for tailings dams" [1]. Although not specifically mentioned in the best available technology (BAT) and best applicable practices (BAP) sections, it is proposed here that the geophysical profession can have a specific role to play in improving this understanding in particular by helping to achieve the thoroughness that the review panel implies needs to be applied to such studies.

[1] [1]2015, Report on Mount Polley Tailings Storage Facility Breach, Independent Expert Engineering Investigation and Review Panel, Government of British Columbia p.132.

A few of the specific points from the review will be discussed with examples from before, during and since 2015 used to show how geophysics plays a part in achieving objectives related to the recommendations.

The use of the word failure here, does not necessarily apply to the resulting constructed structure, but can apply to failure to apply the most cost effective, appropriate, but thorough methodology and technology so that the geophysical study itself successfully meets the objectives.

It is necessary to acknowledge that the best use of geophysics is either to provide useful information to help design a drill program or to extend information derived from a drill program and identify areas for further investigation. In engineering applications aside from a few specific ASTM guided physical property measurements, geophysics cannot stand alone from a drill program. It is also necessary to understand the limitations of the various geophysical methods and to make recommendations based on the results with a full understanding of these limitations. Finally, it is important to recognize that professional Geophysicists are the best source of information during planning for selection of tools, technology, methodology and parameters for geophysical surveys but this can only be done with effective two-way communication.

Through examples three key responsibilities of geophysicists engaged in geotechnical engineering surveys are highlighted. These are:

- Improving communication between Geophysicists and Geotechnical, Civil Engineers, and other Geoscientists to prevent failure in reaching the objective with the geophysical study,
- As always there is a discussion of the limitations of geophysical methods and technology,
- Finally, the inescapable conclusion that thoroughness in the investigation is a must, and extends to the geophysical approach, in these sorts of investigations where the public trust is on the line.

Another statement in the Expert Panel Report: “Thus, the path to zero leads to best practices, then continues on to best technology”. To this it could be added that thoroughness in investigations is of prime importance, and this is also where Professional Geophysics can play a significant role.

Bio: *Doug is the Director responsible for the management of the Geophysics Department at DMT Geosciences. DMT Geosciences is the Canadian Subsidiary of DMT GmbH & Co. KG., based in Essen Germany and is a member of the A Member of the Tüv Nord Group of companies. Doug has over 35 years of geophysics experience ranging from data acquisition, interpretation, project management and senior management at geophysical service companies. Doug has been involved in geophysics for mining, oil & gas and water exploration, and specializes in environmental and engineering applications. His activities have taken him to many countries and different geological domains worldwide, but since 2003 he has been focused on* *the Western Canadian Sedimentary Basin. Doug earned a B.Sc. Engineering Geology from Queen's University in 1984, and an M.B.A., from York University in 1994.*

3D Electrical resistivity imaging (ERI) investigations of surface tailings facilities and underground mine operations; Michael (Max) Maxwell, Ph.D., P.Geo., RMC**;** Golder Associates Ltd.; Robert Eso, Nova Mining Exploration Solutions

The advent of multi-electrode resistivity systems and inversion modeling has provided geophysicists with a powerful tool for imaging subsurface resistivity variations to solve engineering and environmental problems. While 2D electrical resistivity profiling with multiple lines can image the third dimension, 3D layouts can provide even better delineation of subsurface volume variations. In the past 15 years, we have been applying 3D ERI methodology to provide information for civil, environmental and mining investigations to resolve geology and water flow/seepage at surface and underground sites. We provide a review of this work including applications at tailings and power dam facilities, mine shafts, and underground evaporite mines. Our work has been carried out in conjunction with Doug Oldenburg and students of UBC-GIF.

Bio: *Max has more than 40 years of experience in geophysical surveys around North America and internationally. He has conducted geophysical investigations on diverse mining, geotechnical, and environmental projects ranging from small to large scale, including pipeline and road routing, hydrocarbon, contaminant and other hazard detection, marine port and linear infrastructure surveys, underground mining exploration, and mining and infrastructure development. He has extensive experience in various environments including arid and cold regions, mountain, arctic and Antarctic surveys, marine and terrestrial work, underground and surface mining. He also continues geophysical research work in a range of geophysical techniques and particularly 2D and 3D ERI through his affiliation with the University of British Columbia as an Honorary Research Associate. The 3D ERI application work includes 3D imaging of water flow in tailings and power dams and at underground mine sites.*

Radar imaging of TSFs and the potential of 4D tomographic monitoring; Jan Francke, Groundradar Inc.

With regulators intensifying their scrutiny of tailings dam design, construction and monitoring, there will be an increasing reliance on real-time surveillance technology to provide foresight of impending issues. Methods such as slope stability radar, lidar, seismic sensors, extensometers, prism reflectors and satellite radar are established methods of monitoring external changes to a dam. Geophysical instruments are often employed as forensic methods to structural integrity once issues have been identified.

Amongst the numerous geophysical methods suitable for dam integrity evaluations, ground penetrating radar (GPR) offers the highest resolution and can detect subtle changes in moisture. However, GPR suffers from a series of constraints, including limited depth of imaging and cumbersome equipment for deep penetration. Radar cross-hole tomography has been applied in some studies, although the limited cable length for the probes, as well as the cost and complexity of such surveys, have limited its use.

Recent developments in GPR instrumentation and antenna design hold the potential of revolutionizing the use of radar monitoring from within dam structures. Miniature radar monostatic transceivers with on-board data logging have been designed with diameters less than 20 mm. The cost of these units could be in the range of hundreds of dollars, compared to over $25,000 for a consumer-grade system. With complete systems being within the realm of disposability, the concept of permanent installations of radar sensors may be realized. Further improving the viability of such a concept is the development of nano-engineered magnetic antennas, which reduce the size of traditional dipoles by a factor of 20 or more. Complete 30 MHz systems, with antennas and batteries are now pocket-sized, enabling the possibility of closely spaced strings of such sensors controlled via fiber optics from a solar-powered control unit at surface, all mesh-networked via the mine's existing infrastructure or LTE modems.

With strategic geometric positioning of an array of sensors, beam forming and steering may be future possibilities. Limited penetration issues are mitigates by long-term stacking to improve SNR as well as the one-way ray paths inherent for tomography.

These concepts are being developed presently, with the focus not necessarily on accuracy of measurements, but on continuous monitoring for change detection. Longitudinal studies will develop baselines for predicting seasonal moisture fluctuations, and live data streaming to cloud-based processing will provide immediate feedback of abnormal readings to stakeholders.

Bio: *Jan has spent his 27-year career working with long-range GPR in 93 countries. He now develops custom radar technologies for exploration, geotechnical and security applications.*

The role of geophysics in quantitative geotechnical hazard assessment; John McGaughey, Mira Geoscience

Quantitative hazard assessment means computing the probability of geotechnical failure in various contexts, including failure of natural and engineered slopes, tunnels, mine infrastructure, and tailings dams. Within each context there may be multiple failure modes, each of which must be assessed independently because they depend on different underlying factors. Geophysics plays a supporting role by providing important data sets to the integrated geotechnical hazard assessment problem.

As an example, geotechnical hazard in mining is universally understood to depend on many apparently disparate factors acting together, such as stress, stiffness, mine geometry, rock mass character, rock type, structure, excavation rate and volume, blasting, and seismicity. Geophysics has a role in quantifying several of these. We have worked on many projects over the years in both underground and open pit mines with the objective of defining the correlation of such factors with the experience of failure. Whether that failure is slope failure, strainbursting, fault slip-induced rockbursting, roof fall, or any other of many possible failure mechanisms, statistical correlations among the different classes of data can be found, and predictive rules for understanding geohazard based on their quantitative combination can be established and deployed in day-to-day operations. This approach requires application of methods and avoidance of pitfalls that can be standardized into a universally applicable workflow.

The workflow we have developed can in practice be used to drive either knowledge-driven or data-driven hazard computation, including deployment of modern machine-learning methods. Success demands four-dimensional (x, y, z, t) data integration as a pre-requisite: a fundamentally difficult problem. We describe a process and software framework that solves the pre-requisite 4D data integration problem, setting the stage for routine application of quantitative hazard estimation, from simple knowledge-driven (when a history of failure is not available) to data-driven (when it is), including AI or machine learning methods. The workflow and software system bring together structured and unstructured data and interpretation, from drillhole data to all types of geological, geophysical, rock property, geotechnical, mine production, fixed-plant, mobile equipment, and mine geometry data to provide a "data fusion" capability specifically aimed at applying predictive techniques algorithms to geotechnical problems. It does this by maintaining 3D and 4D geometrical data structures, upon which multiple data sets are projected, interpolated, upscaled, downscaled, or otherwise transformed appropriately for each data type so that the variables of importance for each problem can be co-located in space and time, a requirement for the application of any analytics algorithm.

We summarize the concepts and the workflow with case study results, highlighting the role of geophysics in quantitative geohazard assessment.

Bio: *2019 marks the twentieth anniversary of John's founding of Mira Geoscience. Prior to that, he spent 10 years at the Noranda Technology Centre in Montreal as a Senior Scientist in their rock mechanics group. John obtained his PhD in geological engineering at Queen's University and has spent his career working in multi-disciplinary 3D and 4D earth modelling, primarily in mineral exploration and geotechnical applications.*

Shear landstreamer profiling for dam and levee investigation: Single pass MASW, P- & SH-wave reflection technology; David Schieck, Echo Environmental and Geotechnical Services Ltd.

Shear wave velocities (Vs) within consolidated rocks are typically ½ the corresponding compressional or P-wave velocities (Vp) (Vp/Vs ratios ~2), however, within unconsolidated soil materials the ratio of Vp/Vs is often within the range of 6-12. This means vertical resolution of shear wave data within the near surface material, even if recovered frequencies are ½ that of P-wave, are 3 to 5 times higher when time sections are converted to depth. Recent near surface seismic reflection developments using a land-streamer have been commercialized in the Western Canadian by repurposing former exploration seismic equipment. A 16,000 lb IVI Envirovibe is retrofitted with a 6,000 lb shear vibrator pack that can be rotated to transverse or inline orientation. An exploration 'ARAM lite' recording system has been mounted in the cab, 72X10Hz 3 component geophones are mounted on metal sleds spaced 1.5 m apart towed along a kevlar belt. The high multiplicity and large energy source enables high resolution, quantitative investigations in the range of 8 – 200m depths, not possible with any other geophysical methods ideally suited to earth dam applications.

Bio: *David Schieck obtained a BSc. at the University of Western Ontario and got his first job at Geo-X systems in Calgary. At a time when 3D seismics was very new, David wrote 3D data processing code for Geo-X and went on to become the companies first 3D group leader. Early 90's he left Geo-X and was one of the founding graduates of the newly established CREWES project at U of Calgary where he worked on analyzing ground roll dispersion and removal from P-Sv processing. After a one year contract with a Calgary engineering firm acquiring high resolution seismic in the jungles of Suriname to identify high liquefaction clays, David started a small engineering seismic firm (GAPS) in Guelph, Ontario.*

GAPS acquired high resolution seismic for engineering, groundwater and environmental projects in SW Ontario and Nova Scotia. GAPS eventually began working for O&G exploration in NE USA and grew to a full service seismic firm which he sold in 2006. David continued consulting to former clients in SW Ontario until late 2014, until he was hired as the operations geophysicist at Husky Energy where he worked on slip-sweep acquisition and shear wave processing in the Lloydminster area before his position was downsized in early 2016. David took advantage of the downturn and bought two Envirovibes, built a 3C landstreamer from unused ARAM MkII equipment and partnered up with Echo Seismic to start a new environmental and engineering division that is promoting shear-shear high resolution seismic.

Distributed fiber-optic sensing (DAS) in geophysical and engineering applications; Martin Karrenbach, Optasense Ltd.

Distributed Acoustic Sensing (DAS) has matured into a technology that has found application in many different scientific and industrial fields. Using a laser source, a standard telecom-grade optical fibre can be turned into an array with thousands of virtual sensors. All electronics are located away from the sensors, enabling deployment in circumstances where high pressures, high temperatures or other constraints preclude traditional electronic sensing systems. The availability of thousands of sensors along the fiber yields large amounts of high resolution data which can be used in novel algorithms and analysis techniques. After a short introduction to the physical measurement principles, we will show a variety of recent geophysical and engineering applications.

Bio: *Martin Karrenbach is Sr. Manager Innovation at Optasense Ltd. where he is focused on developing novel techniques, algorithms and software in support of fiber-optic sensing data to allow acquisition, processing, imaging and integration with standard seismic, microseismic, flow and engineering data. Prior to joining Optasense he was leading borehole seismic technology development at various small innovative companies. He has a strong interest in computational geophysics and physical system modeling and welcomes interdisciplinary research and development. Dr. Karrenbach received his Ph.D. in Geophysics from Stanford University, M.Sc. in Geophysics from the University of Houston and Vordiplom Physik from Karlsruhe University. He is a member of SEG, EAGE, AGU and SPE.*

Using borehole magnetic resonance to detect free and bound water in tailings and estimate hydraulic conductivity to predict resistance to static liquefaction failure in upstream tailings dams; Marcus Donaldson, Ph.D., Qteq Pty Ltd.; Riaz Tejani, DGI Geoscience Inc.;

Static liquefaction in upstream tailings dams are rare events, but the consequences can be disastrous as witnessed in recent dam failures. These failures happen when loose soils are loaded and cannot adequately drain. Generally, this is associated with clays or other fine-grained material with low hydraulic conductivity. Establishing a depth correlated hydraulic conductivity baseline of a tailings dam is critical in predicting and preventing failures of this type. Additionally, monitoring changes to hydraulic conductivity over the life of the dam considers the dynamic nature of the problem and provides updates to baseline measurements.

Borehole Magnetic Resonance (BMR) allows for the direct quantification of hydrogeological parameters such as total porosity, specific yield, and specific retention. BMR also provides permeability estimates as empirical relationships of these same parameters. Measurements are taken on a decimeter-scale sampling allowing for the detection of relatively thin layers of impermeable material. This technology has been used for decades in the oil industry to predict permeable formations and understand reservoir flow properties. It is now being applied to groundwater and mining applications as tools have become smaller, and more suitable to the borehole diameters typically encountered in mining.

Here we present the capability of using BMR measurements in tailings to predict zones of increased or decreased permeability. The BMR tool can be used in open-hole environments to directly asses the subsurface flow parameters in tailings and provide real-time data. Additionally, measurements are conducive to cased monitoring holes of sufficient diameter (75 mm or greater). The BMR tool can directly measure permeability changes over time with repeated runs. Repetitive runs over time allow for the continued assessment of hydrogeological parameters of dams and improves a dam owner's ability to predict and prevent failure.

Bio:

Marcus Donaldson received a PhD in Magnetic Resonance from the University of California, Berkeley before working with Schlumberger to develop downhole magnetic resonance measurements and tools for oil and gas. He currently works with Australia-based Qteq to provide magnetic resonance solutions to the broader georesources community and partners with geophysical logging companies to bring these measurements to the mainstream.

Riaz Tejani is a business development professional at DGI Geoscience Inc., one of the largest in-situ borehole surveying service-providers in Canada. DGI's partnership with Qtec has introduced borehole magnetic resonance solutions to the minerals/mining & civil/infrastructure development industries within Canada. He is an Engineering graduate from the University of Alberta.

Geophysical Site Investigations at the WAC Bennett Dam; Cliff Candy, Caitlin Shaw-MacLaren*, Frontier Geosciences

After the 1996 discovery of sinkholes at the WAC Bennett Dam in British Columbia, a broad range of geophysical investigations were carried out. This work concentrated on establishing the subsurface extent of the sinkholes and a search for other possible defects. A subset of effective geophysical methods emerged. The crosshole shear wave seismic method proved to be a useful monitoring technique, and continues to be conducted annually. This method is described, and representative results are shown. Technological advances have enabled high resolution underwater inspection using robotics and remote sensing technology. In 2013, this survey was carried out to inspect for defects, and establish a baseline digital elevation model for monitoring. This methodology is described, and examples of the detailed maps are shown.

Bio: *Caitlin Shaw-MacLaren is a geophysicist who graduated from the University of Victoria with a B.Sc. degree in geology and physics and has over a decade of experience in geophysical consulting. Caitlin is a Director of Frontier Geosciences and is experienced in managing a wide* *range of geophysical projects within the engineering, geotechnical, and mining communities. Caitlin specializes in marine and terrestrial seismic methods.*

Peace Project Aquifer Study; Melvyn Best, Ph.D., Bemex Consulting Int'l

The Peace project was a multi-year aquifer study covering a region from just north of Fort Saint John up to the Sikanni Chief River valley. The size of the region was approximately 40 km SW-NE by 120 km NW-SE. The project was coordinated by Geoscience BC and included input from First Nations, local municipalities as well as several petroleum companies. The main goal of the project was to provide an overview of groundwater potential within the region by carrying out a regional aquifer study. The study included 1) a regional depth to bedrock study, along with indications of sand and gravel sections within the Quaternary section, by interpreting the shallow section of approximately 1300 gamma logs obtained from existing petroleum wells (carried out by Petrel Robertson and Quaternary Geosciences) and 2) a 21,000 line km airborne electromagnetic survey with a SW-NE line spacing of 600 m and a tie line spacing of 2400 m (carried out by Skytem) , 3) enhanced processing of specific areas selected from the gamma study and input from First Nations, petroleum companies, and the municipality of Fort Saint John (carried out by Aarhus Geophysics), 4) selection of wells to test geological models (M Best and Levson), 5) comparison of the geological and petrophysical logs from these wells to the initial geological interpretation (V Levson and M Best), and 6) assessing the regional aquifer and hydro-geological potential by the integration of all the available data (carried out by SFU). A large number of companies and individuals were involved with the project, each contributing their expertise to reach the goals set out by Geoscience BC. Significant new information on bedrock depth and distribution of paleochannels were obtained from this study. A better understanding of the interaction between surface and groundwater was also gained from the study. A discussion on interpretation problems and the lack of continuity of sand and gravel aquifers within the paleochannels showed there are still difficulties involved in interpreting such a heterogeneous environment (caused by multiple advance and retreat phases of glaciations). In conclusion, SFU provided recommendations for further work within the Peace region, such as specific ground geophysical studies, more drilling and logging, and a Skytem survey in the southern section of the Peace region.

Bio: *Mel Best began his 30 year career with Shell in Calgary in the minerals department researching the development of an airborne EM system, which he then developed at Shell's research center in Rijswijk, Netherlands: the SWEEPEM airborne EM system. A number of patents and research publications emerged from this project as well as a prototype system. Later, he moved from the minerals department to head up petroleum engineering research for Shell in Calgary. He later left Shell to work for Teknica Resource Development Limited, developing artificial intelligence workstations for seismic processing and interpretation.*

Mel joined the Geological Survey of Canada (GSC) as head of the Basin Analysis Subdivision responsible for research related to the east coast offshore and eastern Arctic hydrocarbon basins of Canada. Dr. Best became Director of the Pacific Geoscience Centre (Division of the GSC) in Victoria, British Columbia 4 years later. As Director, he was responsible for earthquake and seismic studies on the west coast of Canada as well as west coast marine geoscience and Cordilleran geophysics. He stepped down as Director after another 4 years to become a senior research scientist working on environmental and ground water problems. He took early retirement from the GSC after 11 years and started a geophysical consulting practice in oil and gas exploration and production as well as for ground water and environmental studies.

Using AUV Electric Field measurements to monitor the integrity of cathodic protection systems on subsea pipelines; Karen Weitemeyer, Ph.D., Brian Claus, Peter Kowalczyk, Matthew Kowalczyk, Ocean Floor Geophysics Inc.

Ocean Floor Geophysics (OFG) has a successful history of developing numerous magnetic and electric field instruments for ROVs, AUVs and deep-tow systems across a range of applications: resource exploration (SMS mineral and gas hydrate deposit mapping) and for monitoring of seafloor infrastructure, such as off shore pipelines. Each application involves the measurement of electric fields at its heart, however subtle variations of the technique lead to many different methods such as controlled source electromagnetics (CSEM), spontaneous or self potential (SP), non-contact integrated Cathodic Protection (iCP) inspection, Underwater Electric Potential (UEP).

Non-contact monitoring of subsea pipeline cathodic protection (iCP) activity has become an important application. The OFG AUV "Chercheur" performs very well in this role, allowing for the rapid and efficient inspection of subsea infrastructure through the calculation of current flows, anode wastage, and for the detection of damage and anomalies not apparent by other AUV inspection instruments. Extensive field trials were done over a hydrocarbon pipeline in the North Sea. Even though the pipeline exhibited very little electrical activity, the OFG AUV iCP system was able to measure the electrical activity along the pipeline, quantify the current flow of each anode, and calculate the voltage profile along the length of the pipeline.

The OFG AUV iCP system integrates high resolution positioning, camera imaging, multi-beam measurements, synthetic aperture sonar (HISAS), sub-bottom, chemical sensors and other data acquisition sensors, coupled with high data acquisition rates. The OFG AUV iCP system provides a compelling set of measurements for pipeline cathodic protection monitoring and pipeline inspection.

Bio: *Karen Weitemeyer joined Ocean Floor Geophysics in 2017 and is an expert in marine electromagnetic (EM) methods. She has over 10 years world-wide experience in the collection, processing, and modelling of marine EM data. She participated in the development and the collection of the first commercial iCP data set. Karen received her PhD in 2008 from the University of California, San Diego while studying at the Marine EM Lab at Scripps Institution of Oceanography and obtained her BSc (Hon) Geophysics in 2003 from the University of British Columbia.*

Proactive Infrastructure Monitoring and Evaluation (PRIME) Installation in Canada: Protecting National Railways by Monitoring an Active Landslide near Ashcroft, British Columbia; David Huntley*, B.Sc., M.Sc., Ph.D., Peter Bobrowsky, Geological Survey of Canada; Kelvin Sattler, David Elwood, University of Saskatchewan; Jessica Holmes, Queen's University Belfast; Jonathan Chambers, Philip Meldrum, Paul Wilkinson, British Geological Survey; Michael Hendry, Renato Macciotta, University of Alberta

Resilient railway transportation networks require sustainable, cost-effective management of service operations to meet future socioeconomic needs and ensure protection of the natural environment. Where transportation corridors traverse unstable terrain, critical rail infrastructure is a risk of damage and presents potential local and national economic, social and environmental challenges. Monitoring unstable slopes and infrastructure at risk is a cost-effective hazard management practice that also provides important geoscience information to help develop appropriate mitigation measures. In western Canada, the majority of rail freight and passenger trains pass through the landslide-prone Thompson River valley in the Interior Plateau of British Columbia. Landslides studies in this vital transportation corridor began in the late 19^{th} Century. In the early 21^{st} Century geotechnical investigation, remote sensing and global positioning technologies monitor slope instability. These methods, combined with terrain mapping and geophysical surveys have provided necessary sub-surface information to understand the spatial and temporal variations in activity at Ripley Landslide, 7 km south of Ashcroft. This is a small feature (approximately 4×10^5 km^3) but representative of landslides failing in this portion of the transportation corridor, and of importance since both national railway companies have their tracks and infrastructure traversing the landslide. Electrical resistivity tomography results (and corroborated by other geophysical techniques) have hinted at an unusual distribution pattern for surface moisture and groundwater in fractured bedrock and overlying clay-rich sediments containing vertical tension cracks and sub-horizontal shear surfaces. Rapidly drained coarse-grained colluvial, fluvial and anthropogenic units have high apparent resistivities (>500 Ωm). Poorly drained fine-grained glaciolacustrine and morainal units have low to moderate apparent resistivities (<50-200 Ωm). A proactive infrastructure monitoring and evaluation (PRIME) system, installed in November 2017, continuously monitors seasonal changes in electrical resistivity across the headscarp and main slide body. For 2017-2018, changes in ground resistivity attributed to seasonal variation in sub-surface moisture. Precipitation (rain, snow) and ground temperature are recognized as important controls on the distribution of infiltrating soil water and groundwater flux in the slide body. Slope stability at this site is highly sensitive to moisture content. From late spring (March) to early fall (October) when ground temperatures are >0ºC (i.e., unfrozen), infiltrating precipitation results in a progressive decrease in resistivity at depth as the moisture content of sub-surface clay-rich units increases. Over this period, Thompson River levels are high and support the submerged portions of the toe slope. It is during this period that GPS and InSAR monitoring indicate minimum rates of surface displacement. Between late fall (November) and early spring (February), resistivity values increase in glacial deposits as snowfall blankets the slope, the ground freezes (<0ºC) to an estimated depth <2 m; and the river reaches its lowest level. The greatest displacement rates indicated by GPS and InSAR occur with during winter and spring when transitional ground conditions allow snow melt and rainfall to penetrate deep into the still-frozen (or thawing) slide body by way of tension cracks, planar fractures and bedding surfaces. The PRIME system continues to collect data and will provide a more refined picture of moisture-driven processes for landslides in this semi-arid terrain. PRIME time-series data will help reduce the costs of maintenance and improve the effectiveness of mitigation plans. Understanding the impact of season variations in ground resistivity will enable us to develop moisture paths and thresholds for the prediction of slope failure at Ripley Landslide and, by extension, other slides in the Thompson River transportation corridor.

Bio: *David Huntley is a research scientist with the Geological Survey of Canada, with interests in Quaternary landscapes and geohazards (in particular, landslides and tsunamis). The research presented is a collaboration with the British Geological Survey, University of Alberta, and University of Saskatchewan at Canada's premier landslide test site.*