

March 2018

# ETD

EXPLORATION **TRENDS** & DEVELOPMENTS

Advances in  
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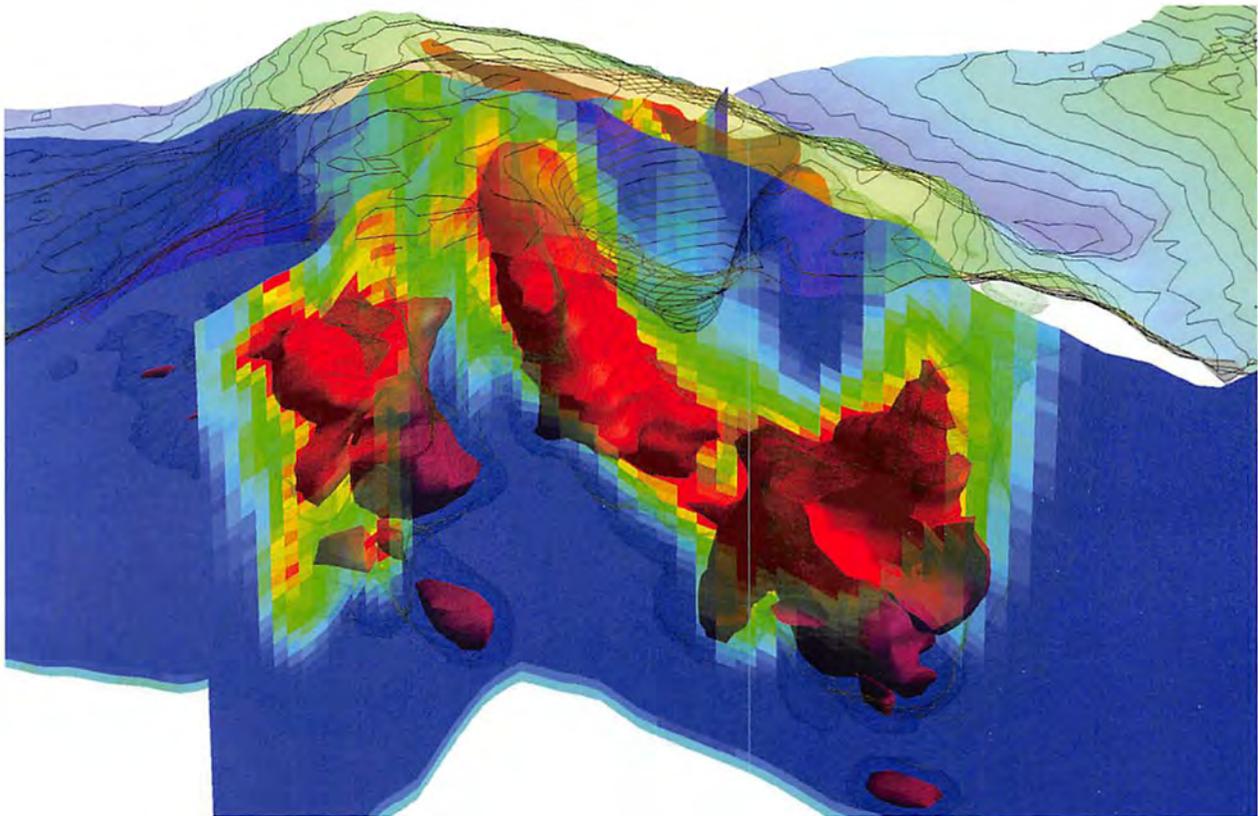
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is an annual publication prepared by Patrick G. Killeen  
9759 Highway 509  
Ompah, ON  
Canada K0H 2J0  
Phone: (613) 479-2478  
E-mail: pkilleen@xplor.net.ca

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*The Northern Miner*  
38 Lesmill Rd, Unit 2  
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M3B 2T5  
Phone: (416) 510-6789  
E-mail: tnm@northernminer.com

**Editor:**

David Perri

**Writer:**

Patrick G. Killeen

**Art Director:**

Melissa Crook

**Production Manager:**

Jessica Jubb

**Advertising Sales:**

Joe Crofts

Michael Winter

**Publisher:**

Anthony Vaccaro

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Cover photo: Flying-Cam's SARAH e 4.0 unmanned helicopter, equipped with a Scintrex CS-VL cesium-vapour magnetic sensor and RMS Instruments' AARC51 adaptive aeromagnetic real-time compensator, in flight near Chifeng, Inner Mongolia, China. Credit: Flying-Cam



**MINERAL EXPLORATION TRENDS AND DEVELOPMENTS IN 2017**

By Patrick G. Killeen Ph.D., Geophysical Consultant and retired Research Scientist, Geological Survey of Canada, Ottawa

This is the second year that Decennial Mineral Exploration Conferences (DMEC) has served as the patron for *Exploration Trends & Developments*. Last year was the lead-up to the very successful Exploration 17 conference, held in Toronto in October. This year DMEC support came from the companies listed in the sponsor's box below.

The ETD review originated with the Geological Survey of Canada (GSC), where for more than 50 years GSC scientists prepared an unbiased annual publication on trends and new developments in geophysical exploration for minerals. This marks the 26th year that Patrick Killeen has written the review, originally as a GSC research scientist.

The Canadian Exploration Geophysical Society (KEGS) was the patron of ETD between 2007 and 2016. DMEC and KEGS are committed to the promotion of geophysics, especially as it is applied to exploration for minerals other than oil: to fostering the scientific interests of geophysicists; and to promoting high professional standards, fellowship and co-operation among persons interested in this industry.

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A double-crew from Abitibi Geophysics setting up a gravity and GPS base station in sub-Arctic taiga, 100 km north of Schefferville, Quebec.

## EXPLORATION TECHNOLOGY IN 2017 THINGS ARE PICKING UP

Credit: Abitibi Geophysics

The pace of work in global mineral exploration picked up in 2017 with more exploration dollars invested than in 2016. Companies reported increased sales of geophysical instrumentation and the number of surveys carried out. One airborne survey contractor outfitted an additional aircraft to meet demand. However the increase in activity was not evenly distributed as some companies reported steady business related to mining, but increased activity in other applications like environmental, groundwater, agriculture and geotechnical. This was to be expected as companies sought out non-mineral applications for their technology in previous lean years. The trend to form partnerships, agreements and joint projects continued. At least one company moved to expanded office space to handle numerous new projects and personnel.

As in previous years there was an increase in the amount of data recorded and processed, as new geophysical equipment had more channels, more components, faster sample rates and even more parameters measured. "Integrating the geosciences" was the theme of October's Exploration 17 conference in Toronto, which begged the question: "Can we generate useful conclusions and interpretations from all of these data?"

The year saw several firsts in airborne surveys and data processing. New systems saw their first commercial surveys, some completely new system prototypes began flying, and combined airborne/ground EM systems are evolving with transmitters on the ground, including one with the ground Tx wire deployed and retrieved from a helicopter in flight. New AEM systems are lighter, fly faster and at lower costs.

Comparison studies of inversions for four TDEM surveys

over a nickel deposit were done as well as the compilation of geophysical signatures of 25 deposits. Inversion capabilities were expanded to include more methods and joint inversions with numerous datasets from both airborne and ground surveys. New UAV magnetic survey systems evolved including one with "sense & avoid" technology for low-level (e.g. 5 m) surveys that fly over obstacles (e.g. tall trees). Two companies developed gamma-ray spectrometer equipment for UAV platforms.

Ground geophysics saw R & IP testers for use on samples or outcrops extended for use in drillholes, and a new magnetic susceptibility meter with a 10-fold sensitivity increase. Data inversion software was improved with an expanded number of parameters, better 3-D visualization, new 3-D inversion of larger datasets in a shorter time and new methods to manage drillhole and sample data. Borehole geophysical technology saw expanded geophysical logging services, development of several new probes, including a neutron probe with an electronic neutron source that can be switched off, a BHEM system with automatic noise recognition and removal and borehole gravity logging with increased speed. Ground EM saw new systems with greater volume of investigation both vertically and horizontally, a new sensor that measures B field and dB/dt simultaneously on all three axes, new radio imaging tomography and new availability of low-temperature SQUIDs. There are new R & IP techniques and methodology, expanded capacity from 350 to 650 receivers/channels in distributed arrays, new IP receivers, new EM noise cancellation software for field use, new emphasis on EM/MT calibration in specially-built chambers, networking of GPR units for seismic-style multi-fold data collection and a new portable gamma-ray spectrometer for ground, borehole and airborne surveys. **ED**

# CORPORATE HIGHLIGHTS

**A**bitibi Geophysics of Val d'Or, Que., reported 2017 was a good year with several innovative projects going into production with results that exceeded expectations. InfiniTEM XL surface TDEM mapped a mineralized lens that a previous fixed-loop TDEM survey missed in the shadow of a larger parallel zone. The increase in both vertical depth and lateral investigation of InfiniTEM XL allows wider reconnaissance line spacing without missing a target, reducing exploration costs. The borehole version of InfiniTEM XL has a correspondingly large radius of exploration. The company introduced ARMIT 3 TDEM sensor in 2017 and it is now possible to define a depth-of-exploration threshold and rely on ARMIT InfiniTEM XL to effectively investigate to that depth. These new configurations generate more data, so to maintain on-time delivery, Geosoft's VOXI processing solution was formally adopted. Abitibi has also entered into several agreements and partnerships to promote useful exploration technology.

Paris-headquartered CGG Multi-Physics acquires, processes, and interprets airborne, marine and land geophysical data for resource exploration and geological mapping, from offices in Toronto and around the world. In 2017 the company launched the CGG Multi-Physics Imaging group, consolidating data processing and interpretation, technical consulting services and commercial software development into a single global team. It is claimed to be the largest and most diverse non-seismic imaging group in the resource industry.

Crone Geophysics & Exploration of Mississauga, Ont., reported increased interest in its Pulse EM TDEM system both for system sales and contract surveys compared to 2016, as well as expanded use of its 3D E-SCAN IP/R technology. Crone's increased emphasis on R&D has resulted in new and improved instrumentation in 2017.

Geophysics GPR of Longueuil, Que., reported that the company now offers geophysical survey services for mineral exploration worldwide through its offices in Botswana, and in partnership with KTTM Geophysics in Colombia, IIC Technologies in India and SubMap Geophysics in Malaysia.

Geotech's new Integrated Helicopter Gravity-ZTEM-Magnetic system in flight.



Terraquest's helicopter magnetic gradiometer system on survey in Ontario's Ring of Fire district.

Credit: Terraquest

**Geotech**, based in Aurora, Ont., and its international subsidiaries offer airborne geophysical surveys and consulting services using its VTEM helicopter time-domain EM system and ZTEM natural field EM helicopter and fixed-wing systems. It also flies fixed-wing and helicopter magnetic, radiometric and gravity systems in North America and abroad. In 2017 the first commercial surveys were flown with two new systems: VTEM ET (Early Time) helicopter system and the new Integrated Helicopter Gravity-ZTEM-Magnetic system over several projects totalling 11,000 line-km. The Integrated System combined the standard ZTEM helicopter sensor and towed-bird cesium magnetometer with the **Canadian Micro Gravity GT-2A** airborne gravimeter, on-board an Astar B3 helicopter.

**Medusa Sensing** of Groningen, Netherlands, reported strong interest from the agricultural and environmental markets in the company's geophysical survey systems and increased demand for gamma-ray surveys for soil mapping. The company intensified collaboration

with South African, Canadian and Chinese partners to apply its sensors for agricultural purposes. Collaborative research programs of three PhD students began with the nuclear accelerator lab of the **University of Groningen**, the **University of Wageningen** and the **University of Waterloo**, focused on Radiation Physics, Agricultural Studies and Geophysics, respectively.

Toronto-based **Paterson Grant & Watson (PGW)** recently moved to a larger office in the same building to accommodate multi-year international projects initiated in Laos, Democratic Republic of the Congo and India, as well as an increase in personnel. In India, PGW partnered with **International Geoscience Services and Datacode** to form **IDPeX Private Ltd.** IDPeX was awarded the technical supervision and quality control contract for the first of three years of a more than 3 million line-km aeromagnetic and radiometric survey for the **Geological Survey of India**. PGW also completed interpretation projects in Canada, Ireland and Africa, and is now managing data acquisition and interpretation projects

in Mexico and South America. The company, which is focused on geology-driven geophysical consulting and structural interpretation services, celebrated its 45th anniversary in 2017.

Concord, Ont.-based **Pico Envirotec Inc (PEI)** supplies airborne and ground geophysical survey systems worldwide including off-the-shelf instruments and customized, turn-key systems. In 2017, PEI delivered multiple units of the PGIS-2 portable gamma-ray spectrometer system in China and the U.S. including four PGIS-2-1 (1-litre detector) units employed in environmental surveys of old uranium mines by the **U.S. Department of Energy**. A PGIS portable spectrometer suitable for use on a UAV is in development and is expected to be ready early in 2018. The battery-powered system with no electrical connections to the UAV, includes integrated GPS and laser altimeter and capability to transmit data for real-time viewing. PEI has been working on delivery, installation and testing of an airborne gravity meter in Vietnam and new magnetic survey systems for clients in Mexico. A new Mag/Spec system is in production



for delivery to China early in 2018. The company continued its upgrade program, whereby older DOS-based systems can be traded in towards the purchase of the newest hardware. Pico Envirotec Inc. will be renamed **NUVIA Dynamics Inc.** starting January 1, 2018; the address is unchanged. NUVIA Dynamics will continue providing the same products, services and support to customers around the world.

Toronto-based **Quantec Geoscience** reported a greater use of its IP and MT technologies at mine sites in the last year, as well as growing demand across the globe. Surveys were carried out in Africa as well as eastern Europe and across the Americas. Quantec, after 30 years, refreshed its branding with a new red logo.

**Radiation Solutions Inc. (RSI)** of Mississauga, Ont. reported that it was status quo in geophysical sales for 2017 which included airborne gamma-ray spectrometer systems to Africa, Asia, Australia and North America. The company saw steady business with mining geophysics customers and increased activity with clients in other applications.

“  
In 2017 Terraquest flew both fixed-wing and helicopter surveys in the U.S., Mexico, South America and Canada, including helicopter magnetic gradiometer operations in Ontario’s Ring of Fire.

Ottawa-based **Sander Geophysics Ltd. (SGL)** specializes in high-resolution airborne surveys for petroleum and mineral exploration and environmental mapping. SGL offers fixed-wing and helicopter, gravity, magnetic, EM, radiometric, methane and scanning LiDAR surveys, using state-of-the-art technology. To date, the company has flown more than 13 million line-km of airborne geophysical surveys worldwide and 2017 was another good year. SGL has developed new markets for its unique AIRGrav system, as the company initiated a large gravity survey in the Middle East for geoid modelling. SGL flew the final phase of a three-year EM, magnetic and radiometric survey in Ireland and the company was recently awarded a follow-on three-year contract with the same system.

Vancouver based, **SJ Geophysics** saw increased demand for their universally-distributed Volterra acquisition system, with a mix of IP and EM projects in the Dominican Republic, Greenland, Panama and Turkey. In addition to acquiring geophysical data, the company provided inversion modelling, interpretation and on-site data quality supervision services related to a number of international projects. Internally, the R&D team worked on fine-tuning the Volterra acquisition system hardware. The highly-sensitive induction magnetometers were further calibrated, closely monitoring results and characterizing the frequency response to determine the influence of potential long-term drift in the response of the sensors. The Volterra unit’s timing was greatly improved, and uncertainties in

the data due to noise and other factors were significantly reduced. Developments in the signal processing package capabilities included improvements in the MT/CSAMT processing codes.

**Terraquest** of Markham, Ont. provides high-resolution airborne geophysical surveys including gravimetric, magnetic, horizontal gradient, radiometric, and VLF-EM as well as HyRez helicopter TDEM methods. In 2017 the company flew both fixed-wing and helicopter surveys in the U.S., Mexico, South America and Canada including helicopter magnetic gradiometer operations in Ontario’s Ring of Fire. 2018 marks the 30th anniversary of the company’s first deployment of a commercial fixed-wing horizontal magnetic gradient system. 

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# AIRBORNE GEOPHYSICAL SURVEYING



Precision GeoSurveys conducting a magnetic and radiometric survey near Hawthorne, Nevada.

Credit: Precision GeoSurveys Erik Keyser

**C**GG Multi-Physics reported on surveying with its three EM technologies. The company deployed the Helitem system on numerous exploration surveys for resource companies in Africa, Australia, North and South America. After upgrades in 2016, the redesigned Tempest fixed-wing TDEM system was utilized on surveys in Australia and North America in 2017 mainly for groundwater and geological mapping. **Geoscience Australia** is collecting conductivity data for geological mapping; the AusAEM project will collect data over an area of 1,000,000 sq. km using Tempest. In addition, the USGS awarded the company a multi-year Tempest groundwater mapping project. CGG's Resolve technology continued to be used for high-precision conductivity mapping applications. Numerous Falcon and HeliFalcon surveys were flown for exploration and government clients worldwide. Released in 2016, Full Spectrum Falcon saw increased deployment in 2017 especially for clients interested in the long wavelength gravity field data provided by sGrav combined with the high-resolution Falcon gravity gradient data.

**Discovery International Geophysics** of Saskatoon, Sask. continued to use the Brisbane, Australia-based **Gap Geophysics SAM** (Sub-Audio Magnetics) technology for helicopter-borne (HeliSAM) surveys in Canada. Discovery has adapted the HeliSAM survey technique for remote North American field conditions with the development of a device called HeliWinder to deploy and retrieve transmitter wire on the ground using a helicopter. With it, the economic HeliSAM hybrid ground and airborne TEM and MMR system can be deployed in any

remote bush or mountainous terrain. "Ground" EM and resistivity surveys can now be carried out in terrain previously too difficult or expensive to survey on the ground. Line cutting or ground traversing is not required with the combined HeliWinder/HeliSAM system. A minimal ground crew is lowered into position by helicopter to set up the transmitter and assist with wire deployment and retrieval.

**EON Geosciences** of Montreal uses both fixed-wing aircraft and helicopters to provide high-resolution airborne magnetic, gamma-ray spectrometric and gravity surveys. Both the ETHEM time-domain and the Hummingbird frequency-domain EM systems are helicopter-only techniques. The company kept its crews busy flying large surveys in the Northwest Territories in Canada for the **Northwest Territories Geological Survey (NWTGS)** and **Natural Resources Canada (NRCan)**. EON also flew in Alaska, for the state's **Division of Geological & Geophysical Surveys (DGGs)**. A full magnetic gradiometer and gamma-ray spectrometric system was supplied for the **Geological Survey of India's** Multisensor Aero-geophysical Survey project. The company was also awarded aeromagnetic surveys to be flown in the U.S. in 2018.

**Geophysics GPR** continued to offer heliborne and fixed-wing magnetic, VLF-EM, radiometric, gravity and TDEM (GPRT-EM). GPR reported the company is currently participating in a large regional airborne magnetic and radiometric survey for the Geological Survey of India.

**Geosphair Aviation**, based in Montreal, which specializes in Airborne Survey Aircraft Rental and Operation, has flown a total of 500 hours of magnetometer and LiDAR surveys for

clients in Canada. The company provides the survey platform and equipment only, as a subcontractor, and does not bid directly on survey projects. In 2018 the latest release of the GEM magnetic compensation system and VLF are scheduled to be tested and Geosphair's Piper Navajo and Super-Cub have projects booked. The Super-Cub will be equipped with amphibious floats for the summer in support of the Seaplane Bathymetric Platform R&D project.

Geotech was awarded numerous airborne geophysical surveys for government agencies around the world totalling over 160,000 line-km in 2017. The surveys flown included various combinations of magnetics, radiometrics, ZTEM, VTEM and VTEM ET for Morocco, Australia, India, South Africa and the U.S., as well as for Ontario (MNDM), North Dakota (NDSWC) and the University of Utah (Energy Geoscience Institute).

Moscow-based Geotechnologies continued its activities in airborne time-domain and frequency-domain EM, magnetics and radiometrics. In 2017 the company manufactured GT-MAG-2 gradiometry equipment for airborne magnetic surveys and several magnetic base stations for the Norilsk branch (NF) of VSEGEI. In addition, technical support for the fixed-wing frequency domain airborne EM system was provided to the ALROSA Group that has used Geotechnologies' EM4H systems for regional surveys in Siberia since 2004.

In 2017, MagSpec Airborne Surveys, based in Perth, was awarded five large airborne magnetic/radiometric and elevation surveys by the South Australia government as part of their Gawler Craton Airborne Magnetic Survey (PACE Copper program) — comprising a total of 560,000 line-km. To meet the requirements, the company set up a new system (using a Cessna 210), and had up to three aircraft flying simultaneously.

In 2017 New-Sense Geophysics, based in Markham, Ont., carried out a variety of magnetic and radiometric surveys

using both fixed-wing and helicopter platforms. The projects were flown across South America (Peru, Chile, Paraguay, and Argentina) and in North America. These included regional surveys and smaller-target programs related to mineral exploration for gold, silver, copper and zinc as well as for structural geology information.

Precision GeoSurveys, based in Vancouver, specializes in low-level airborne geophysical surveys in remote and mountainous terrain. The company has flown helicopter and fixed-wing high-resolution magnetic, radiometric, and EM surveys in Africa, Asia, Europe and North America. In 2017, Precision flew 1TEM time-domain EM, frequency-domain EM, magnetic, and radiometric surveys across western Canada and the western U.S.

SGL reported that airborne surveys were completed in North America, South America, Europe and Australia. The company flew several large airborne gravity and magnetic surveys for petroleum exploration in South America and helicopter gravity and magnetic surveys for mineral exploration in North and South America, large magnetic and radiometric projects in South America and Australia as well as several regional magnetic gradient and radiometric surveys. Involvement in NASA's IceBridge climate-change monitoring surveys with AIRGrav continued over Antarctica. Other surveys included magnetic-only surveys and methane-mapping surveys. Airborne methane sensing surveys are conducted with ultra-sensitive, high-resolution sensors mounted in the survey aircraft to record methane gas concentrations in the air which can be matched to known methane sources and potential hydrocarbon seeps for petroleum exploration, or man-made sources for environmental monitoring. In 2017 the company carried out two methane sensing surveys for research purposes, mapping and quantifying ground-source methane.

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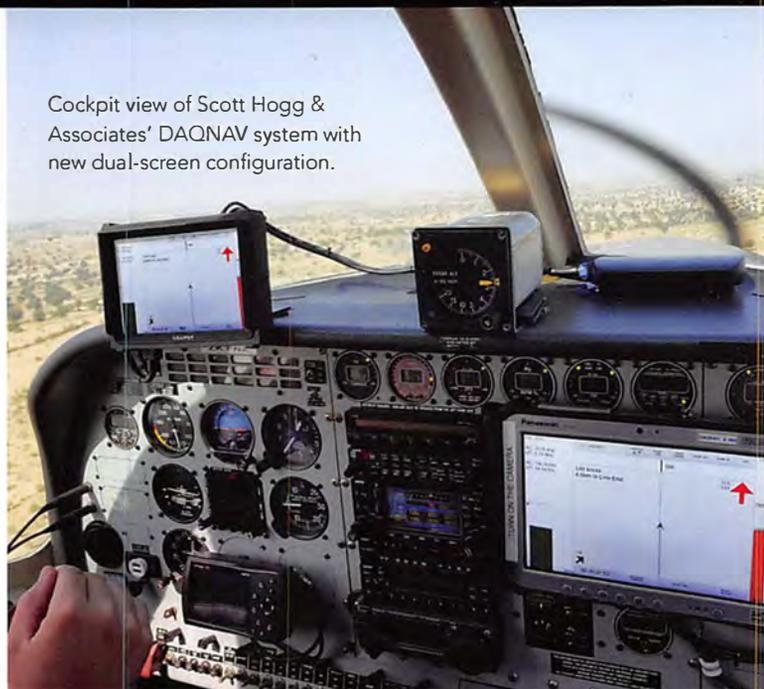



In 2017 the Heli-GT helicopter 3-axis magnetic gradiometer system, developed by Toronto-based **Scott Hogg & Associates**, was used for surveys in Newfoundland and Ontario for base metal, diamond and gold exploration. The entire Heli-GT sensor package; magnetometers, radar altimeter and GPS system is housed in a bird that is towed 25 metres below the helicopter providing reduced magnetic interference and significantly lower noise level for the measurements than for non-bird systems.

**SkyTEM Surveys**, headquartered in Aarhus, Denmark flew its SkyTEM312 for mineral exploration surveys in Quebec, Ontario, Newfoundland, British Columbia, Yukon and Alaska. A 4,000 line-km high-resolution SkyTEM312 survey flown in the summer of 2017 in the Buchans area of Newfoundland found several conductivity anomalies as potential drill targets. The SkyTEM method was employed for mineral exploration in Ecuador and Chile. It was also used to confirm the availability of water for a mine in Sudan. About 9,000 line-km were flown in a TEM survey for diamond exploration in Angola, mapping both near surface and deep geology to identify the primary kimberlite sources of alluvial diamonds. In Australia, an AEM survey was flown over a 150 sq.-km base metal project in the Batten Fault zone, Northern Territory as well as a survey over a VMS prospect to help identify extensions to Zn-Au-Ag-Pb deposits. Mineral exploration surveys were flown for **Geoscience Australia** and water-resource mapping surveys were flown for the **CSIRO**. In Europe, the first SkyTEM312HP (High Power) survey was flown in Sweden for deep-seated nickel sulphide mineralization. SkyTEM312 was employed in Finland to map magmatic Ni-Cu-PGE mineralization associated with mafic and ultramafic intrusions. The **Geological Survey of Sweden (SGU)** conducted a groundwater survey with SkyTEM and in the U.S. the company worked with Stanford University to survey drought-stricken areas of California including two surveys for salt water encroachment studies along the coastline of Monterey and Marina California. The U. S. **Army Corps of Engineers** and the **Wyoming Department of Environmental Quality (WDEQ)** used the SkyTEM for environmental mapping investigations at a former air force base missile site in Wyoming. The **University of Illinois** and the **Illinois State Geological Survey** also used it to investigate sand erosion and lake-floor topography along the shore of Lake Michigan, from Chicago to the Wisconsin border.

In addition to flying fixed-wing and heli-borne airborne geophysical surveys for private companies in Australia, Southeast Asia and Africa, **Thomson Aviation**, based in Griffith, New South Wales, was awarded more than 530,000 line-km of airborne mag/spec surveys for **Geoscience Australia** over the Gawler Craton in South Australia. The company also successfully completed a 50,000 line-km airborne gravity survey in Western Australia for the **Geological Survey of WA** (through Geoscience Australia). In 2017 the development of rotary-wing and fixed-wing UAVs for collecting high-resolution magnetic data continued.

Cockpit view of Scott Hogg & Associates' DAQNAV system with new dual-screen configuration.



## Airborne Data Acquisition and Processing

**Aarhus Geophysics** based in Denmark, conducted numerous AEM consulting projects with modelling of Induced Polarization (AIP), from all major helicopter TEM systems. Applications ranged from mineral exploration (porphyries or kimberlites) to geological mapping. 3-D models of AEM-derived chargeability are now routine. Besides chargeability, the "IP corrected" conductivity models often provided valuable new insight into geological models. The company continued groundwater mapping and impartial assessment of different AEM systems, from feasibility studies to data comparisons. For example, comparison of inversion results from VTEM, SkyTEM, Xcite and Spectrem data was done at the Sunnyside Nickel mine in Botswana.

**CGG Multi-Physics** consolidated its 3-D depth inversion modelling capability to include airborne, ground and marine EM data with potential field survey data. The algorithms, developed entirely in-house, work with both frequency and time-domain EM data, include VTI and diagonal anisotropy, for nodal and streamer (airborne, marine) data types. The multi-grid and vertically unstructured mesh implementations facilitate modelling of large 3-D models (1 G cells) required for accurate representation of extreme terrain, prospect detail and large survey data sets. Joint inversion via cross-gradient terms allows diverse data sets to integrate via inversion (e.g. AEM with AGG, or with ground MT, gravity or magnetics).

These codes provide the unique ability to include constraints for the quantitative inclusion of surface or subsurface geological data during 3-D inversion modelling which generates a result consistent with all available data, increasing geological plausibility. This is done by steering the inversion using cross-gradient regularization, where the reference gradient model is derived directly from geology. Because the methodology is generic, it can be expanded to derive a controlling gradient field from the wide range of sub-surface attribute

data available in exploration and development projects. CGG's Multi-Physics Imaging group completed multiple cross-gradient inversion projects during 2017, mainly for energy and mineral exploration.

In 2017, Lakewood, Colo.-based, **Condor Consulting** continued working on a wide range of exploration problems including projects with a focus on gold, base metals, (mainly copper) and uranium. The company's GeolInterp lithostratigraphic assessment was applied primarily to banded-iron formation and orogenic gold projects in North America. In the past year a major compilation study of the aeromagnetic signatures of porphyry copper deposits was completed. This was a two-year project done under the sponsorship of CAMIRO Project 205, supported by six major mining companies. The last such study was undertaken in 1970. Twenty-five deposits were examined with detailed geology provided along with images of the basic aeromagnetic data. Ancillary

geophysical data such as radiometrics, EM and IP were also available. Condor conducts special studies on porphyry copper systems and in 2017 continued work on the Kemess deposit system in northern B.C. Results of a detailed assess-

ment of the aeromagnetic responses of the Kemess South deposit are available on Condor's website. The company also initiated an extensive assessment of airborne and ground geophysical data over the Casino porphyry Cu-Mo-Au deposit in the Yukon. Casino is unique for northern Cordilleran deposits as it was not glaciated like most porphyry deposits in B.C. Consequently, Casino has some very unusual geophysical characteristics that make it similar to deposits in Chile's Atacama desert. The results of this work will be the subject of a series of technical presentations at major conferences in 2018.

In 2017, **Geotech** introduced its new Quick 2-D forward modelling and inversion tool for airborne natural field and time-domain EM, gravity and magnetics. It can quickly evaluate the geophysical response of simple or complex-shaped geologic models, which can be easily assigned appropriate physical properties and tested with a variety of airborne methods. The objective is to provide a common model and visual solution space for easier evaluation of multiple technology platforms.

In an industry first, **SGL** provided the processed x and y horizontal gravity components for an AIRGrav survey, in addition to the traditional z component. All of these data are publicly available from **Geoscience Australia**. The company



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A UAV magnetometer system equipped with "sense and avoid" technology, developed by Devbrio Géophysique and operated by Abitibi Geophysics.

Credit: Devbrio Géophysique

continued to be involved in several projects designed to enhance the resolution and accuracy of gravity data from AIRGrav surveys, and to improve geoid measurements using AIRGrav. In addition to forward modelling to assist clients with survey design, several large integrated interpretation projects were completed in 2017. The primary datasets were from gravity and magnetic surveys flown by SGL. Data used to constrain the interpretations included seismic data, borehole data and available geological and geophysical information. Interpretation was performed using in-house SGL software, as well as commercial 2-D, 2.5-D and 3-D modelling software.

The DAQNAV airborne navigation, magnetic compensation and data recording system, developed by **Scott Hogg & Associates**, has been in operation since 2013. The DAQNAV's acquisition module logs data from all devices outputting data. The navigation module enables users to load and view in real-time their own flight plan, background map image, DTM grid and drape surface grid. The latest version operates entirely on Panasonic's FZ-G1 (10") and FZ-M1 (7") tablets, both capable of running up to 18 hours on the tablet's internal

battery. In 2017 new features were added to the DAQNAV system and it now directly supports **Radiation Solutions'** RS501 spectrometer as well as **Kroum VS Instruments'** KMAG4 magnetometer counter and KANA8 analog/digital converter. It can now also be run in dual-screen configuration to provide both pilot and operator their own display. In 2017 **McPhar International** installed DAQNAV systems in two Pacific Aerospace 750XL aircraft conducting a geophysical survey in India.

The GT-Grid mapping system developed by the company has been used to process more than one million line-km of gradient data collected by airborne survey companies around the world. In 2017, GT-Grid projects were carried out for companies in Canada and Kazakhstan. GT-Grid is compatible with airborne survey systems that measure horizontal gradient but the full benefit of GT-Grid is realized when using the company's 3-axis Heli-GT system to accurately resolve magnetic gradients in the north, east and vertical directions. The GT-Grid process ensures that the magnetic grid produced is consistent with measured horizontal gradients as well as the total field, which is not provided by conventional gradient-enhanced gridding methods.

## Aeromagnetic Surveying

**Abitibi Geophysics**, in partnership with Gatineau, Que.-based **Devbrio Géophysique**, has flown, in survey configuration, what might be the first UAV magnetometer system with "sense-and-avoid" technology. The concept, developed by Devbrio, allows the UAV to be programmed to fly at a mean terrain clearance of 5 m above treetop level. The system will detect an obstacle such as a tall tree and fly over it without breaking line. The low-level survey data are useful in mapping subtle changes in the magnetic field not clearly resolved by conventional airborne surveys.

**Flying-Cam** with R&D offices in Belgium has jointly developed a high-precision unmanned Air Mag Survey Platform with **LAUREL Technologies**, which has offices around the world including Hong Kong and San Jose, California. Successful acceptance testing was performed in September 2017. The Flying-Cam Airborne Robotic Engineering team designs and manufactures unmanned helicopters based on a unique electric platform developed in-house, called SARAH (Special Aerial Response Automatic Helicopter). The company, which was started in 1988 has become a recognized provider of close-range aerial filming services to the movie industry. Today the company manufactures and sells the SARAH e 4.0 helicopter globally as an integrated solution with modular payloads or as a standalone OEM product.

Established in 1991, **LAUREL Technologies** is a provider of scientific exploration equipment, specialized in oceanography and geophysics and most recently a developer of unmanned vehicle technologies and their application. The Air Mag Survey Platform consists of an electric unmanned airborne Flying-Cam SARAH e 4.0 helicopter, a **Scintrex CS-VI** cesium-



Credit: Gregory Bedenko

SkyTEM on survey for minerals in Kazakhstan.

with arrays of 8 magnetometers compensated in real-time. For UAV platforms, a prototype system for dual-magnetometer gradiometry with real-time compensation has been completed and fully qualified. The AARC52 includes a built-in dual-frequency GPS receiver (Novatel's OEM7-series) and a next-generation Host CPU, achieving a 2-fold increase in data output and recording rates, relative to its predecessor (AARC51).

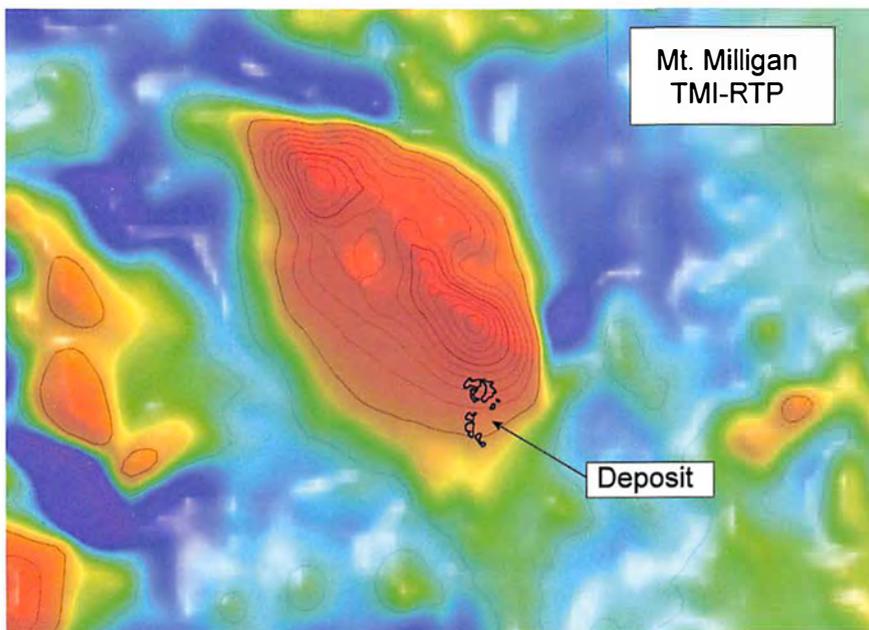
Other developments include the addition of embedded ancillary (barometric pressure & temperature) sensors for some members of the AARC500 family, a doubling of data-output rates for small form-factor systems, and more efficient multiplexing of auxiliary GPS variables. The company reported that system sales for the various models in the AARC500 family remained steady throughout the year including multiple units of the most advanced model in the series: the DAARC500 data acquisition & real-time compensation system with 8 magnetometer inputs. The majority of contracts, including recent Turkish airborne systems, included engineering and integration services and advanced training programs.

### Airborne Electromagnetic Surveying

Toronto-based Expert Geophysics is offering a new airborne EM technology: mobile magnetotellurics (MMT), an advanced generation of airborne AFMAG technologies. The MMT technology uses naturally occurring EM fields with frequencies from 25 Hz to 30 kHz. Based on extensive experience in developing equipment and signal/data processing algorithms to measure natural EM fields, MMT combines the latest advances in electronics, airborne system design and sophisticated signal processing techniques. An airborne bird, towed by a helicopter, measures magnetic field variations, while a

vapour magnetic sensor and the AARC51 adaptive aeromagnetic real-time compensator from RMS Instruments with a dedicated fluxgate sensor to provide attitude data to the real-time compensator. A radar altimeter provides altitude and the onboard RTK-GPS delivers location data to the compensator datalogger together with true heading (dual GPS antenna-based). Calibration routines and survey flight paths designed in Flying-Cam's 3-D graphical user interface can be performed fully automatically. For the acceptance tests, the SARAH e 4.0 unmanned helicopter was operated in automatic mode both on land (Inner Mongolia) and at sea (East China sea) where it successfully located a sunken ship of 18 m by 140 m, lying at 30 m depth.

In 2017, Mississauga, Ont.-based, RMS Instruments introduced innovations in aeromagnetic compensation. Conventional (fixed-wing and helicopter) platforms include new applications





**COMPILATION OF AEROMAGNETIC AND OTHER GEOSCIENCE DATA FOR PORPHYRY COPPER DEPOSITS**

In 2017, Condor Consulting published an aeromagnetic compilation of 25 porphyry copper deposits as part of a CAMIRO-sponsored project. This compilation is now available to non-sponsors.

A flyer outlining the deposits covered and a sample report can be accessed from Condor's web site:

<http://www.condorconsult.com/downloads/index.html>

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The cost of this report is \$US2,500.

A copy of the report will be on-hand at Condor's booth at the Round Up 2018-booth #235 and the PDAC 2018-booth #6400-North Building

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ground station measures electric field variations. The ratio of the magnetic and electric field magnitudes in both in-phase and out-of-phase components provides analytic parameters in selected frequency bands. Both electronic and signal-processing use advanced noise processing techniques to ensure high quality data even for weak natural EM fields. A cesium-vapour magnetometer is used for total magnetic field recording. The lightweight, aerodynamic bird is ideal for cost-effective surveys using small helicopters. Two MMT systems are now available for surveying.

**Geotech's** latest development in the VTEM system family is the new VTEM LBF (Low Base Frequency) time-domain system that was successfully tested in late 2017. The low (for time-domain EM) 15 Hz base frequency allows the extension of late off-time channels for recording the decay of secondary EM fields. The latest off-times provide better discrimination of highly-conductive targets such as nickel-copper, more reliable exploration under conductive overburden cover and greater depth of investigation. VTEM LBF expands the latest time acquisition to 19.5 milliseconds. The company also added system refinements to its new VTEM ET (Early Time) helicopter time-domain EM system that was field tested in late 2016, and first flew commercial surveys in 2017. So far it has been used in a variety of applications, including groundwater, diamonds, gold and strategic metals. The new VTEM ET system features faster turn-off and earlier time-gates (5  $\mu$ sec) for more precise, near-surface resistivity characterization. The VTEM ET system also uses the proprietary Full Waveform implementation.

In 2017 **Geotechnologies** continued to improve the EQUATOR helicopter-borne EM system. The main features of EQUATOR are simultaneous time-domain and frequency-domain measurements with a wide range of flight speeds during a survey. The company completed a survey of the entire country of Rwanda using EM, magnetics and gamma-ray spectrometry. Surveying the mountainous part of the country with accurate navigation was possible using the NAVDAT system and skilled pilots. Automation of data acquisition and navigation significantly increased flight duration.

SGL provides EM surveys using their fixed-wing frequency domain system (SGFEM) which acquires both EM and magnetic data and can be combined with other sensors (e.g. gravity, radiometric, methane). The SGFEM four-frequency system is suited for high-speed, high-resolution resistivity mapping for mineral exploration, environmental and geotechnical applications. In 2017, a significant upgrade was made to the SGFEM system to further improve stability and reliability.

In fall of 2017 **SkyTEM Surveys** launched a new generation of helicopter transient EM (TEM) systems with reduced survey costs and improved depth of exploration. The technologies are SkyTEM312 HP (High Power) with 12 turns of the coil around a 340 sq.-m transmitter loop and SkyTEM306 HP with 6 turns of the coil. The new systems are much lighter than other TEM systems with the same power and are designed to fly at speeds

up to 150 km/h, or almost twice the speed of other TEM systems, lowering survey costs. While surveying for **Geoscience BC** the SkyTEM312FAST system collected over 1,000 line-km per day, an unprecedented data acquisition rate for any TEM system. This new generation of TEM technology can deliver preliminary data and inversions within 48 hours after collection. This allows near real-time review of survey progress and results and the ability to quickly adjust system parameters to optimize results. Both systems are equipped with a high-power 250A transmitter and a fully digital 3-channel receiver for continuous sampled and streamed data with real-time signal gating and integrated B-field. Enhanced features include extremely high accuracy due to a 5 MHz sample rate with 36-bit resolution in three channels and superior rejection of high-frequency noise. The systems can be re-configured in the field to compensate for varying altitude requirements and to optimize depth of penetration.

**Terraquest** continued to commercialize its new HyRez helicopter TDEM system, with examples of data acquired over the Sudbury Igneous Complex. The system which is exclusively operated by Terraquest, uses under-utilized frequency bandwidth with time gates from 0.4 to 40  $\mu$ sec. It has the ability to differentiate resistive and shallow lithologies, map near-surface geology to a depth of about 70 m and, being light-weight, is deployable at high altitudes. Applications include resistivity mapping of geology related to targets such as diamonds, gold and lithium, as well as for near-surface engineering and environmental studies.

During 2017, **Thomson Aviation** along with **Monex GeoScope** and **RMIT** continued to build, evaluate and test an entirely new airborne TDEM system ("BIPTEM"). Both B and dB field data were acquired concurrently from a fixed ground loop survey at Lewis Ponds, New South Wales at a base frequency of 12.5 Hz. An IP target coincident with one from a ground survey was identified, demonstrating the potential to directly delineate economic mineralization. The BIPTEM system will be offered in Australia as a commercial service in early 2018, with a global release to follow.

## Airborne Gamma-ray Spectrometric Surveying

In 2017 **Medusa** presented the first data from drone-borne gamma-ray surveying compared to ground-survey data and soil samples. An algorithm was developed to handle the non-linear absorption behaviour of gamma radiation measured by a low-flying (less than 30 m) sensor. The company also commercially released their MS-1000, a fully-self-contained CsI gamma-ray detector for use underneath a drone.

## Airborne Gravity Surveying

**CGG Multi-Physics** reported on experience with the sGrav airborne gravimeter: a small, strap-down instrument designed for drape surveys to complement Falcon Airborne Gravity

Four of Sander Geophysics' Caravans in Bolivia for a large gravity and magnetic survey.



Gradient (AGG) data at longer wavelengths. The sGrav, which does not require a stabilized platform, can be easily deployed with the Falcon AGG system in a small aircraft. It was found to be very robust to air turbulence during draped airborne surveys. The Falcon Plus system launched in the spring of 2015 and the company's newest development in the Falcon family of AGG systems, was proven over **Geoscience Australia's** Kauring gravity test site west of Perth. During the summer of 2017 Falcon Plus flew a large mineral exploration project over Somerset Island in northern Canada. The HeliFalcon was used for an ultra-high-resolution gravity survey to map small sinkhole features inside a working oilsands open-pit mine in Alberta. The survey was flown with a 10 m line spacing and 10 m flying height. Customized data processing and 3-D inversion of the data resulted in an ultra-high-resolution density model to identify the sinkholes.

**Gedex Systems** of Mississauga, Ont. announced the first commercial surveying with its High-Definition Airborne Gravity Gradiometer (HD-AGG) in 2017. The HD-AGG was designed to achieve a resolution of 1 Eotvos Hz<sup>-1/2</sup> or 1 Eotvos RMS noise at a spatial resolution of 60 m when flown from a fixed-wing survey aircraft. The company reported the system is providing performance comparable to other AGG systems

in this competitive technology. Currently flown in a Cessna Caravan, Gedex anticipates improving the system performance by a factor of two or more in 2018 when it commences surveys using a Dash-8 platform.

SGL reported their 12 AIRGrav systems were busy flying airborne gravity surveys worldwide for petroleum and mineral exploration and for geological mapping, environmental monitoring and geoid modelling. In 2017, AIRGrav surveys were flown in North America, South America and Antarctica, and a large survey was started in the Middle East. For the majority of surveys, airborne magnetic data were recorded simultaneously. The company was again involved in **NASA's IceBridge project** in 2017, the eighth year that SGL has supplied its AIRGrav airborne gravimeter to assist with its polar research. The campaign was flown from mid-October to the end of November by NASA's P3 aircraft based in Argentina. The mission of Operation IceBridge is to collect data on the changing polar land and sea ice and maintain continuity of measurements between ICESat missions. The original ICESat mission ended in 2009, with ICESat-2 scheduled for launch in 2018.

The latest TAGS-7 airborne gravity system by **Micro-g LaCoste (MGL)** of Lafayette, Colorado, continues to achieve repeatability in the 0.5 milliGal range. A TAGS-7 system leased by the U.S. **National Geodetic Survey** is now being flown as part of the GRAV-D (Gravity for the Redefinition of the American Vertical Datum) project using a Centaur Optionally Piloted Aircraft (by **Aurora Flight Sciences** of Manassas, Virginia). The Centaur's line-following ability is a significant improvement over normal autopilot performance for airborne gravity surveying. The TAGS-7/Centaur system was also used with excellent results for a large airborne geophysical survey completed in December 2016 for the **California High-Speed Rail Authority (CAHSR)**. Flown in extremely challenging environmental and cultural conditions across the Los Angeles Basin and southern and central California mountain ranges, the system yielded excellent results to be released in early 2018. **E D**

GRx8-32      GRx8mini      GRx2

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# GROUND SURVEY TECHNIQUES

Quantec Geoscience's field crew carrying coils for the SPARTAN MT system.

Credit: Quantec Geoscience

## Physical Rock Properties & Elemental Analysis

**Instrumentation GDD** based in Quebec City, Que., reported that the new borehole option of the GDD SCIP Tester now allows measurement of resistivity and chargeability directly under field conditions, in exploration drill holes and in production holes in mining.

**Terraplus** of Richmond Hill, Ont., introduced the KT-10H Magnetic Susceptibility Meter with a sensitivity of  $10^{-7}$  SI, an order of magnitude higher than the KT-10. It has a circular sensor, and includes a pin mode for measuring samples with rough and uneven surfaces, such as outcrops. The KT-10H can be upgraded to a KT-10H Plus for measuring magnetite.

## Ground Data Acquisition & Processing

In 2017, Toronto-based **Geosoft** expanded its VOXI Earth modelling service by adding IP and Resistivity to the existing magnetic, gravity, gravity gradiometry and FDEM data inversion suite. Enhancements to VOXI IP and Resistivity and the IP extension include improved QC tools, improved support for local coordinates and the ability to view interim results for each completed iteration. The company enhanced 3-D visualization and navigation in Oasis montaj, Target and Target for ArcGIS platforms and improved 3-D rendering of voxels. A new voxel smoothing option uses real-time interpolation of data to display a smooth image. New voxel caching and pyramiding algorithms with OpenGL shader technology provides better performance when displaying large voxel models. A new 3-D animation tool was also added that combines multiple 3-D snapshots to create a video, which can be saved and shared to visually tell a story about the project.

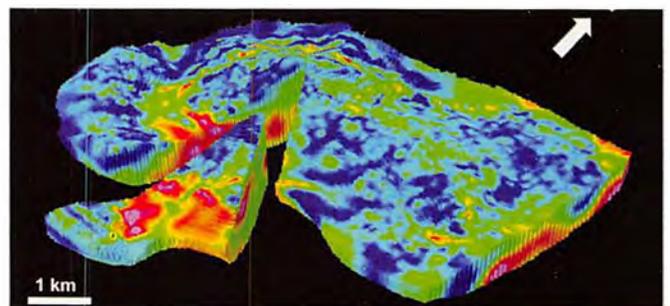
Working in partnership with Sudbury-based **Minalytix**, Geosoft introduced a new Software-as-a-Service (SaaS) solution for managing drill hole and sample data. MX Deposit simplifies how drilling data are collected, managed and shared. The data can be logged and accessed from anywhere in the world. A mobile data entry application is now available for more efficient

data collection in the field. MX Deposit is also integrated with Geosoft Target, Target for ArcGIS and Oasis montaj platforms.

**IRIS Instruments**, based in Orleans, France, added an innovative software building block to the flowchart of its full 3-D Electrical Resistivity and IP Tomography (3D ERT). This block, called FullWaveDesigner helps prepare a survey using a FullWavers system. The geographical locations of potential electrodes and the current injection positions, which form the "geometry of the survey," are important to obtain good resolution and depth penetration using 3D ERT performed with distributed modules. The FullWaveDesigner software, which is directly linked to Google Earth, is an important part of the framework of a full 3D ERT survey from the survey design to the interpretation.

New waveform options were added to the MultiLoopGL modelling web app by Kingston, Ont.-based **Lamontagne Geophysics**. It is now possible to calculate a response once and then look at the results with various waveforms, sampling schemes and frequencies. The response profile plots can be viewed in the 3-D scene or the output time step file can be plotted in 2-D using the 3CPlotter web app. Using 3CPlotter the calculated response can be compared to or subtracted from field data.

**Quantec Geoscience** expanded their data processing, inversion, integration and interpretation capabilities. This includes application of Telluric Cancellation (TC) and Periodic Noise



Survey results from a large-scale 3-D chargeability survey by Quantec.

Credit: Quantec Geoscience

(PN) removal technologies to the processing stream for DCIP data, further enhancing resolution and the ability to image at depth. The use of a code for the Joint Inversion of DC resistivity with MT resistivity resulted in inversions with additional interpretation products for the two survey methodologies. In several data integration projects the geophysical data, drill-hole geological and rock-physical property data and structural/geological models were combined. This provides an integrated interpretation with typing of anomalous responses resulting in improved targeting in complex geology. Inversion capabilities were also expanded for 3-D inversion of larger data sets in a shorter time.

## Drillhole Methods

Through a partnership with **SEMM Logging**, a world leader in borehole logging headquartered in Vesdun, France, **Abitibi Geophysics** now offers a full suite of borehole logging services for mining and exploration applications. In addition to optical and acoustic imaging for core orientation, the company is encouraging the use of physical property logging to better understand the geology and select the most responsive geophysical method for a given environment and to improve 3-D inversions.

**Advanced Logic Technology (ALT)**, based in Luxembourg, reported that new slim-hole NMR logging tools are now employed in the mining industry. The NMR technique, used in the petroleum industry for decades, measures hydrogen and hence water content of pore spaces in the rock. The processed data can yield information about porosity, pore size distribution and differentiate between free water, capillary-bound and clay-bound porosity. Mining applications include mapping moisture content, specific yield and dry weight density in iron-ore deposits or mapping coal seam gas content and permeability in coal mining. ALT has developed a new NMR module for the WellCAD software to provide processing, visualization and interpretation of NMR data.

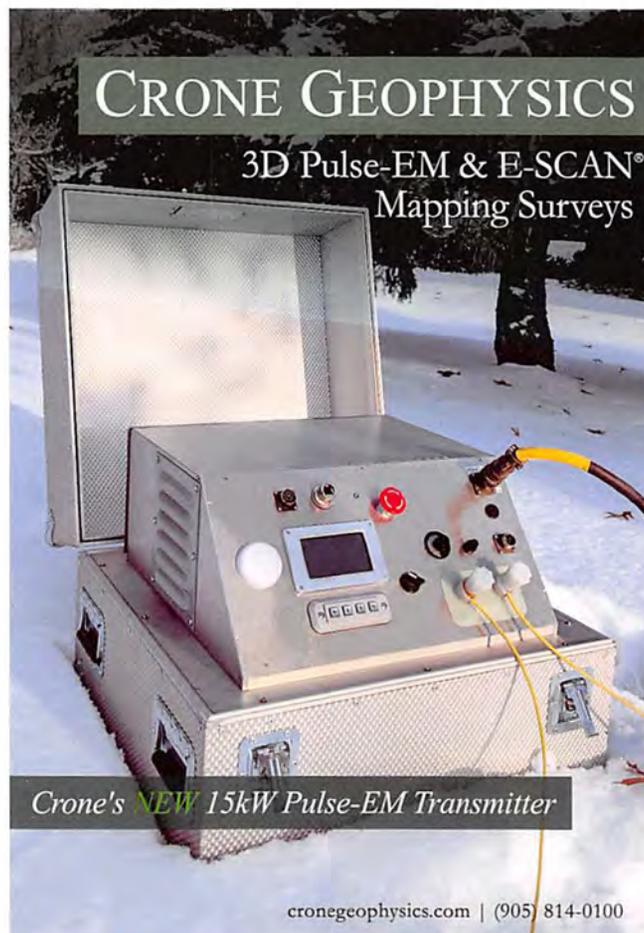
**Crone Geophysics** collected large numbers of full-waveform TDEM time-series data sets on surveys during 2017, as it has become routine to collect it while smart-stacking the data. The time-series data are sampled at 100 kHz, and the data analysis during 2017 was invaluable for testing new smart-stacking algorithms and learning about noise in borehole TDEM data near active mines. The company improved its smart stacking, which removes linear drift and some higher orders of background field variation, and also has optional automatic noise recognition and removal. In some cases, probe movement is the dominant source of noise, so probe-motion monitoring was introduced in their CDR3 receiver which prompts the operator when it is safe to take a reading. Crone's manufacturing facility mainly supports its survey contracting business, but in 2017 it did sell complete borehole TDEM systems with both B and dB/dt probes.

Whitehorse-based **Icefield Tools Corporation** completed a wireline interface modem, to communicate and deliver power

to its solid-state Gyro Path North Seeking Gyroscope (NSG). The system, successfully tested to depths of 9000 m, allows operation in real-time or memory mode. During a survey the instrument can seamlessly switch between onboard batteries or external power. The drop-capable system is accurate to  $\pm 1$  degree with a gyro compass time of less than one minute.

**Lamontagne Geophysics** continued development of the UTEM 5 down-hole EM system (U5BH project). After bench-testing two prototypes, a final design is being implemented with sensitivity on all respective components at least 10 times better than the UTEM 4 down-hole sensor. There has been a delay of more than five months in the development of the magnetically-shielded chamber needed for the U5BH project because it was halted in July 2017 by order from **Esafe** (Electrical Safety Authority) which objects to many aspects of the chamber prototype. It would want electrical house-wiring methods used everywhere in the apparatus (use of conduits, junction boxes and grounding of all shield panels) making it useless as a shielded enclosure. At the time of writing, there was no solution in sight and legal action was being considered.

Denver, Colorado-based **Mount Sopris Instrument Co.** has developed a new 19 mm diameter natural gamma logging tool for surveying inside geo push rods, and other small-diameter



Icefield Tools' solid-state Gyro Path North Seeking Gyroscope with tablet.



Credit: Icefield Tools

applications. In addition, the company has developed SIP (Spectral Induced Polarization), and non-source neutron generator geophysical logging tools. SIP response (also known as Complex Resistivity) is measured by applying sine wave currents into the formation at frequencies from 1 mHz to 10 kHz. Impedance and phase angle are determined by correlating induced voltage and stimulus current. These frequency vs. phase and impedance spectral signatures provide reliable information about lithology, permeability, effective porosity, grain/pore size distribution and surface area.

Mount Sopris together with **Starfire Industries**, based in Champaign, Illinois, have developed a new neutron geophysical logging probe that eliminates the use of radioactive materials for neutron production. This will solve problems for users who have been restricted from using Am241-Be or Deuterium-Tritium (D-T) sources. The 4 Curie-equivalent, high-output, long-life electric Deuterium-Deuterium (D-D) fusion neutron generator in the tool provides radiation on/off capability, increasing safety for operators, while reducing the regulatory burden associated with radioactive sources.

Borehole Gravity (BHG) services are provided by **Micro-g LaCoste**. Numerous improvements in the past two years to both the GRAVIOLOG and Bluecap borehole gravity tools have delivered, high-accuracy results with less than 5 microGal repeatability and density estimates of less than 0.005 g/cm<sup>3</sup> accuracy for approximately 5 m station intervals. A key tool improvement is the replacement of bubble levels with MEMS tilt sensors on both tools. This vastly shortened the time to level downhole, reducing station reading time to about two minutes. Other tool upgrades include the addition of natural gamma ray and CCL, which has improved depth positioning to within 1 or 2 cm downhole.

**SJ Geophysics** reported an increased demand for their Volterra-BHEM system including a leasing agreement to a third-party geophysical contractor. Key features of the system are its adaptability to measure with multiple sensors simultaneously, its portability and the internal data logging functionality that allows surveying below the drill bit, while rods are being pulled. This is critical when holes are at high risk of collapse and makes surveying horizontal or up-hole feasible.

The Volterra-EM system is powered by fully-programmable transmitters that provide an overall current of 18 A peak-to-peak, for 100% duty cycle, or 10 A for 50% duty cycle. The units can be connected in parallel to increase current output. The transmitter can be programmed to a frequency best suited

to the geological environment and avoid local noise interference. Advanced signal processing algorithms can separate the data from two isolated loops transmitting different distinct frequencies. Surveying two loops simultaneously reduces traverses, resources and time spent surveying.

## Ground Electromagnetic Methods

**Abitibi Geophysics** reported that InfiNiTEM XL is proving to have excellent depth of exploration as well as lateral exploration equal to the depth, plus resolution of off-set targets previously undetected in the shadow of larger anomalous zones. The company reported a BH InfiNiTEM discovery of a new mineralized zone, which was greater than 600 m off-hole at a depth of 1,000 m. A surface InfiNiTEM XL survey resulted in the discovery of a previously blind zone of mineralization at a depth of greater than 800 m near an operating VMS mine. The continuation of ARMIT development with Dr. James Macnae at **RMIT University** in Melbourne, led to the introduction of the ARMIT 3 sensor. ARMIT 3 measures B-field and dB/dt simultaneously on all 3 axes on base frequencies from sub-1 Hz through to 30 Hz. ARMIT 3 sensors are manufactured in Val d'Or, Que.

In a new development, the company can now do radio imaging tomography. During 2017 Abitibi entered into an agreement with **GEOFARA** of Saint Petersburg, Russia, to provide FARA's radio imaging services in North America. FARA is a radio imaging technology that investigates and maps resistivity contrasts between boreholes. The cross-hole tomography is presented as a visual showing conductive mineralization between the boreholes.

**ClearView Geophysics**, based in Brampton, Ont., has designed ruggedized survey platforms for its snowmobile-mode TDEM and cesium magnetometer surveys. Lighter components such as "race-car" lithium batteries, wider and longer sleighs for better stability and stronger components designed for very cold temperatures enables faster data acquisition and better data quality with less vibration at higher speeds. The separation of the transmitter and receiver coils from the main electronic components also allows more accurate measurements simulating an airborne survey on the ground.

**Crone Geophysics** has developed a new transmitter for its borehole and surface TDEM system which is higher power and yet the Tx with power source remains 2-person portable. The new 15 kW transmitter which delivers up to 500 V and will output 60 A current, retains its portability due to its PFC (power factor correction) design and a PF close to unity. This reduces weight and allows the use of smaller AC generators than would normally be required. Any waveform can be transmitted (standard 50% with high-accuracy linear ramp turn-off or 100% duty cycle, or other) and accurately digitally-controlled with high-frequency switching. Setup time is minimized due to its automatic loop measurements and calculations of resistance, inductance and current adjustment. Peak loop current is held constant during the survey, confirmed with automatic

measurements made and stored by the transmitter throughout the day. GPS synchronization is available or a high-accuracy clock can be used.

The Jessy Deep, high-temperature SQUID (HTS) sensor for deep TEM exploration continues to be offered by **Discovery International Geophysics** under an agreement with **Supracon AG** from Jena, Germany. In 2017, the company added the liquid helium, low-temperature SQUID (LTS) sensor. The higher signal-to-noise (S/N) ratio of the LTS sensor and the faster measurement time provides significant advantages over the HTS, although maintaining a supply of liquid helium on the job site is more of a challenge than liquid nitrogen. However, where ambient background noise due to minor ground movement or geomagnetic disturbances is low, the greater S/N of the LTS will provide higher quality TEM data from deep conductors with very low signal strength.

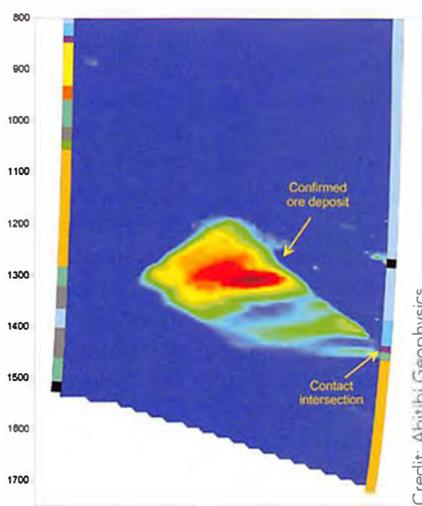
In 2017, Mississauga, Ont.-based **Geonics**, further enhanced the capabilities of its TDEM instrumentation for detection and characterization of UXO. The company developed the EM63 Flex Array, a flexible configuration system that provides continuous full-transient data from each of multiple (up to four) receiver coils. An integrated real-time filter rejects responses from magnetic soil. The unit also contains tools for advanced data processing that enables superior target detection and significant reduction of false-positive alarms. The EM63 Flex Array also provides many user-adjustable indicators for real-time data visualization and anomaly recognition.

Quebec City-based **Instrumentation GDD** has improved the penetration depth of its Beep Mat for operation in humid environments. This efficient, inexpensive tool for magnetic and relative conductivity EM measurements was developed and manufactured by GDD in 1976-80, and is still widely used for prospecting.

A prototype of the UTEM 5H transmitter has been field tested by **Lamontagne Geophysics** over the last year. The development project has increased power efficiency to over 90% and doubled the regulation bandwidth. The new transmitter can be powered by a combination of one or two motor generators of 240 V or 120 V AC and can operate at output levels ranging from 2.5 kVA to 10 kVA.

**Superior Exploration** of Batchawana Bay, Ont., continued with their innovative use of a traditional VLF geophysical instrument, the EM-16. The company has carried out ground VLF surveys, which do not require cut lines, throughout North America since 2011. VLF field data are processed using software co-developed by **EMTOMO** of Portugal with Superior. Data can be presented as a variety of profiles also showing elevation and geological information and can be displayed as plan maps and 3-D shadow maps. 2-D Inversion models can show geological information and drill sections.

**Supracon**, located in Jena, Germany, now offers to all explorationists their highest sensitivity SQUIDs, the low-temperature SQUIDs, which previously had limited availability. The system named JESSY DEEP LTS can be applied in active and passive methods for magnetics and electromagnetics (e.g. TEM, CSAMT, MT, MIP) which require the recording of very small signal amplitudes (noise floor below 1.5 fT/vHz) with a frequency-independent transfer function and with large dynamic range signals of high-power TEM. Features include a dynamic range up to 2000 nT (e.g. 200 amps in a 100 m loop) and a slew rate up to 150 mT/s (e.g. switching 15 amps in a 100 m loop in 1  $\mu$ sec).



A radio imaging map (RIM) of mineralization between holes.

## Gravity Surveying

Concord, Ont.-based **Scintrex** reported that preliminary 2017 sales of the new and improved CG-6, which was introduced in 2016, have been strong, with positive feedback from customers. Recent improvements to the CG-6 Autograv firmware were added to enhance the user-interface experience and improve efficiency of survey operations. The CG-6 also offers Bluetooth integration and a handheld tablet computer for remote operation.

## Induced Polarization

**Abitibi Geophysics'** OreVision is now believed to be the most-used Resistivity/IP configuration in eastern Canada. Since its introduction in 2014, continued development and dedicated crews have increased productivity in the field by a factor of 2.5. Results are so effective that clients have committed to survey blocks as large as 2,000 line-km. Many discoveries have been made since 2014 and the company has assigned staff to generate new case studies. IP research is now focused on source discrimination and constrained inversion. A new borehole IP approach has been successfully tested in a scale-model tank and confirmed with synthetic modelling.

With many years of IP/resistivity survey work with 2-D and 3-D arrays **ClearView Geophysics** continued with transmitter improvements to increase the signal to noise ratio for higher resolution at greater depths. The company has developed preferred survey array methodologies for sub-vertical gold mineralization, first pass surveys, follow-up surveys and for information from deep layers. UBC inversion software and spectral processing are used to prioritize drill targets.

**Crone Geophysics** completed and field tested the prototype Mark 7 3D E-SCAN resistivity mapping technology, which includes new real-time QA/QC capabilities in its optional 3-D IP functions. Competent E-SCAN resistivity data sets have

been acquired to depths greater than 4,000 m, supporting objective 3-D inversion modelling conservatively terminated at approximately 2,500 m. This is due to a uniformly distributed, uniformly all-directional and sufficiently high-density 3-D pole-pole field data set to support unambiguous 3-D inversion. The Mark 7 adds new features for this deep mapping, including circuit characterization (spectrum analysis) and normalization of contributions and attenuations due to system hardware and wiring. An increased level of signal sensitivity, noise reduction and certainty of signal origin can therefore be achieved. The Mark 7 can acquire pole and dipole data in line-based, offset current line-based and the all-directional modes typical of distributed IP/resistivity systems. This will enable fair comparison of E-SCAN's usual dense and evenly-distributed, all-directional pole-pole data set to any other array and survey configuration. The Mark 7 advances were evaluated in a recent large 3-D resistivity survey conducted in northern Nevada's National Mine district. Full field deployment of the Mark 7 is planned for mid-2018.

**Dias Geophysical**, based in Saskatoon, Sask., completed resistivity and IP surveys in the U.S., Chile, Australia, China and Canada. The company continued development of its proprietary DIAS32 resistivity and IP technology, and expanded its survey capacity from 350 receivers/channels to over 650, which represents the largest distributed array capacity in the world. The DIAS32 system now has added the DIAS32 technology. Delivering 25 kW at 5,000 V, this new transmitter has the highest power-to-weight ratio in its class. In addition, the transmitter offers high-speed waveform control, internal timing control and current monitoring. Dias reported the 3-D DIAS32 survey was key to targeting the discovery drill holes at the Arrow South unconformity uranium deposit in the southwest Athabasca basin in Saskatchewan.

The Multipole Resistivity Imaging or MRI-32 DCIP resistivity method developed by **Discovery International Geophysics**, using DIAS32 distributed array receivers, is now being used routinely for deep uranium exploration in the Athabasca basin, and for high-resolution mesothermal vein gold exploration in Canada. The DIAS32 distributed array system also allows for greater "n" levels, limited only by the length of the survey lines, and for reconfiguration of the readings into larger dipole "a" spacings, for increased depth of exploration.

**Instrumentation GDD** reported that in 2018, the new Multi-Rx mode GDD IP Receivers will be able to run distributed IP surveys with monitoring QC/QA of the data directly in the field. It is already possible to merge and process data from a combination of multiple GDD IP Receiver's output files from 2 to 32 channels using the GDD Post-Processing IP Software. Also the new 20,000W-4800V-20A flexible Multi-Tx mode with GDD's model Tx4 IP Transmitters (5000W-2400V-20A), allows a user to link up to four units to obtain maximum power and depth of investigation. The latest GDD Communication boxes (GDD-RTE01) allow collection at the GDD IP Receiver PDA, of real-time information (power and current) broadcasted by the



David Goldak, president of EMPulse Geophysics, celebrates in September 2017 after the first-ever collection of PULSAR data in the Sudbury area.

Credit: Abitibi Geophysics

Tx4 IP Transmitter, including recording of the current in an output file. The GDD Post-Processing IP Software can be used to cancel the telluric noise using time-stamped signals from a remote station and to deactivate some channels or even an entire reading.

**Quantec Geoscience** reported that ORION 3D DCIP and MT surveys now offer cost-effective applications through the new ORION swath methodology. This survey requires fewer receiver units and less line-cutting, yet provides deep effective and rapid 3D DCIP coverage through the use of multiple survey lines simultaneously read and then rolled along, much like application of seismic surveys. In 2017, the company expanded its inventory of broadband RT-160 receivers which have six pairs of HF and LF digitizers, and are deployed as part of SPARTAN MT surveys and ORION 3D surveys when high-frequency MT is to be acquired.

Quantec developed a new processing tool to remove and manage certain types of periodic noise not easily managed with traditional filters. Called PNR (for Periodic Noise Reduction), the tool successfully mitigated noise caused by cathodically-protected pipes in a recent IP survey. This new tool should permit IP acquisition in environments previously considered too noisy.

**SJ Geophysics** continued to provide customized 3-D IP solutions. Increased inventory of Volterra units now allows multiple large-scale 3-D IP surveys to be conducted concurrently. The company is developing their own current monitors with improved mechanical design and reduced cost compared to commercial versions. This will allow the use of multiple units, improving the tracking of the input waveform and the detection of current leakage. 2017 saw a renewed interest in the system's ability to acquire a fully active 2-D IP survey traverse. Laying out an entire line of dipoles while injecting current at the mid-point of each dipole results in more than double the data density of a traditional rolling 2-D IP array of  $N = 1$  to 10. The benefits include greater data density and maintains near surface resolution with increased depth of investigation.

**Georent**, a **Terraplus-Iris Instruments** joint venture based at the Terraplus location, added a distributed IP system to their rental pool. The distributed system is geometry-free, allowing the operator to deploy the autonomous receivers anywhere in the grid. The receivers remain stationary while the transmitter is moved through and around the grid, which

enables the operator to collect true 3-D data. The distributed system consists of 20 V Full Waver two-channel receivers (40 simultaneous channels), one I Full Waver single-channel recorder to log the electrical current from the transmitter, Full Waver Designer software to design the survey grid, and Full Waver Viewer processing software.

## Magnetotelluric

In 2017, Toronto-based **Advanced Geophysical Operations and Services (AGCOS)** introduced upgraded versions of the company's Super Multifunction Broadband EM receivers GEPARD-4 and GEPARD-8. They are equipped with high-sensitivity interchangeable electrical (E) and magnetic (H) channels which can operate in any configuration providing significant advantages in AMT, MT, LMT and MVP field surveys. The capability of the GEPARD system to simultaneously acquire broadband (43 kHz to 0.00001 Hz) EM data eliminates the need to conduct additional TDEM measurements for static shift correction. Turn-key GEPARD-4 and GEPARD-8 systems are supplied with data-processing software and a full set of induction coil magnetic sensors and fluxgate magnetometers. Compact, low-noise, non-polarizing electrodes with large contact surface areas are supplied in copper, lead and silver.

**EMpulse Geophysics** of Dalmeny, Sask., continued to advance its new PULSAR (Pulse-Aurora) receiver with the collection of the first-ever PULSAR dataset in the Sudbury area with its two prototype receivers. Due to the high dynamic range of PULSAR, and power-line noise cancellation software, survey operations were successfully conducted within 200 m of a major power-line. In the past, it would not have been possible to survey within 1,000 to 1,500 m of the power-line. A new aspect of the PULSAR receiver is the collection of horizontal magnetic transfer functions (MTFs). A trial survey (with their original SFERIC receiver) over Trevali Mining's Halfmile Deep orebody (Bathurst camp, New Brunswick) showed clear indications of the drill-defined orebody in the estimated horizontal MTFs. As a result, the company's 3-D inversion code was modified to invert horizontal magnetic-transfer-functions, in addition to the impedance phase tensor and tipper. However, even without horizontal MTFs, a joint inversion of the impedance phase tensor and tipper proved to be effective at delineating the Halfmile Deep sulphide body to nearly 1,000 m depth. For the Sudbury PULSAR data, EMpulse expects that the horizontal MTFs will further increase the sensitivity to conductive structures, while also providing better immunity to cultural noise (than the tipper). Importantly, the impedance phase tensor, tipper and horizontal MTFs are all static-free quantities which greatly increases the reliability and interpretability of the final 3-D inverted model.

**Quantec** now uses a non-magnetic coil calibration chamber. One key to the high-quality results that Quantec produces for MT surveys is using accurately and consistently calibrated magnetic field coils. This permits use of the most appropriate

band-specific, highest sensitivity and quality tools from a variety of manufacturers, yet ensures the best results for surveys. Quantec employs a 3-layer passive shielded and active field cancellation calibration room for calibrating magnetic field sensors to determine the calibration constants to extract geophysical parameters from the signals measured at the magnetic field sensors in the field. The calibration process, unique among MT surveyors, consists of transmitting 18 square wave frequencies using the odd harmonics to calculate the coil response, ranging from 750 Hz to 0.0009 Hz (close to 1100 second period).

**SJ Geophysics** continues to incorporate additional survey techniques into their Volterra Acquisition system. With recent improvements in the MT/CSAMT processing codes, the company is now capable of collecting MT/CSAMT data as a ground technique. Work is also being completed on simultaneous collection of short-interval MT, extracting value from full waveform data during the down-time between IP readings.

## Ground Penetrating Radar (GPR)

**Sensors & Software**, based in Mississauga, Ont., has developed a new concurrent receiver operation for the SPIDAR architecture. SPIDAR enables a number of GPR units to be networked together. This makes possible many new applications for GPR, including rapid seismic-style multi-fold data collection for improved subsurface imaging and physical property calculations. The DVI 500 data acquisition unit is now a standard part of the company's GPR systems. The new unit features a colour touchscreen, Wi-Fi, GPS and improved user interface, making operation simpler, data acquisition faster and providing the ability to analyze data in the field in real-time. The DVI 500 exports data through both wireless and hard-wired connections. Custom systems are also routinely designed for clients with unique GPR needs for many applications, including mining. A new borehole winch allows rapid acquisition of zero-offset and multi-offset gathers using a pulseEKKO borehole system. The automated winch provides positioning and triggering, making borehole data collection more accurate and significantly faster with rapid generation of tomographic images of the subsurface and possibilities for new GPR applications in shallow boreholes.

## Ground Radiometric Surveying

In 2017, **GF Instruments** of Brno, Czech Republic, introduced a new 2048-channel gamma-ray spectrometer called Gamma Surveyor Vario. The instrument combines all useful features and accessories for field, borehole and carborne surveys with K, U, Th assays and dose-rate measurements. The versatility of the instrument is enhanced by a wireless probe assembly, and NaI(Tl) or BGO detectors of several volumes (including the carborne version). It also has built-in or external GPS and spectrum stabilization, using natural or man-made gamma-ray sources, especially useful for rapid reliable measurements at very low gamma activities. **E D**

## COMPANIES AND WEBSITES

**Aarhus Geophysics:** [www.aarhusgeo.com](http://www.aarhusgeo.com)  
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**Wyoming Dept of Environmental Quality:** [www.deq.wyoming.gov](http://www.deq.wyoming.gov)

## ABBREVIATIONS

(for acronyms used in the text)

**A** Ampere  
**AC** Alternating Current  
**AEM** Airborne EM  
**AFMAG** AMT  
**AMT** Audiofrequency MT  
**B** Magnetic Field  
**BGO** Bismuth Germanate  
**BH** BoreHole  
**CCL** Casing Collar Locator  
**CPU** Central Processing Unit  
**CSAMT** Controlled Source AMT  
**Csl** Cesium Iodide  
**CSIRO** Commonwealth Scientific and Industrial Research Organization  
**dB/dt** rate of change of B with time  
**DC** Direct Current  
**DCIP** Direct Current Induced Polarization

**DTM** Digital Terrain Model  
**EM** Electromagnetic  
**GPS** Global Positioning System  
**Hz** Hertz (cycles per second)  
**IOCG** Iron Oxide Copper Gold  
**IP** Induced Polarization  
**kHz** kiloHertz  
**kW** kiloWatt  
**LiDAR** Light Detection And Ranging  
**LMT** Low Frequency MT  
**MEMS** Micro Electro Mechanical System  
**MIP** Magnetic IP  
**MMR** Magnetometric Resistivity  
**MT** MagnetoTelluric  
**MVP** Magnetovariational Profiling  
**NaI** Sodium Iodide  
**NMR** Nuclear Magnetic Resonance  
**nT** nano Tesla  
**OEM** Original Equipment Manufacturer  
**PDA** Personal Data Assistant

**QA** Quality Assurance  
**QC** Quality Control  
**R** Resistivity  
**RMS** Root Mean Square  
**SIP** Spectral IP  
**SQUID** Superconducting Quantum Interference Device  
**TDEM** Time Domain EM  
**TEM** Transient EM (TDEM)  
**Tx/Rx** Transmitter/Receiver  
**UAV** Unmanned Airborne Vehicle (Drone)  
**UBC** University of British Columbia  
**UTEM** University of Toronto EM  
**UXO** Unexploded Ordnance  
**V** Volt  
**VLF** Very Low Frequency  
**VMS** Volcanogenic Massive Sulphide  
**VTI** Vertical Transverse Isotropy  
**W** Watt



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