March 2019

ETD

EXPLORATION TRENDS & DEVELOPMENTS

Advances in GEOPHYSICAL TECHNOLOGY

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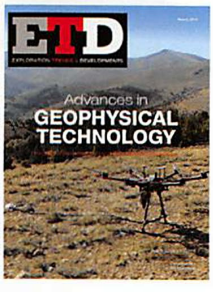
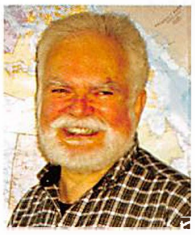


Cover photo: MWH Geo-Surveys' RTK multi-rotor UAV equipped with GEM Systems' DRONEMag (UAV magnetometer) on a mineral exploration survey in Ely, Nevada. Credit: Kevin MacNabb/ MWH Geo-Surveys



MINERAL EXPLORATION TRENDS AND DEVELOPMENTS IN 2018

By Patrick G. Killeen Ph.D., geophysical consultant and retired research scientist, Geological Survey of Canada, Ottawa

This is the third year that Decennial Mineral Exploration Conferences (DMEC) has served as the patron for *Exploration Trends & Developments*. DMEC organized the very successful Exploration '17 conference, held in Toronto in 2017, the sixth in the series of conferences which began in 1967. This year DMEC support came from the sponsoring companies listed on page 23.

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 27th 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 the 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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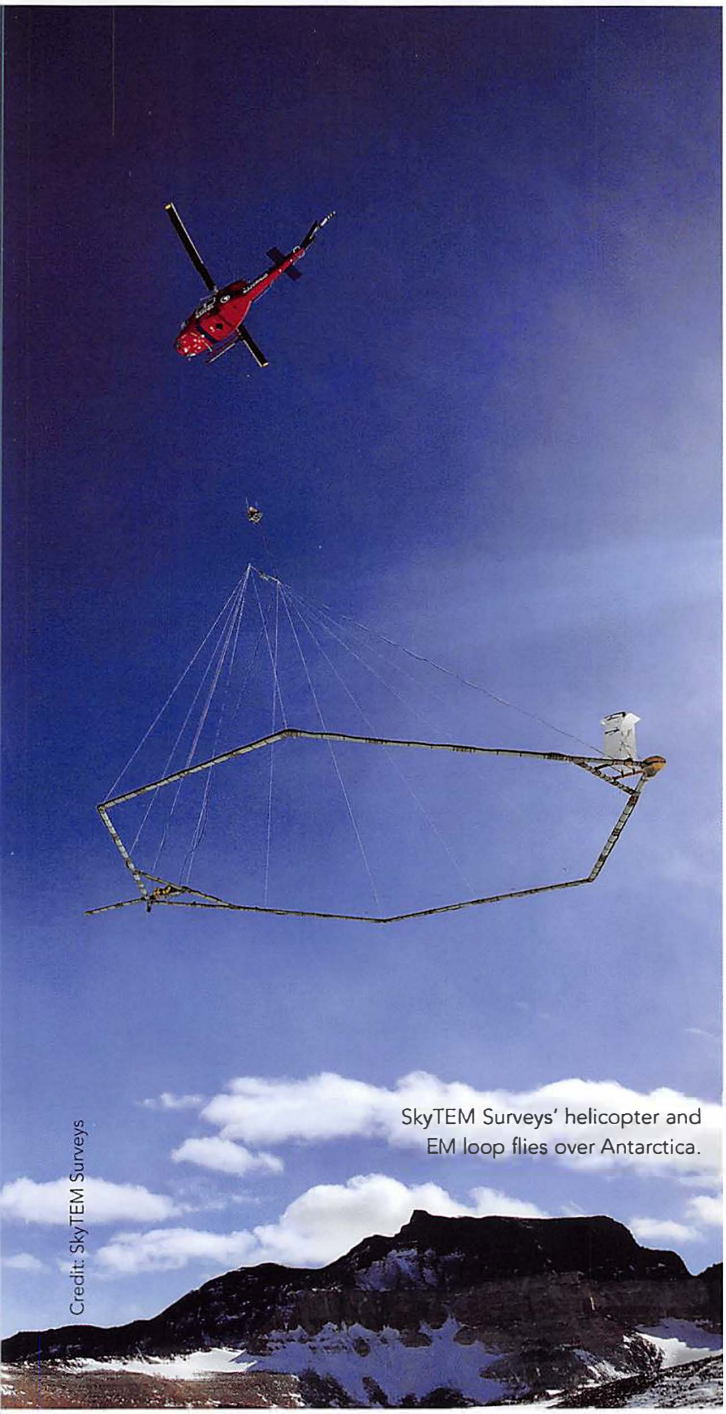
THE YEAR OF NEW DEVELOPMENT



SkyTEM Surveys' helicopter and EM loop flies over Antarctica.

Credit: SkyTEM Surveys

The general consensus is 2018 was a positive year for mineral exploration as budgets increased over 2017. Geophysical technology saw a mixture of improvements ranging from incremental to substantial and even radical. Survey contractors reported being surprisingly busy in spite of the downturn in some commodity prices like nickel and copper and that international work continued to increase. More companies entered into partnerships, working relationships and collaboration, both international and domestic in 2018.

Airborne survey contractors reported conducting large surveys worldwide on numerous government projects. The UAV (drone) market seems to be taking off as the number of flight tests of new lighter, smaller versions of geophysical technology increased, including magnetic, radiometric, EM and even gravity. Airborne survey systems were updated to fully digital, and some new techniques and new versions of earlier AEM systems appeared. Several airborne survey contractors outfitted new aircraft, some with increased capabilities (e.g. twin-turbine engines), and several completely new aircraft were modified in Canada for multi-parameter surveys, had the equipment installed, tested and then delivered to clients overseas. Airborne IP (AIP) is becoming more commonly used but being relatively new, work is still ongoing to determine and fully use its capabilities as well as find any limitations. SQUID-based Full Tensor Magnetic Gradiometer technology, previously proprietary, was released into the commercial market.

An interesting new European Union (E.U.) project is developing new technology and methodology to find deeper and smaller mineral deposits. It has about 16 partners from government, university and private industry and includes airborne, ground and borehole techniques as well as a long-shot plan to use muons.

On the data processing side there seems to be a shift towards "pay-as-you-go" which means, instead of purchasing software that may be used infrequently, clients pay only when they use it. Software is also becoming easier to use so it doesn't require a specialist to run. There have been many software improvements especially for viewing data in 3D. There is new software for processing tensor magnetic data to go along with the increasing number of tensor mag and gradiometer developments. The use of AI and neural networks is increasing, especially for AEM. There is also increased ability to merge disparate data sets. Borehole geophysics saw improved gravity logging, a new neutron tool, a spectral IP (SIP) tool and an optical televiewer with a UV light to identify minerals by their characteristic fluorescence.

Companies reported increased use of new ground geophysical technology introduced last year such as RIM, for imaging conductors between boreholes, as well as one company's first borehole electrical resistivity tomography (ERT) survey. A new IP technique uses a hybrid borehole-surface approach. Ground EM and electrical surveys saw new higher power TX's and lower noise, higher sensitivity Rx's, that are ultra-wide band and can be used in wireless arrays. One company can combine up to 6 transmitters for maximum power and depth penetration. The use of 3D technology continued to expand from data acquisition methods to data processing. For example, 3DIP is now offered by numerous companies. In GPR, advances saw development of signal stacking methods that double the penetration depth and can record signals 100 times smaller than before.

In 2018 the geophysical industry invested heavily in equipment development to measure more parameters and to improve data quality. Software development exploded, improving data processing and interpretation tools to invert, model and integrate dissimilar data sets. E&D

Expert Geophysics' MobileMT survey equipment in northern Saskatchewan's Athabasca basin.

Credit: Expert Geophysics

CORPORATE HIGHLIGHTS

Abitibi Geophysics of Val d'Or, Que., reported that increased geophysical activity coincided with release of several innovative products, resulting in its busiest year ever. In 2018 surveys were about 50% for gold and the rest for base metals, specialty metals and uranium. The OreVision IP continued to be Abitibi's most popular geophysical technique. ARMIT OMNI-Vision TDEM system saw growing application in exploration at depths greater than 500 m. The FARA Radio Imaging Method (FARA RIM), a tomographic mapping tool, was also in greater use primarily because it confirms the presence or absence of conductive mineralization between boreholes, reducing drilling.

Turkey's government and the **Geological Survey of Turkey**, Mineral Research and Exploration General Directorate (**MTA**) launched a program to upgrade the country's geoscience data base. It contracted a Turkish consortium (**EMI-Dayk-Foto**) to generate new high-resolution airborne 3-component magnetic gradient and gamma-ray spectrometric data that MTA will process in their new data processing centre using **Geosoft** Oasis montage. Toronto-based **Advanced Technology Solutions** and **CFU International** of Turkey delivered two new Turkish-registered geophysical survey Grand Caravans. **Lake Central Air Services** of Gravenhurst, Ont. modified the aircraft and **RMS Instruments** of Mississauga, Ont. installed and tested the equipment.

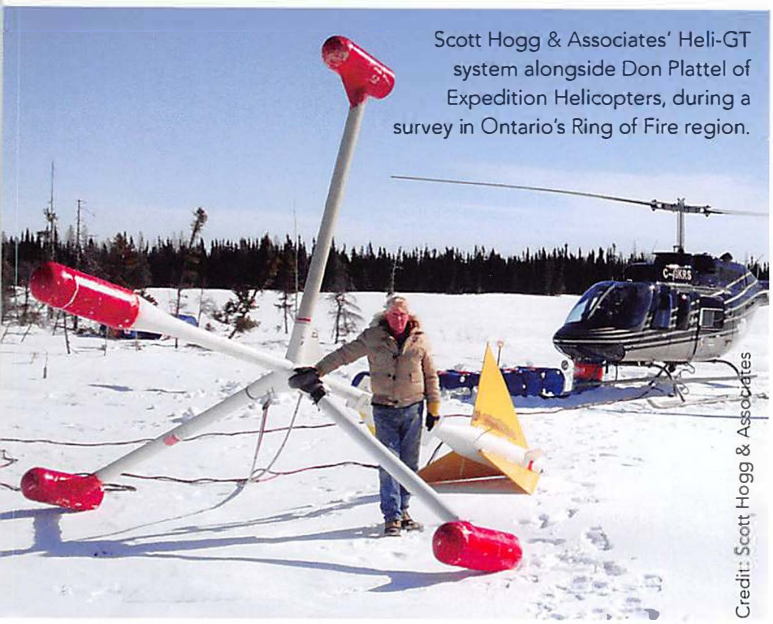
Toronto-based **Advanced Geophysical Operations and Services (AGCOS)** continued development and upgrades to its broadband multifunction EM receivers GEPARD-4 and GEPARD-8 for ground EM methods. In 2018 the company began offering contract ground surveys using numerous EM methods, consulting, data processing, interpretation and reporting services. AGCOS reported increasing interest in its new high sensitivity exploration technique which combines natural EM field (MT, AMT, MVP) and controlled-source EM methods (FDEMS-IP). The main advantage of this integrated technology is that the same EM receivers and sensors record both natural and controlled-source data using a single field array minimizing field personnel and improving productivity.

Crone Geophysics & Exploration of Mississauga, Ont., reported increased demand for its Time Domain Pulse EM system, particularly internationally. In 2018 surveys were conducted on six continents using both Pulse EM and 3D E-SCAN IP/Res systems.

Dias Airborne, a new airborne geophysical company, is a joint venture between **Dias Geophysical** based in Saskatoon, Sask., and **Supracon AG**, the makers of the Jessy Deep LT and HT SQUID sensors. Dias Airborne introduced HeliFTMG, a Full-Tensor Magnetic Gradiometer (FTMG) system powered by Supracon's LT SQUID sensor technology. The HeliFTMG is a heli-borne system with acquisition and processing software which Supracon developed with the Anglo American group of companies, and has a record of successful deployment. HeliFTMG survey services are available worldwide on an unrestricted commercial basis. Advantages of the FTMG method include improved source characterization and resolution.

Discovery International Geophysics established a new division at their operations centre in Saskatoon, Sask. in partnership with **Gap Geophysics Australia** to provide heli-borne sub-audio magnetics (SAM) surveys in Canada and the United States (U.S.). Discovery enhanced the HeliSAM survey technique with the development of HeliWinder, a device to deploy and retrieve transmitter wire on the ground using a helicopter.

The European Union has established the **ExplOre European Exploration Project**, an ongoing public-private initiative to expand exploration capabilities for deeper and lower grade ore deposits. Led by the **Geological Survey of Finland (GTK)**, the project engages about 16 partners including the state geological surveys of Sweden (**SGU**) and Spain (**IGME** & **CSIC**), two Swedish universities (Lulea & Uppsala) and a number of private companies. Objectives include developing new deep, high-resolution geophysical exploration concepts and technologies



Scott Hogg & Associates' Heli-GT system alongside Don Plattel of Expedition Helicopters, during a survey in Ontario's Ring of Fire region.

Credit: Scott Hogg & Associates

including airborne and ground EM, borehole systems, and magnetotelluric and seismic methods. The project which runs until March 2020 will also develop the use of virtual sources, noise interferometry and muons for deep mapping.

Geophysics GPR of Longueuil, Que., provides ground geophysical survey services in mineral exploration worldwide, in particular Africa and South America. Through its subsidiary **GPR Botswana** it completed a magnetic and gravity survey and with partner **KTTM Geophysics** the company participated in a large magnetic and IP survey in Colombia.

Toronto-based **Geosoft** announced it was now officially part of **Seequent**, headquartered in New Zealand. The acquisition brings together Seequent's Leapfrog 3D geological modelling software suite with Geosoft's Oasis montaj geoscience platform to provide subsurface geoscience and modelling software solutions for the mining, civil engineering, energy and environmental sectors.

New developments in 2018 at Quebec City-based **Instrumentation GDD** include a cubic EM antenna with 3 axes for EM surveys. It weighs only 9.5 kg, has dimensions of 33 x 33 x 38 cm and an inclinometer to provide levelling compensation. The company improved its Multi Parameter Probe (MPP) with new software that supports the Android system via Bluetooth or cable. The PDA can be replaced with a cellphone, tablet or laptop, to visualize the magnetic susceptibility and absolute EM conductivity information from the MPP. Also, the reading module of the Beep Mat, model BM8, has been enhanced to transfer data like a USB key. Now a computer recognizes the BM8 as a USB key to transfer data from magnetic and relative EM conductivity measurements.

Medusa Radiometrics in Groningen, The Netherlands, reported continued growing interest in radiometric sensors for crop field scanning and soil mapping in 2018. Demand for low-weight sensors for drones in environmental studies and prospecting increased as drone-borne measurements replace walking surveys. Medusa's R&D programs now include collaboration with the German Institute for Geosciences and Natural Resources (BGR) and the University of Cologne.

Mira Geoscience, headquartered in Montreal, continued to expand its integrated interpretation software and consulting services for mineral exploration from offices in Canada and Australia. The company has focused on an interactive approach to validation and modification of geological hypotheses and models through forward modelling and inversion. 2018 saw two releases of VP Suite's VPmg and VPem1D, and the launch of VPutility — a new free tool to create and modify VP models. These programs are fundamental to interpretation workflows for geologically-based forward modelling and inversion of potential field and TDEM data. Their performance has been radically improved and connected to Geoscience ANALYST to view and share results in 3D for free.

In 2018 **Nuvia Dynamics** completed the acquisition of Concord, Ont.-based **Pico Envirotec Inc**, a supplier of airborne EM, magnetic and radiometric instrumentation and data acquisition systems for mineral exploration. NUVIA is a subsidiary of global construction enterprise, **Vinci Construction**, headquartered in France.

Toronto-based consulting firm **Paterson, Grant & Watson (PGW)** marked a successful first year for its joint venture company in India, **IDPeX**, which carried out technical

supervision and quality control of more than 700,000 line-km of aeromagnetic and radiometric surveying for the **Geological Survey of India's** OGP airborne survey. PGW completed interpretation of over 600,000 line-km of magnetic and radiometric data for World Bank projects in the Democratic Republic of Congo (PROMINES), Burkina Faso (PADSEM) and Mozambique (MAGTAP) with partners including **IGS**, **Xcalibur**, **BRGM** and **Gondwana**. For each project, PGW prepared two interpretation products: a traditional lithostructural interpretation and a surface geology and regolith interpretation. The latter product was prepared with an innovative workflow that extracts unique classes from the combined geophysical, digital elevation and satellite imagery data. A Random Forest classifier is applied across an extensive array of training areas resulting in a detailed, precise model of surface material and geomorphology as a set of attributed polygons.

Toronto-based **Quantec Geoscience**, completed surveys in more than 12 countries and made significant improvements to equipment and processes. The company carried out its first borehole ERT survey in conjunction with **Geoserve Tomography** of Kiel, Germany. In-hole surveys are acquired with either 4 m or 16 m electrode spacing and current depth capability is 400 m with the Tomography system. Quantec also entered into two working relationships for operations in Colombia and Brazil with **Petroseismic** and **Intergeo** respectively.

Sander Geophysics (SGL), based in Ottawa, flies high-resolution fixed-wing and helicopter gravity, magnetic, EM, radiometric, methane and scanning LiDAR surveys for petroleum and mineral exploration, and environmental mapping. In 2018 SGL flew numerous combined gravity and magnetic surveys, as well as standalone gravity surveys and combined EM and radiometric surveys. Since its introduction in 1999, over 3 million line-km have been flown with its airborne gravity system, AIRGrav.

Vancouver-based, **SJ Geophysics** is an international ground geophysical contractor specializing in DC resistivity/IP, EM (including borehole, BHEM), gravity and magnetic surveys. In 2018 surveys around the world included projects in Australia, Dominican Republic, Mexico, Mongolia and Panama. Demand for its distributed acquisition system, Volterra, continued to grow. For IP applications the systems' capabilities lead to greater data densities, farther offset recordings and improved azimuthal distributions for deep investigations with near surface resolution. The ability to acquire AMT/MT data in conjunction with an IP survey have led to multiple combined IP/MT surveys.

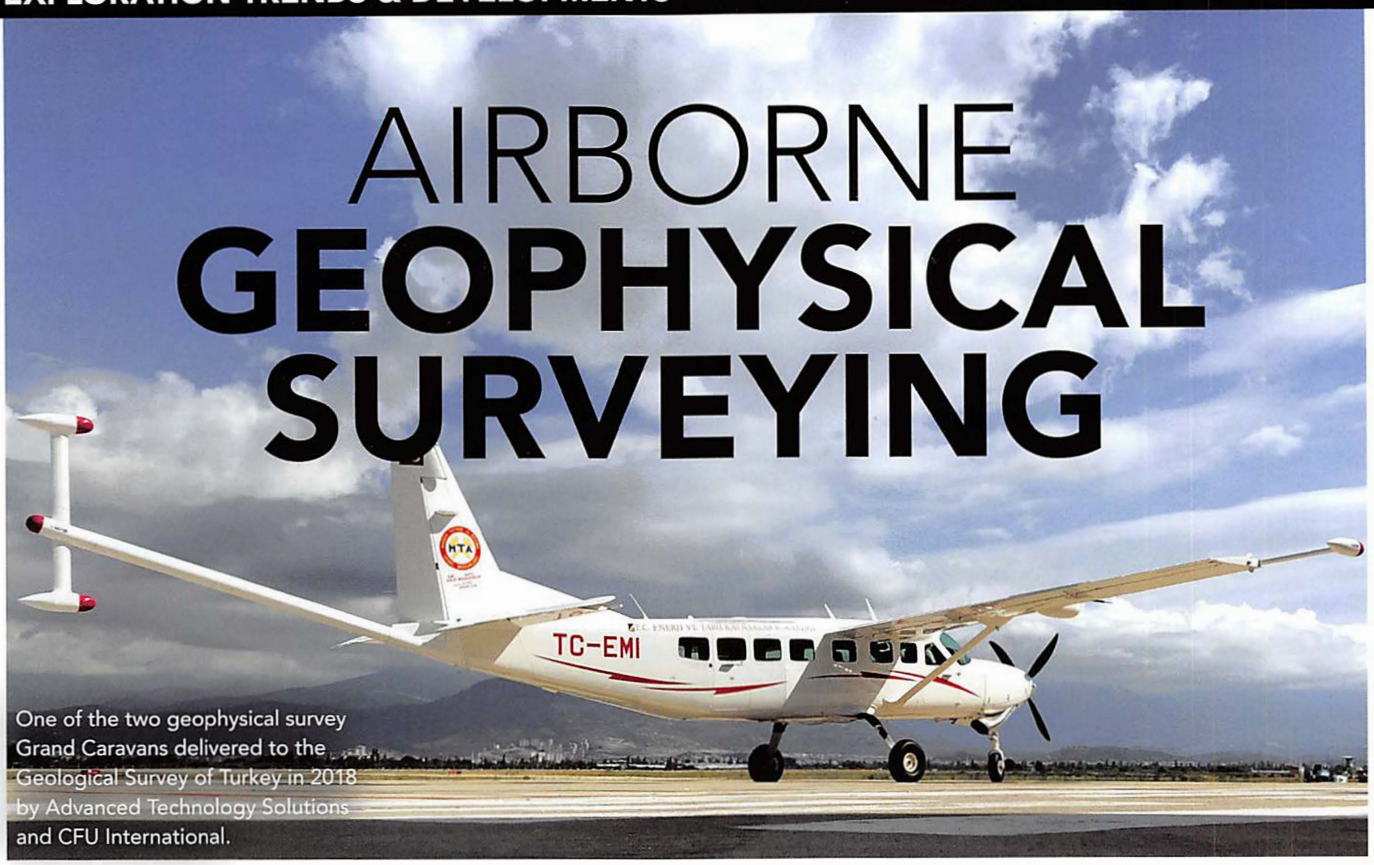
SkyTEM Surveys (headquartered in Denmark), opened a sales and data processing office in Toronto in 2018 to accommodate growth throughout North America. Operations and logistics of SkyTEM Canada continued to be managed by partner **Devbrio Geophysics** headquartered in eastern Quebec. The company developed and launched its SkyTEM High Power (HP) airborne TDEM technology; small, light-weight, versatile systems with deep mapping capability. In 2018 it entered into South America flying large mineral exploration projects.

Southern Geoscience Consultants (SGC) of Perth, Australia, previously focused on Australia, expanded to the Americas, opening an office in Toronto in 2018. SGC is a group of experienced geophysicists providing consulting services for mineral and petroleum explorers. The Toronto office offers planning, management, quality control, processing, imaging and interpretation of geophysical surveys. It will also provide management of exploration programs as well as geophysical equipment rentals, rock physical property measurements for core or hand specimens and software development. The company executed projects in Australia, Asia and the Americas in 2018 and expanded its survey contracting activities by adding BHEM and surface TEM surveys. The new SGC ImageRobot software enables quick, easy creation of geospatial images from grids of geophysical or geochemical data. All images are geo-referenced and can be used in any GIS, modelling, interpretation or map-making software. Software has been developed in-house to process, image and interpret data acquired using passive seismic devices such as the Tromino and turn-key surveys using the Tromino are also offered. GIS capabilities for integration with geophysical and geological surveys include processing and interpretation of ASTER and LANDSAT 8 satellite data in addition to DEM and topocadastral services.

Thomson Aviation based in Griffith, Australia, reported it now routinely conducts ultra-detailed to regional fixed-wing and heli-borne magnetic, radiometric and gravimetric geophysical surveys in Australasia and around the world.

Triumph Instruments of Georgetown, Ont. built its seventh AirTEM helicopter time domain EM system with five available in Canada and two internationally. The company saw an active 2018 with surveys in British Columbia, Ontario, Quebec and Newfoundland. The latest developments include a larger 12 m diameter airframe and the ability to acquire off-time profiles at "zero-time", immediately after the transmitter shut-off, for improved near-surface mapping. Triumph has established a relationship with Sudbury, Ont.-based **Caracle Creek International** for international surveys and airborne consulting. Triumph also offers a three-sensor magnetic gradiometer based on the Scintrex CS-3 total magnetic field sensor.

AIRBORNE GEOPHYSICAL SURVEYING



One of the two geophysical survey Grand Caravans delivered to the Geological Survey of Turkey in 2018 by Advanced Technology Solutions and CFU International.

Credit: CFU International

Airborne, marine and land geophysical data are acquired, processed, and interpreted for resource exploration and geological mapping from **CGG Multi-Physics**' offices in Toronto and globally. The company, headquartered in Paris, reported that during 2018 it focused deployment of its AEM technologies and Falcon AGG systems on resource exploration, geothermal, water, and government mapping projects.

EON Geosciences of Montreal provides high-resolution airborne magnetic, gamma-ray spectrometric and gravity surveys using fixed-wing aircraft or helicopters. The ETHEM time-domain and the Hummingbird frequency-domain EM systems are both flown with helicopters. In 2018 multiple crews were kept operating for a large portion of the year flying large aeromagnetic surveys in the Northwest Territories and Labrador, for **Natural Resources Canada (NRCan)** and in Michigan for the **United States Geological Survey (USGS)**. In addition EON flew several aeromagnetic surveys in the U.S. for the mining and oil & gas industries.

Geophysics GPR continued to offer airborne survey services in heli-borne and fixed-wing magnetic, VLF-EM, radiometric, gravity and TDEM (GPRTEM). In 2018 the company completed a large regional magnetic and radiometric survey for the **Geological Survey of India**.

Geosphair Aviation, based in Montreal, specializes in airborne survey aircraft rental and operation. During the winter, the company's Navajo flew an aeromagnetic survey in the Whitehorse, Yukon area for **GDS** of Montreal and later was busy flying small LiDAR grids in eastern Canada. The company's Super-Cub was used as an R&D platform under contract to **Girdit** (Finland) in July 2018 in a project that involved flight testing miniaturized airborne geophysical instruments, developed for UAV platforms. In other testing, the new MEMS magnetic sensor MFAM (miniaturized scalar atomic magnetometer) from **Geometrics** was compared against the **GEM Systems** GSMP-35A sensor. The new device uses a 1 cubic mm volume of cesium gas, is only about 15 cm^3 in size and requires only 2 W of power per sensor. The GEM aeromagnetic compensation software was used to remove any aircraft interference. Another project involved a small gravimeter weighing only 25 kg with a current draw of 8 amps, which was installed in the super-cub and flight tested. The iCORUS strap-down gravimeter produced by **iMAR** (Germany) was flown over existing ground gravity stations, and measurements were compared with upward continuation of the ground data. These surveys demonstrated the applicability of miniaturized UAV airborne technology for mineral exploration.

Geotech, based in Aurora, Ont., was awarded airborne geophysical surveys for government agencies around the world totalling over 100,000 line-km in 2018. The surveys included magnetic, radiometric, ZTEM, VTEM and VTEM ET for Morocco, India, Chile, the **North Dakota State Water Commission (NDSWC)** in the U.S. and the **Ministry of Northern Development and Mines (MNDM)** in Ontario. In addition, VTEM surveys were completed in Finland and Germany for the EU-funded INFACT Project coordinated by **Helmholtz-Zentrum Dresden-Rossendorf (HZDR)**. A second VTEM survey was flown for the **South African National Roads Agency SOC Limited (SANRAL)** for road planning in the Eastern Cape Province of South Africa. Geotech and its Chinese partner **ARCN** were awarded combined VTEM and ZTEM surveys by the Government of China for a major National Railway project on the Tibetan Plateau. It involved evaluation of geological hazards to 1500 m below the surface for tunnel engineering in a mountainous region with elevations above 4000 m.

In 2017-2018 Norilsk branch (NF) of **VSEGEI** installed a magnetic gradiometer on an An-3 fixed-wing aircraft for the first time, using the GT-MAG-2 equipment from Moscow-based

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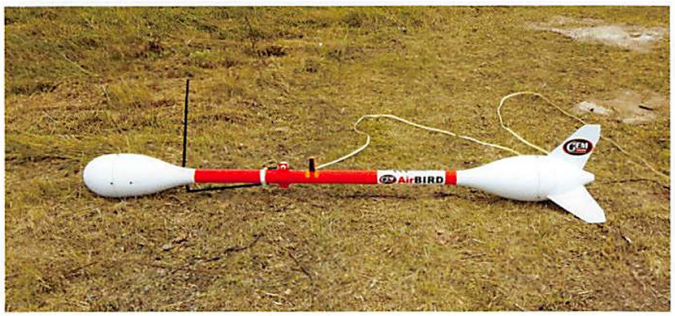


Credit: GEM Systems

GEM Systems' AirBIRD turnkey light-weight towed-bird magnetometer system designed for UAVs.

A drone equipped with Medusa Radiometrics' MS 1000 NaI scintillation detector.

Geotechnologies. Two 2-channel devices were combined in one unit. This made it possible to measure signals from up to four sensors as well as three antennas for satellite navigation systems (GPS/GLONASS). The antennas determine the orientation of the aircraft and the direction of the gradient vector. The ReinMag software from Geotechnologies was used for magnetic compensation. In summer 2018, Geotechnologies performed a series of experiments to measure magnetic field gradient tensor components with promising results that will lead to future tensor magnetogradiometers on board the aircraft.

MPX Geophysics, with headquarters in Toronto and offices in South America and SE Asia, conducts airborne geophysical and remote sensing surveys internationally for the mining, oil & gas, civil and environmental engineering sectors. In 2018 the company's six airborne systems completed approximately 100,000 line-km of high-resolution helicopter magnetic and radiometric surveys. It was active in SE Asia and Africa working with Calgary-based partner **Airborne Petroleum Geophysics (APG)** which conducts helicopter and fixed-wing magnetic/gravimetric surveys. MPX also flew helicopter TDEM surveys in the Americas with the **Nuvia Dynamics** PTHEM technology.

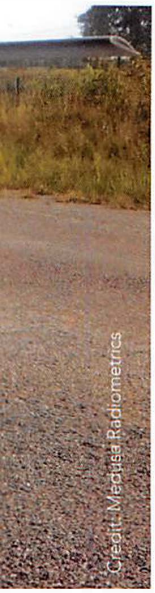
New Resolution Geophysics (NRG), headquartered in Cape Town, South Africa, continued to fly high-resolution helicopter and fixed-wing magnetic and radiometric surveys, fixed-wing gravity and helicopter TDEM surveys in Africa, the Middle East and Australasia. The company's aircraft fleet added its first twin-turbine engine P406 fixed-wing based in South Africa and configured for high-resolution airborne gravity surveys globally.

Precision GeoSurveys, based in Vancouver, which operates a combination of owned and chartered helicopters and fixed-wing aircraft, specializes in flying low-level airborne geophysical surveys in remote and mountainous terrain. It has carried out high-resolution magnetic, radiometric and EM surveys in Africa, Asia, Europe, South America, and North America. In 2018, Precision flew EM, magnetic, and radiometric surveys across western Canada and western U.S.

In 2018 **Sander Geophysics** flew magnetic and radiometric surveys in North America, South America, the Middle-East, Europe and Australia. SGL's 12 AIRGrav systems were operating worldwide. These included a very large gravity-only survey in the Middle-East, designed to improve geoid modelling, as well as several large gravity-only surveys in Australia for regional mapping. In addition, several fixed-wing gravity and magnetic surveys were flown in South America and North America, including a survey flown for the Geological Survey of Canada for regional mapping, and a high-resolution survey for mineral exploration. Several helicopter gravity-only and combined gravity and magnetic surveys were also flown for mineral exploration in North America. SGL flew a small UAV (hexacopter) magnetic survey for mineral exploration in Europe. Methane sensing surveys were carried out using its unique SGMethane equipment and modelling for environmental monitoring and baseline mapping. 2018 was the ninth year that SGL was involved in **NASA's IceBridge** climate change-monitoring project supplying its AIRGrav airborne gravimeter to assist with NASA's polar research over Antarctica. It was flown by NASA's DC-8 aircraft based in Chile. The project for the first time featured overflights by NASA's recently launched ICESat2 satellite. The mission of Operation IceBridge is to collect data on the changing polar land and sea ice between ICESat missions, so 2018 was the last year for the airborne IceBridge missions. The company flew the first year of a newly-awarded three year EM, magnetic and radiometric survey in Ireland which was a follow-on to an earlier three year survey SGL flew in the government's ongoing multi-disciplinary **Tellus** program. SGL has conducted airborne mapping of most of Northern Ireland and the Republic of Ireland, with a goal to map the entire island by 2023.

Toronto-based **Scott Hogg & Associates** reported that in 2018 it carried out surveys across Canada in base metal, diamond and gold exploration programs using its Heli-GT helicopter georeferenced 3-axis magnetic gradiometer system. The unique towed-bird combination of four high sensitivity cesium sensors and accurate pitch, roll and yaw determination allows measurement of total field and magnetic gradients in the true east, north and vertical directions.

SkyTEM306 HP and SkyTEM312FAST (able to fly at 150 km/h), were used for mineral exploration and groundwater mapping in Africa, Australia, Canada, U.S. and Italy. In North America SkyTEM312 was used for mineral exploration surveys in California, Ontario, Newfoundland, British Columbia, Alberta and Nunavut. **SkyTEM** formed a strategic alliance with **Aerocientifica**, a Brazilian airborne survey company. The SkyTEM312HP was combined with a **Sander Geophysics** AirGRAV gravity system in the NE part of Brazil and flown over 44,000 line-km. SkyTEM312Fast was employed for a 22,000 line-km survey in central Brazil and a geotechnical survey was flown in Chile. The company continued to expand into Africa with the SkyTEM312 HP system in the Areachap Belt, Northern Cape, South Africa and in Namibia for mineral exploration. In


Credit: Meagher Radiometrics

Australia several variations of SkyTEM including SkyTEM306HP, SkyTEM312HP and SkyTEM312 were employed in mineral exploration for very near surface geotechnical mapping and for the **CSIRO** to map water resources. In Europe, geotechnical investigations were carried out with the SkyTEM304 system for Swedish and Norwegian Geotechnical Institutes, a SkyTEM306 HP survey was flown in the vicinity of Milan, Italy and a SkyTEM312 was used for mineral exploration in Northern Ireland. In the U.S SkyTEM312FAST technology was employed for water surveys in six states.

Terraquest of Markham, Ont. provides high-resolution airborne geophysical surveys using gravimetric, total field magnetic, horizontal gradient, HyRez Helicopter TDEM, radiometric and proprietary digital Matrix VLF-EM methods. In 2018 the company conducted both fixed-wing and helicopter surveys in Canada, and magnetic, radiometric and Matrix helicopter operations in Mexico and Central and South America as well as two regional magnetic and radiometric surveys totalling 99,000 line-km in Missouri and South Carolina for the USGS. Commercialization of Terraquest's new HyRez Helicopter TDEM system continued with the acquisition of new data examples. Terraquest was also selected by **VeriDaaS LLC** an American LIDAR provider to carry out a 1400 km² LIDAR survey in upstate New York with the advanced Galaxy LIDAR system. The high-resolution survey resulted in a data set with average point density of 12 points per m² over the entire survey area.

In 2018 **Thomson Aviation** flew a number of fixed-wing and heli-borne airborne geophysical surveys in Australasia and SE Asia. The company was awarded a large airborne mag/spec survey for the **Northern Territory Geological Survey (NTGS)** and **Geoscience Australia** over the Tanami Region of the Northern Territory. These surveys totalled more than 275,000 line-km. Also awarded was a 90,000 line-km airborne mag/spec survey in the Central Isa region of Queensland for the **DNRME**, to commence in early 2019.

Tundra Airborne Surveys (TAS) of St Catharines, Ont., provides combined magnetic horizontal gradient and VLF-EM surveys using its Diamond DA-42 Twin Star. The aircraft is outfitted with dual wing tip magnetometer pods (16.2 m apart) and a 90 cm nose stinger for the VLF antenna. In 2018 TAS was busy flying low level horizontal magnetic gradient and VLF surveys for diamond exploration in Northern Ontario and Quebec as well as a survey in Central Baffin Island. TAS celebrated its fifteenth year of operation in 2018.

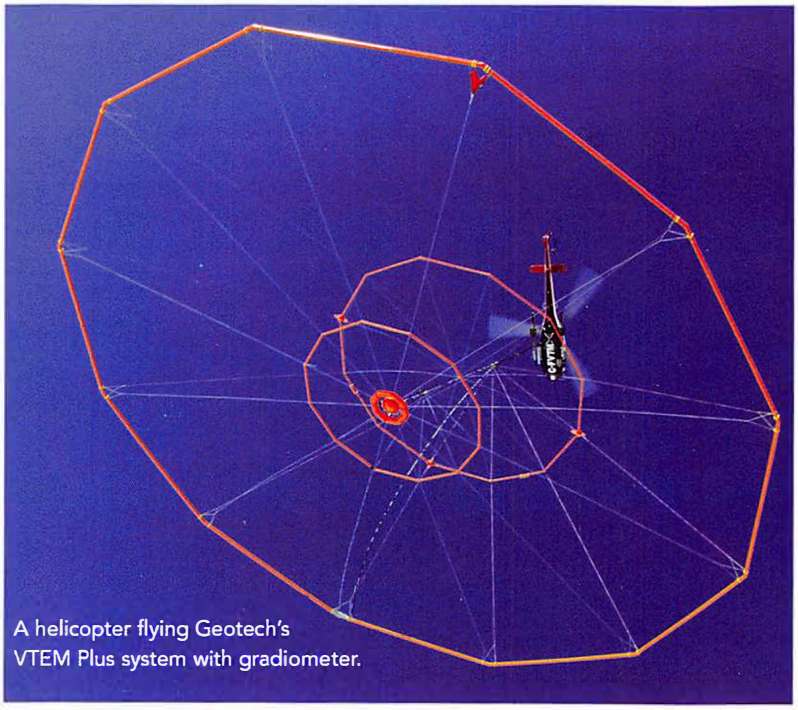
Airborne Data Acquisition and Processing

Denmark's **Aarhus Geophysics** offers advanced processing, inversion and modelling of AEM data. Rigorous description of systems and modelling enables merging of datasets from different AEM systems, collected at different time periods. In a recent 6500 km² project in Western Australia, the company merged several surveys, acquired with different VTEM systems, Xcite and HeliTEM, between 2009 and 2018. In spite of the difference in their technical features, a seamless 3D conductivity distribution was produced for a 3D geological model. The resulting conductivity map, referenced to a depth of 40 m, displayed geological features relevant to exploration, such as paleochannel distribution and pattern of conductive shales. The company expects that AIP (IP effects in AEM data) will soon become standard practice in the industry, given its added value in exploration. Aarhus Geophysics' services and research associated with modelling of AIP (including major **Horizon 2020** projects of the E.U.) keep expanding as AEM systems evolve with larger dipole moments, better S/N and lower base frequencies.

Geotech continued to provide advanced interpretation for its VTEM, ZTEM and aeromagnetic surveys including **Geoscience Australia** GALEI 1D inversion for VTEM, **UBC-GIF's** 3D ZTEM inversion code and **Geosoft** MVI 3D magnetic inversion. In 2018 the company developed a new kimberlite targeting tool for VTEM data based on the Keating Method for aeromagnetic interpretation. It is also integrating new Artificial Intelligence (AI) tools for exploration targeting, such as advanced Deep Neural Networks (DNN) using Google's Tensorflow implementation and Geosoft's Python API in Oasis montaj. Geotech reported widespread interest in its AIIP (Airborne Inductively Induced Polarization) mapping tool for extracting Cole-Cole parameters from VTEM TDEM data, both for recent precious and base metals projects and for historical VTEM data sets.

In 2018 **Medusa** released the first embedded version of its patented "full spectrum analysis" (FSA) technology. In FSA, virtually all spectral data are used to derive radionuclide concentrations yielding the best achievable results in spectral fitting. The technology is now embedded in the Medusa gamma-ray spectrometers and is used to process data "on the go."

A Geoscience ANALYST interface for GIFtools will be



A helicopter flying Geotech's VTEM Plus system with gradiometer.

Credit: Geotech

launched by **Mira Geoscience** in 2019. GIFtools is the product of a multi-year, industry-supported R&D project at UBC to facilitate the use of UBC-Geophysical Inversion Facility (GIF) 3D forward modelling and inversion programs for gravity and magnetic gradient, resistivity and IP, EM, and spontaneous potential data. This new interface will use the UBC-GIF suite to prepare data, create meshes, incorporate constraining geologic information, run inversions and visualize results. Data, inversions and all relevant data and geological models can be shared as open-format Geoscience ANALYST workspaces accessible through the free visualizer. The Geoscience INTEGRATOR 3.0 release of the 4D data management system enhances the capacity to find, integrate and analyze data, models, files and documents. Spatial, temporal and metadata searches make data easy to find via ANALYST or a web browser. Geoscience INTEGRATOR will also provide the public repository for the **CMIC Footprints Project** data and models when they become available in 2019. GOCAD Mining Suite, a fully integrated, multi-disciplinary earth modelling solution, was updated to version 17u2, offering greater connectivity to VP Suite for creation, validation, and modification of 3D geological models.

The DAQNAV airborne data acquisition, navigation and magnetic compensation system, developed by **Scott Hogg & Associates** is believed to be the only single-source data acquisition and navigation solution currently available to the survey industry. In 2018, the DAQNAV system became a 100% wireless data acquisition and navigation system. The company's new WireFree module transmits all incoming geophysical and navigational data wirelessly to the DAQNAV system. This makes more space in the aircraft cockpit, increases data transmission reliability and provides a mobile data QC solution to geophysical operators. WireFree is available as an upgrade to previous DAQNAV systems or an add-on to new systems. The company continues to offer its GT-Grid mapping system for measured magnetic gradient information. In 2018, GT-Grid projects were carried out for companies in Canada and Australia. The GT-Grid high-resolution map is unique in its ability to correctly present very complex geological scenarios with multiple trend directions.

Spectrem Air of Lanseria, South Africa, is now flying its full tensor SQUID magnetometer developed and refined over many years of in-house R&D. Sydney-based **Tensor Research** has been working with Spectrem Air to develop interpretation tools for the complex datasets from these surveys. ModelVision provides full tensor forward modelling and joint inversion for the multi-channel data enabling survey simulation or direct interpretation of the survey data. The system produces six channels of magnetic gradient data which effectively measure the curvature of the magnetic field at each measurement point. Unlike total magnetic field data, it is possible to immediately determine on which side of the aircraft the magnetic source is located and with just a few measurements, ModelVision can determine the location, depth and properties of the target. The 3D information available in the tensor can provide considerable geological information from a single data profile. The company released a beta product extension for ModelVision called QuickDepth which applies artificial intelligence (AI) principles to the estimation of depth, magnetic properties and geology from magnetic data. AI shortens the interpretation process while keeping the interpreter in full control. It uses both the line data for the highest possible depth precision and the total magnetic intensity grid for information on the shape characteristics of each anomaly. AI is also used to evaluate interference from overlapping anomalies to help assess confidence in the depth estimates. The magnetic tensor is computed by FFT transformation of the grid and used to derive geological characteristics. This is used to constrain and improve the precision of depth estimation methods including the following: Tensor, Euler 2D, Peters' Length, Werner, Deconvolution, Tilt Depth and Euler 3D. An upgraded version will be released with version 17 of ModelVision in early 2019.

Aeromagnetic Surveying

Abitibi Geophysics' AeroVision UAV magnetometer system, powered by the AIM LOW technology from **Devbrio Geophysics**, has proven to be very successful. It is believed to be the only UAV mag system with real-time collision avoidance. Using this superior navigation system, AeroVision has flown entire surveys where the standard deviation in vertical variance was less than 1 m. Magnetic data quality is crucial, and the clover-leaf flying test shows that the heading error is less than 1 nT at the intersection point for all three systems in production. AeroVision high-resolution magnetics have become widely accepted because of the clarity and accurate location with which it maps detailed geological features.

Gatineau, Que.-based **Devbrio Geophysics**' AIM LOW technology has a real-time collision avoidance system ensuring safe operation with survey speeds up to 12 m/s even in rugged terrain, by using an algorithm that constructs a 3D surface for the whole survey area. Using a laser altimeter to fly over the terrain of the 3D surface, the UAV maintains a consistent magnetic sampling interval regardless of topography. Up to three UAV survey crews can share the same landing area for increased productivity and the UAVs communicate with a single base ensuring safe separation distances are maintained.

Data analysis and processing are done automatically with deliverables ready within 24 hours. Devbrio also continued its long-time partnership with **SkyTEM Surveys** from Denmark, handling all of their surveys in Canada and the U.S.

Markham, Ont.-based **GEM Systems** has improved their optically pumped potassium magnetometer sensor designed specifically for UAVs, the DRONEmag, for ultra-high sensitivity magnetic measurements. The sensor offers the highest sensitivity (0.0002 nT @ 1 Hz), resolution (0.0001 nT) and absolute accuracy (+/- 0.1 nT) with the lowest heading error (+/- 0.05 nT) currently available on the market. Data are retrieved post flight via the onboard flash memory. Modular options include GPS, laser altimeter and IMU. The company also offers a Pixhawk-enabled version for seamless integration into a UAV. In addition to the DRONEmag, two turn-key solutions for UAV applications have been developed. The AirBIRD is a UAV-towable system which includes both the AirBIRD (aerodynamic housing and components) as well as ground station (laptop, software, etc.). The AirBIRD contains a high-sensitivity potassium magnetometer (GSMP-35U), GPS, laser altimeter, IMU and a RadioLink, where all data are synchronized and transmitted to the ground station in real time using GEMDAS. The AirBIRD total length is approximately 2.1 m and total weight is less than 3.6 kg including all components added and battery. The second turn-key system, for larger UAV platforms, is the first magnetic gradiometer (sensors have 1.5 m vertical separation) designed for UAV applications (~8.5 kg) such as mapping very small, near-surface anomalies.

R&D work at Mississauga, Ont.-based **RMS Instruments**, focused on characterization of aspects unique to aeromagnetic compensation of UAV platforms including for example, close proximity to interference sources and hovering-mode calibrations as an alternative to conventional "box-mode" calibrations. This work and collaboration with groups using single-rotor helicopter UAV platforms, has yielded excellent results. In particular, a recent series of tests with the AARC51 installed on **Flying-Cam's** SARAH platform, demonstrated (real-time) compensated performance comparable to conventional manned helicopters: residual errors of the order of 40 pT (FOM ~ 2.0), and improvement ratios around 5. The new AARC52 real-time adaptive compensation systems for aeromagnetics were designed for UAV applications, with the same compact and light (< 2 kg) footprint of the AARC51. The AARC52 supports dual magnetometers for gradiometer applications and includes a dual-frequency embedded GPS receiver and additional connectivity. In 2018, all models in the AARC500-family were improved through enhanced firmware including auto-adaptive mode, built-in frequency-domain analysis functions and built-in barometric pressure and temperature sensors.

Supracon AG, located in Jena, Germany, has made its superconducting technology in an airborne SQUID-based Full Tensor Magnetic Gradiometry (FTMG) system available on a commercial basis. The measuring device, brand-named JESSY STAR, has flown in several production surveys enabling development and refinement not only of the hardware, but also of the advanced data processing and analysis software which takes care of and maintains the specific magnetic gradient tensor properties. This provided new insights in interpretation and improved the effectiveness of magnetic methods for mineral exploration. Anglo American and De Beers, the primary sponsors of the development of the JESSY STAR technology, have relinquished exclusivity on the full technology, which makes it available to the wider exploration community. The use of highly sensitive superconducting sensors, which result in overall flight noise levels below 5 pT/m is a significant advantage for exploration. It provides higher precision for locating geological boundaries along with new magnetic field features derived from the full tensor measurement. This includes information about the direction of magnetization and the mapping of remnant magnetization.

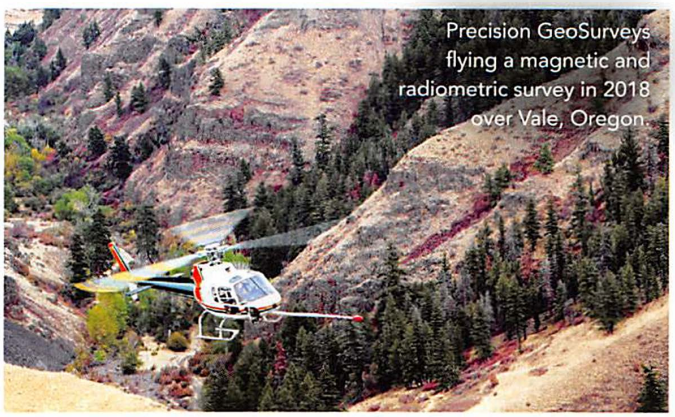
Airborne Electromagnetic Surveying

CGG Multi-Physics offers three airborne EM technologies: Helitem, Tempest and Resolve. In 2018, the company updated its Helitem technology. Historically, receiver motion-induced noise has been the primary limiting factor in acquiring useful low base frequency AEM data. Upgraded receiver system electronics and a patented receiver suspension system now

allow Helitem AEM operation at a base frequency of 7.5 Hz. An innovative change in transmitter pulse-shape, from half sine to square, enables early off-time measurement and effective energizing of deep targets. A comparison of resistivity images from CGG's 30 Hz and 7.5 Hz Helitem systems showed that the 7.5 Hz data provide more interpretable near-surface information and more accurate deep geological information. The upgraded Tempest fixed-wing TDEM systems, now available worldwide, were used extensively during 2018 on groundwater, geological mapping, and mineral exploration projects in Australia, Canada and the U.S. System upgrades include: a 30% increase in transmitter power with faster and cleaner Tx turnoff, receiver improvements in signal-to-noise and increased depth range. The system now produces high quality data at selectable base frequencies from 12.5 to 15 Hz, increasing exploration depth. The Tempest completed the largest AEM survey ever undertaken — covering over 1,000,000 km² in northern Australia. Data are to be released publicly to stimulate exploration in the region. The company's Resolve technology continued to be used for precision conductivity mapping in 2018, in water management and mineral exploration.

Expert Geophysics of Toronto reported an active year with MobileMT, their new airborne EM and magnetic technology which uses natural EM fields. Commercial surveys were conducted in Canada (New Brunswick, Ontario Saskatchewan), Ecuador and Australia to explore for gold, porphyry copper and uranium. Four MobileMT systems are currently available for commercial operations. The company also offers data processing, data inversion and interpretation services. System features include a broad frequency range (25 Hz - 20,000 Hz) and more than 20 extracted frequency gates, which extends high-resolution investigations from surface to over 1 km depth and permits the selection of optimal frequency gates. Noise reduction is achieved with the high digitizing rate (73,728 Hz), and elimination of data bias distortions by independently registering each electrical component on the base station from two grounded lines (signal and reference). This feature was not available in the previous generations of the AFMAG system.

GEM Systems has developed a new UAV-towed VLF-EM system (GSM-90AVU) based on their on-board manned-aircraft VLF system. It uses a two frequency multi-component receiver that measures the in-phase and quadrature components from two separate radio transmitters in the VLF frequency range with sampling rates up to 10/s and +/- 45 degrees of horizontal tilt correction. Options include GPS, laser altimeter and IMU.



Precision GeoSurveys flying a magnetic and radiometric survey in 2018 over Vale, Oregon.

Credit: Erik Keyser

Geotech completed the design and testing of a new B-field EM sensor for low (12.5 to 15 Hz) transmitter base frequency TDEM measurements. It extends late off-time channels for recording the decay of the secondary EM response and is expected to become commercial in 2019. A new design for the next generation in airborne natural field EM technology was introduced in 2018 based on the company's patented AirMt technology. The new system features three orthogonal 1.25 m receiver coils fully integrated into a single housing with a custom-designed vibration-dampening suspension system. It uses a patented method for measuring and computing the Rotationally Invariant Parameter, as well as individual coil transfer functions for a complete multi-component Tipper analysis. Measuring frequencies between 22 Hz and 30,000 Hz, the system includes an optional horizontal magnetic gradiometer with a 6.5 m sensor separation. Testing of the new system which is lighter weight, higher efficiency and has greater manoeuverability, will continue in 2019. Geotech reported increased demand in 2018 for its VTEM and ZTEM helicopter EM technologies including the VTEM Plus (26 m dia.) with horizontal magnetic-gradiometers, the VTEM Max (35 m dia.) large dipole-moment system for deep exploration and the lightweight VTEM Terrain (17 m dia.) system for rugged and mountainous terrains. The ZTEM (7.2 m dia.) natural field EM system with Compact Base Stations (CBS) was used for porphyry copper and epithermal gold exploration and the ZTEM Lite sensor was used for challenging high elevation EM surveying. The company also reported increased interest in the VTEM ET, introduced in 2017. The system has improved near-surface resolution for groundwater applications and increased sensitivity to resistivity/alteration mapping, particularly for gold exploration. Also first introduced in 2017, commercial use of the Integrated Helicopter Gravity-ZTEM-Magnetic system continued. It combines the standard ZTEM helicopter sensor and towed-bird cesium magnetometer, with the **Canadian Micro Gravity (CMG)** GT-2A airborne gravimeter.

NRG has updated the processing flow and receiver suspension for its Xcite Helicopter TDEM system. The fundamental elements of the system remain the same, with the inflated loop, fully streaming data on-time and off-time and fast transmitter waveform turn-off. The near square wave provides early time (near surface) resolution due to its very fast

transmitter pulse turn-off speed, coupled with late time (deep penetrating) performance in a single pulse waveform. There are currently 5 Xcite systems in operation in Africa and Australia, with more in production.

NUVIA Dynamics has enhanced its P-THEM Helicopter EM system. P-THEM uses the company's proprietary IMPAC data acquisition system with dedicated EM infrastructure including transmitter coil and on-board transmitter; suspended receiver, suspended magnetometer and tow cable with weak link. The system delivers a dipole moment of 220,000 Am² which can be upgraded to 380,000 Am² for deeper work. It is now equipped with a custom tail fin for robust and smooth flight, reducing noise. The P-THEM design is based on loop asymmetry which can be easily interpreted with several commercial software packages. Nuvia claims that recent tests with the system at the Reid-Mahaffey test site, near Timmins, Ont., showed the highest resolution results compared to other systems flown over the site.

In 2018 **SkyTEM**'s new generation of helicopter transient EM (HTEM) systems were employed on mineral exploration and groundwater mapping projects globally. The new SkyTEM HTEM systems have a new TEM transmitter with an output of 250 A, reduced transmitter size and weight and only require a small 340 m² carrier frame while still maximizing depth of investigation and all SkyTEM systems are now flown on this small light frame configuration. New receiver coils were developed using novel suspension techniques for a factor of 10 reduction in the noise level. These coils use a 12.5 to15.0 Hz base frequency instead of the previous 25.0 to 30.0 Hz, increasing depth penetration and improving characterization of discrete targets due to an increase in off-time from 15 ms to 32 ms. The SkyTEM312 HP (High Power) has 1,000,000 NIA for mineral exploration and great depth penetration while the SkyTEM306 HP systems with 500,000 NIA, 25.0 to 30.0 Hz base frequency, can be operated at speeds up to 150 km/h, and offer high near-surface resolution and depth of penetration. Systems can also be re-configured quickly in the field, for example, SkyTEM306 HP can transform to a SkyTEM312 HP or vice versa.

Airborne Gamma-ray Spectrometric Surveying

Medusa's first drone-borne spectrometer, the MS-1000 which was released in 2017, has led to the development of the MS-350 which is even lower in weight (about 2.3 kg) for use under the smallest-payload drones. Like the other Medusa sensors, the MS-350 is fully self-contained, processing and storing all radiometric data on-line. It is intended for use in high spatial resolution surveys, particularly in areas that are difficult or dangerous to access on foot.

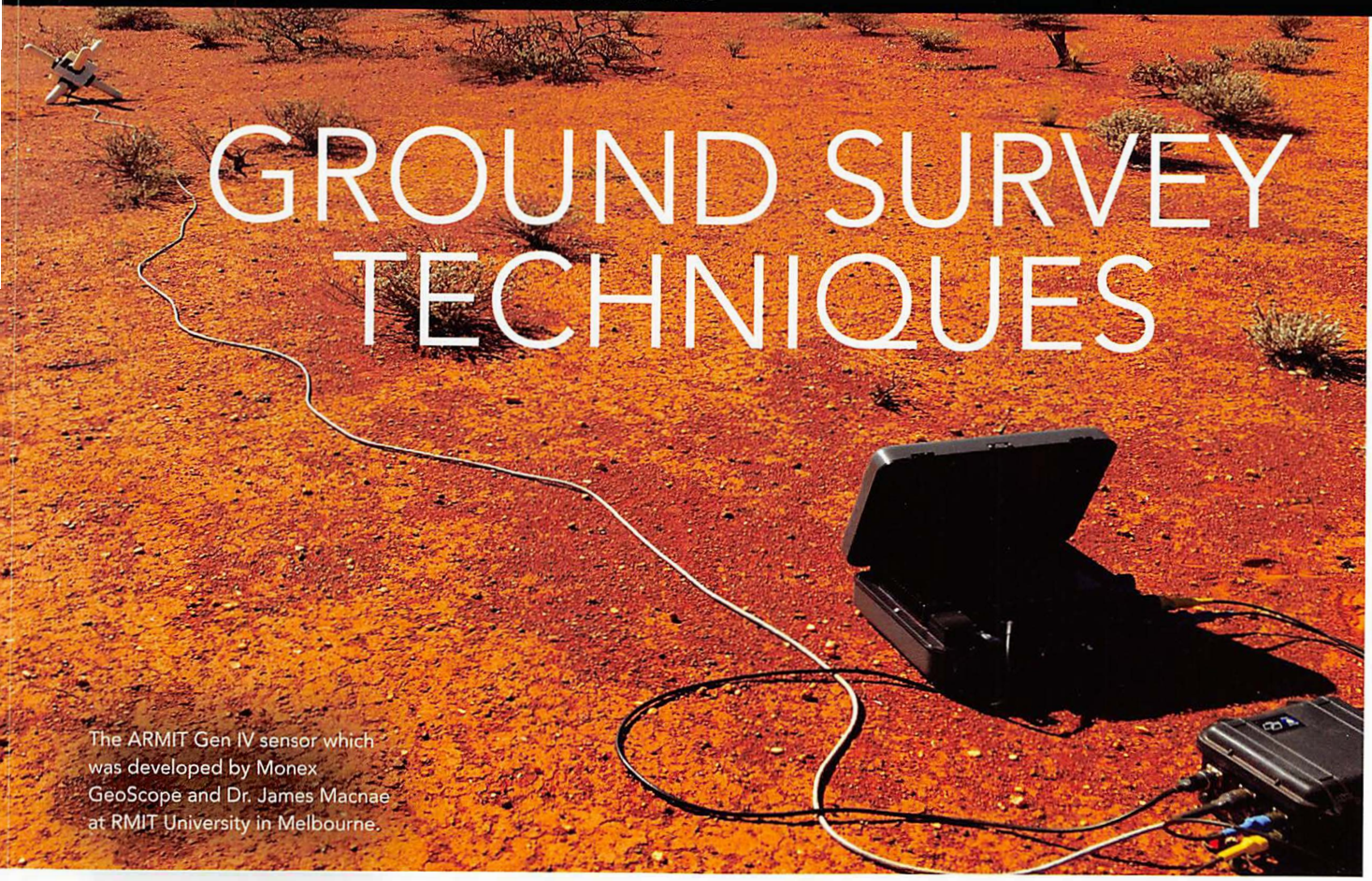
Airborne Gravity Surveying

The Falcon Airborne Gravity Gradiometry (AGG) systems were designed specifically for use in light aircraft and helicopters and to isolate the instrument from aircraft-induced noise. In 2018, **CGG Multi-Physics** flew the highest number of Falcon AGG line-km since it was first deployed. AGG surveys were flown in PNG, Australia, Japan, Brazil and Canada, targeting oil and gas, coal, iron ore, base metals and gold. Full Spectrum Falcon was deployed in Australia and PNG proving especially useful for longer wavelength gravity information (> 20 km). The Falcon Plus system, launched in 2015, and in operation globally is the newest development in the Falcon family of AGG systems. Its low noise capabilities were proven over the Geoscience Australia Kauring gravity test site west of Perth. CGG Multi-Physics is the only contractor that has published its test data. A helicopter version, HeliFalcon, is used where ultra-high-resolution gravity data are required to evaluate small exploration targets. In 2018 it was deployed in the Americas.

Gedex Systems of Mississauga, Ont. continued development of its High-Definition Airborne Gravity Gradiometer (HD-AGG) in 2018. The HD-AGG was designed to achieve a performance of 1 Eotvos RMS noise at a spatial resolution of 60 m when flown in a fixed-wing aircraft. Currently operated in a Cessna Caravan aircraft, over the past year the company focused on improving data quality, reliability and productivity. To date, it has demonstrated a noise performance of 6.3 E RMS at a spatial resolution of 60 m which is expected to be reduced by a factor of two when the system is transferred to the Dash-8 survey aircraft in 2019. Advances have also been made in data processing workflow with the company now claiming performance at a level better than other existing fixed-wing AGG systems.

NRG is now offering its Xtract airborne gravity surveys globally using their new F406 twin turbine, or their STOL performance PC6 single turbine-powered fixed-wing aircraft. The technology uses CMG gravimeters (e.g. GT-2A) with capabilities enhanced with NRG's patented Active Thermal Control System (ATCS) technology. The gravity sensor is mounted inside a gyro-stabilized unit and data from the gyros, inclinometers, angle sensors and dual frequency GPS are used to drive servo motors which maintain the sensor in a vertical position. In addition, isolation from environmental influences such as temperature, pressure and vibration, improves the performance of the GT meters.

GROUND SURVEY TECHNIQUES



The ARMIT Gen IV sensor which was developed by Monex GeoScope and Dr. James Macnae at RMIT University in Melbourne.

Credit: Monex GeoScope

Physical Rock Properties and Elemental Analysis

Terraplus of Richmond Hill, Ont. introduced sensors with a curved shape for the KT-20 Physical Property Measuring System which improves the sensitivity for measuring magnetic susceptibility or conductivity on core samples and also improves data quality as the curved design enhances the contact between the sensor and core sample. Curved sensors are available in 10 kHz or 100 kHz frequencies, in four different sizes for BQ, NQ, HQ and PQ sized core samples. The company also announced that the KT-10 magnetic susceptibility meters are now compatible with the geological data management software Geobank, from **Micromine** (headquartered in Australia), designed to maintain the quality, integrity and usability of data.

Ground Data Acquisition and Processing

In 2018 Lakewood, Colo.-based **Condor Consulting** reported working on a series of collaborative projects to promote new technologies and interpretation approaches. Condor worked with **Geosoft**, **DIAS Geophysical** and **NexGen Energy** to optimize the modelling of 3D IP data. The company also collaborated with with **Phoenix Geophysics**, publishing a position paper on the value of MT for deep copper exploration. With the cooperation of **Expert Geophysics**, two MMT AFMAG data sets were processed and the results were presented at the SEG 2018 conference. Working with **SISPROBE**, based in Meylan, France, Condor assessed the value of the passive seismic survey technique for a number of advanced mineral exploration programs. The firm conducted a major review at Western Copper and Gold's Casino porphyry copper-gold deposit in the Yukon. The review entailed a total re-assessment of the IP and MT data acquired in 2009, using state-of-the-art 2D and 3D modelling. The major outcome was the definition of a deep (650 m) conductive body situated on the southern margin of the known deposit. Finally, Condor has entered into a commercial joint venture with **Ronacher and McKenzie Geoscience**, based in Sudbury, to allow both companies to offer integrated services to clients.

Kingston, Ont.-based **Lamontagne Geophysics** completed the current phase of the MultiLoopGI. modelling tool development with new direct tools for scaling, duplicating and replacing conductors within a model and with enhanced importation of waveforms. Development is now concentrated on Gridplot, a web app aimed at survey-layout design and the building of 3D models for the **MGEM** multi-grid 3D modelling tool. Gridplot makes it possible (on orthogonal views) to underlay and register at the exact scale, a digital map (or any image) and provides tools to design or modify overlain vector graphic elements. A processing method called SLproc is also under development for electrical conductivity and magnetic permeability imaging of complex data sets obtained in Step Loop surface EM surveys. SLproc can be thought of as the inverse process in EM inversion but it uses a pattern recognition and expert systems approach rather than a linear inverse approach. One key step in the processing is a multidimensional matched filter process that can be applied in x, y and log time when used on step response data. The aim is to use MGEM as the forward modelling process in an EM imaging and inversion system for difficult conductivity environments.

On the consulting side, **Mira Geoscience** continued its integrated approach to geological and geophysical modelling techniques. The Cave Rocks nickel and gold project area in Australia is a good example where an integrated 3D geological model was produced within GOCAD Mining Suite based on existing geological mapping, very sparse exploration drilling, and airborne geophysical data. When tested against geophysics, the gravity, magnetics and AEM data conflicted with the originally modelled geology. The original geological information depicted the main, central fold as a south-plunging anticline, but from modelling the geophysical data, it became clear that the overall plunge direction was a north-plunging syncline.

Quantec Geoscience now has faster turnaround time with 3D MT inversions. Robust 2-coil solutions for MT produce significantly more data, increasing inversion times. Today a robust 3D inversion can be provided in 5 to 10 business days regardless of the survey size. CLARUS is Quantec's new facility, to use its proprietary PW code (Phil Wannamaker) along with DC and IP data in pole-dipole and dipole-dipole configurations in a joint inversion process. The code now supports non-uniform dipole spacing and IP inversion can also be done using a MT reference model. In 2019 the company will investigate the theoretical significance of IP modelled with MT vs. DC. Full waveform data "clean routines" include optional telluric cancellation (TC) by collecting remotely sampled MT data, (natural EM field variations) and the recently implemented Periodic Noise removal (PNR), a useful tool for collecting data in noisy environments.

Sydney-based **Tensor Research** released version 16.0 of its ModelVision magnetic and gravity interpretation system with a new live drillhole modelling and editing window for working with drillhole magnetometer systems. A new tool was developed that can populate the subsurface with an array of bodies to build voxel or point source models for constrained inversion or equivalent source inversion. The voxel tool is effective for building 3D basin models from gravity data.

Drillhole Methods

Gravilog, the borehole gravity system developed by Concord, Ont.-based **Scintrex** between 2005 and 2008 and operated commercially by **Abitibi Geophysics** for several years, has been modified to improve efficiency. Abitibi tested the new Gravilog system and designed new optimized survey procedures. The quality of the collected data is very good with RMS error comparable to surface gravity surveys and the time and survey costs to log a borehole have been reduced substantially. The Gravilog system measures excess mass and in-situ density of mineralization and host rock. Prioritization of early stage drill-targets can therefore be made on the basis of both conductivity and estimated tonnage.

Advanced Logic Technology (ALT) (Redange, Luxembourg) released a new slimhole optical televiewer (the QL40 OBI-2G-

UV), with a white (visible) light and an ultraviolet (UV) light source in the same logging tool. Borehole wall images can be acquired in separate logging runs using either light source. The UV light shows the characteristic fluorescence of certain minerals and hydrocarbons in-situ. This extends applications for the televiewer beyond lithological and structural analyses to include mineral identification and hydrocarbon contamination studies based on fluorescence.

ClearView Geophysics based in Brampton, Ont., has been applying cross-hole IP/resistivity surveys and developing methodology to image geologic features between boreholes. The method involves current electrodes at "infinity" perpendicular to strike and potential electrodes P1/P2 in adjacent boreholes with P3 at the "anchor hole" collar for quality control. Standard borehole IP configurations, such as "detection" logs with pole-dipole or dipole arrays, or "directional" logs with gradient variants have been used for decades with varying degrees of success. For gold exploration where disseminated sulphides are the target, measurements across boreholes is complicated and difficult to interpret. However, with inversion software such as UBC 3D chargeability and DC resistivity routines, and with accurate drillhole survey data typically supplied by the client, between-hole results can be obtained and displayed with interactive 3D software or with simple select 2D depth slice presentations. UBC 3D magnetic inversions can also be completed quickly on proprietary ground magnetic data or public-domain airborne magnetic data to add confidence to interpreted trends and further prioritize targets. The company has been successful in combining surface IP/resistivity data with cross-hole data to enhance the inversion results.

Development of the U5BH down-hole EM system continued at **Lamontagne Geophysics** emphasizing increased sensitivity of all 3 components, with the first phase concentrated on the sensitivity of the 3-axis sensor. A new mechanical design for the system is being tested to improve many aspects including mechanical rigidity, high pressure performance and orientation precision. The UTEM 5H transmitter development continued with an updated digital control system, improving overall efficiency to more than 90%. It also has monitors and automated fail-safe shut-down controls for a variety of waveform errors, internal overloads, loop antenna load conditions and electrical safety conditions.

Denver, Colo.-based **Mount Sopris Instrument Co.**, and partners **ALT** (Luxembourg) and **Starfire Industries** (Champaign, Ill.) are near completion of a new slimline borehole neutron generator that operates on standard geophysical wirelines without radioactive sources. Using a 4 Curie-equivalent Deuterium-Deuterium (2.5 MeV D-D) fusion generator, the new tool has on/off capability and neutron emission at the end of the generator, an important innovation allowing much closer near- and far-placement of detectors in the sonde. Applications include semi-quantitative measurement of in-situ porosity, petrophysical properties, lithology correlation and aquifer quality. Mount Sopris and New Jersey-based partners (**Ontash & Ermac** and **Rutgers University**) and **ALT** have developed a borehole spectral induced polarization (SIP) tool. SIP response is measured by applying sine wave currents from 1 MHz to 10 kHz and impedance and phase are determined by correlating induced voltage and stimulus current. Measurements from this 4-electrode Wenner array enable indirect determination of lithological and physical properties including permeability, effective porosity and grain/pore size distribution.

Ground Electromagnetic Methods

Abitibi Geophysics introduced the ARMIT OMNI Vision TDEM loop configuration in 2018, an innovation that transforms its patented InfiniTEM system into a multi-loop and multi-target TDEM exploration system. This configuration of three equal-sized loops, designed for optimal coupling with both subvertical and subhorizontal conductors, is energized in the OMNI Vision pattern, and the ARMIT sensor and receiver simultaneously record the full waveform B-field and dB/dt response. The result is that with one pass along a survey line ARMIT OMNI Vision explores to depths of 1,000 m to detect both subvertical and subhorizontal targets with a wide range of conductance, from superconducting nickel sulphides to weak conductors. This highly effective TDEM exploration tool can resolve targets of any orientation and any conductance at great depth.

AGCOS developed new wideband magnetic sensors: the AMS-47 (10,000 to 0.0001Hz) and AMS-27 (1000 to 0.0003Hz) with a shorter measurement base to simplify vertical magnetic component installation and for marine EM applications. It also improved its AMT sensor (AMS-15) for the 50,000 to 0.1Hz frequency range. This sensor is suitable for AMT, CSAMT and FDEMS methods for investigations from 5 m to 3000 m depth. The company also developed and put into production

its portable battery-powered AT-3000 transmitter with a 40 A current output. The AT-3000 has easy setup and operation, a controller with flexible output options, current waveform recording and does not require any external devices.

R&D at **Crone Geophysics** has increased its emphasis on power and advances in discretization of targets at greater depths while keeping portability a priority. A new, more powerful transmitter, based on the successful trials of the 15 kW Tx introduced in early 2018, will begin field testing in 2019. New automation will reduce data acquisition time and new QA/QC measures will provide added confidence in the data.

Discovery International Geophysics continued to offer the Jessy Deep SQUID sensor for deep TEM exploration under a North American exclusivity agreement with **Supracon AG**. In 2018 both the HTS high temperature SQUID (liquid nitrogen) and the ultra-sensitive LTS low temperature SQUID (liquid helium) were in use on surveys in Canada and the U.S.

In 2018, Mississauga, Ont.-based **Geonics** was developing a system for continuous measurement of near surface soil resistivity to a depth of 50 to 70 m, and for shallow mineral exploration. It has a rigid multi-turn transmitter loop and ultra-high frequency receiver coil separated from the transmitter loop by 5 m, controlled by the Geonics G-TEM TDEM instrument. It is designed for rapid in-field assembly and disassembly taking less than 15 minutes for two people to set it up.

The new ARMIT Gen IV sensor expands upon a **Monex GeoScope** R&D project to develop the ARMIT 3 with Dr. James Macnae at **RMIT University** in Melbourne. ARMIT sensors measure both B and dB fields simultaneously with noise levels orders of magnitude less than a fluxgate. The sensor does not require cryogenics or special handling. Significantly, corner frequency has been lowered allowing the sensor to reliably operate in the sub 1 Hz range making it suitable for use in conductive terrains to look for deep, late-time anomalies. Accurate accelerometers provide information to automatically correct sensor orientation. Reference waveforms correct thermal drift at each sounding. Sampled at up to 312,500 Hz, data are processed in the field for viewing the final response without post-survey processing. Capable of operating in high field gradients, soundings can be taken in close proximity to the Tx wire for Fixed Loop surveys. When combined with the terraTEM24 the Monex GeoScope ARMIT Gen IV sensor operates with the ease of a fluxgate but with the sensitivity of a SQUID.

Gravity Surveying

Scintrex announced the Gravilog Slim Hole Gravity Probe for logging is now available for purchase worldwide. Also new for 2019 is the RG-1 ROV Gravity Meter for sea floor gravity measurements in ROVs and land applications in remote and automated vehicle operation. The meter is self levelling within +/- 45 degrees, has low power consumption and is light and compact. The RG-1 uses the same fused quartz sensor design

and performance specifications as the Gravilog. The company has also made an improved user interface for the CG-6 Autograv.

Induced Polarization

Abitibi Geophysics' IP research continued to focus on source discrimination and constrained inversion. A new borehole IP technique is based on a hybrid surface-borehole approach using a DAS system (**IRIS Instruments**) which has been successfully used in Noranda. Both borehole-to-surface and surface versions are now offered as standard products. The DAS system is especially suited for large mineralization systems such as porphyry copper or skarn. For smaller vein-like occurrences, cabled systems such as OreVision or IPower3D deliver more detailed reconstruction of the electrical properties of the basement rocks.

Dias Geophysical's DIAS32 system has been used in more than 25 3D IP surveys worldwide and now survey capacity has been expanded to more than 800 channels. Dias has introduced several new processing methodologies to augment the CVR acquisition technology. Due to the high volume of data from DIAS32 surveys, the data sets must be culled to meet the limitations of modern 3D inversion software. The company's Smart Dipole processing method automatically extracts expanding dipoles from the source data set producing small dipoles near the current injection point, and large dipoles for larger transmitter-receiver offsets. The resulting multi-scale data set is better suited for accurate inversion modelling than mono-scale dipole data sets.

After several years of testing, the innovative **GDD** communication boxes were formally introduced in 2018. Their main purpose is to perform distributed acquisition as a system to link several receivers wirelessly and conduct multiple electrical surveys simultaneously. 3D data can be analyzed and quality controlled directly in the field for each GDD IP receiver in the survey. The system can potentially increase the depth of investigation, exponentially lower the noise (being a wireless system), and minimize the number of personnel in the field by having total local control of all units in the installed configuration. Using the communication boxes, with several receivers (from 2 to 32 channels) and the latest digital GDD IP transmitter, model Tx4 (5000W-2400V-20A) will increase the power and current injected into the ground, achieving both good signal quality and increasing investigation depth. With the latest version of the GDD post-processing software, the output files from the multiple IP receivers can be merged for analysis and interpretation using new improved algorithms for making pseudo sections and for synchronization. Uniquely, model Tx4 can now be linked on Up Chain mode to connect from two to six Tx4s, reaching a maximum power up to 30,000W-4800V-20A. The multi-Tx mode, working with multiple receivers and performing as a Distributed Acquisition System is suitable for deep exploration projects.

A worker deploys wire in Chile for Quantec Geoscience

Credit: Quantec Geoscience

Magnetotelluric

AGCOS has developed and tested a new technique for mineral exploration which uses the natural EM field and includes AMT, MT, MVP and TC (telluric currents) methods in a special configuration. The technique reduces exploration costs, increases survey productivity and can estimate depth, size and conductivity of the target.

In 2018, Toronto-based **Phoenix Geophysics** increased the supply of its Ultra-Wideband Magnetotelluric (UMT) system. It has two receivers available; a five-channel (MTU-5C) and an eight-channel (MTU-8A), both highly ruggedized and with simple operation. An embedded screen delivers QC information for the field operator. The receivers feature continuous (up to 96 kHz) sampling rate, ultra-low power consumption and ultra-low noise digitizer. The company has introduced an advanced MT database manager, EMpower, which it claims can reduce operating costs by 20% via simple, intuitive operation and fast processing codes. Phoenix has also been developing a Real Time MT Monitoring system (MTU-RT) for research applications,which is an autonomous system that connects to any existing local network and sends time series data in real time. Using power supplies such as solar panels or thermoelectric generators, the system has been continuously logging data at the Kilauea volcano in Hawaii for more than 8 months and is also employed elsewhere in the U.S. and Japan. It is the first system that can provide monitored data from the upper AMT band (10 kHz) to the MT and LP range which permits monitoring of geoelectrical signals that may be generated by deep volcanic or tectonic activity.

Quantec continued to provide broadband MT using a 2 coil approach for magnetic data acquisition. The SPARTAN MT system provides both AMT capability, low frequency acquisition and the FULL Frequency application. Using separate high and low frequency coils is more comprehensive and covers

more bandwidth than a single broadband coil. The results at the very high end and low end of the spectrum provide improved overall resolution of the subsurface. The increased use of deep 3D surveys saw the company carry out a number of ORION 3D and ORION Swath surveys in 2018. TITAN24 has been configured to run with a dipole as little as 20 m. With simultaneous sampling of over 48 dipoles along the line, TITAN provides 2 direction in-line current transmitting, for every line, to reduce any acquisitional footprint. This bi-directional data provides robust 2D inversion results on lines up to 5 km long. The RT-120 data receivers allow MT data collection in addition to IP, so overnight runs of MT across more than 24 to 48 tightly spaced receivers provides significant deep multi-parameter data. In 2018 Quantec demonstrated the significant advantage of running TITAN MT surveys collecting both TM and TE mode vs. conventional TM mode only (often referred to as EMAP). When running TITAN EMAP or "TITAN-light" mode (in-line only electric field measurements), the slightly extra logistical addition of putting out the cross-line electric significantly improves the overall MT response and resolution resulting in a better resistivity depiction of the subsurface. Significant upgrades were made to its QT RT-160 data receivers which contributed to improvement in phase shift (2 degrees) at the high end frequencies (10 kHz). This improved resistivity accuracy in the high frequency (near surface response for MT). The RT-130 receivers were tested successfully to receive CSAMT data and further tests will evaluate the addition of Natural EM source data. This is expected to enhance the standard CSAMT surveys. The company now routinely incorporates accurate coil location information into acquisition procedures and inversion processes. TITAN data processing and inversion can now accept this information reducing the effect of the non-uniform source which is new for users of TITAN MT surveys. Quantec also improved the response of the H series coil manufactured by Phoenix Geophysics, and worked with the company to improve and upgrade Quantec's H series coils. Use of an in-house calibration chamber by Quantec facilitates routine re-calibration of the magnetic coils to account for any changes in their specifications after years of operation.

Zonge International based in Tucson, Ari., has developed a new broadband EM receiver called ZEN. The new high-resolution, multi-channel ZEN receiver is designed for acquisition of controlled- and natural-source geo-electric and EM data. It uses a 32-bit ADC designed specifically for geophysical applications. The 32-bit resolution enables successful surveys even in areas of cultural noise where 16-bit or 24-bit receivers may not easily detect signals. With wireless arrays it is a true Distributed Acquisition System and each analog signal can be measured wherever topography and accessibility make it convenient. The new receiver is rugged, portable, environmentally sealed and fully compatible with Zonge transmitters and controllers. With a frequency range of DC to 1024 Hz and 1 to 6 channels (user expandable) its survey capabilities include: resistivity, IP, complex resistivity, CSAMT, harmonic analysis and MT.

Ground Penetrating Radar (GPR)

Sensors & Software, based in Mississauga, Ont., has released the pulseEKKO Ultra Receiver for use with low frequency (12.5, 25, 50, 100 and 200 MHz) antennas for imaging deep geological structures and for mineral exploration. Data acquisition with the Ultra Receiver is now thousands of times faster than before, which has huge implications for collecting GPR data. A primary concern for GPR technology is the achievable depth of penetration. This is limited by the electrical conductivity of the material and by masking of the GPR signals at depth by stronger, random, background radio noise, called the "noise floor." One way to see weaker, deeper signals is to stack the GPR data traces many times. The increased speed of the Ultra Receiver is used to stack GPR traces up to 65,536 times, reducing the noise floor and making it possible to see GPR signals 100 times smaller than before. This can double the depth of penetration with little reduction in data collection speed. To sample the smaller GPR signals properly, the Ultra Receiver now collects data in 32-bits. This increases the possibilities for the use of GPR in many geological applications.

Ground Radiometric Surveying

Georadis s.r.o. of Brno, Czech Republic, introduced the D230A UAV Gamma-Ray Spectrometer. The D230A uses two 51 mm x 51 mm detectors (either BGO or NaI) and two 1024 channel gamma-ray spectrometers to measure and map the total intensity of gamma radiation as well as the intensity in the potassium, uranium and thorium energy windows. E&D

COMPANIES & WEBSITES

Aarhus Geophysics: www.aarhusgeo.com
Abitibi Geophysics: www.ageophysics.com
Advanced Logic Technology: www.alt.lu
Aerocientifica: www.aerocientifica.com.br
AGCOS: www.agcos.ca
APG: www.apgeophysics.com/site/home
BRGM: www.brgm.eu
Canadian Exploration Geophysical Society (KEGS): www.kegsonline.org
Canadian Micro Gravity: www.canadianmicrogravity.com
Caracle Creek International: www.caraclecreek.com
CFU International: www.cfu.com.tr
CGG Multi-Physics: www.cgg.com/multi-physics
ClearView Geophysics: www.geophysics.ca
CMIC Footprints Project: www.cmic-footprints.laurentian.ca
Computational Geoscience: www.CompGeoInc.com
Condor North Consulting: www.condorconsult.com
CRM GeoTomography: www.crmgtm.com
Crone Geophysics & Exploration: www.cronegeophysics.com
CSIRO: www.csiro.au
Devbrio Geophysics: www.devbrio.com
Dias Geophysical: www.diasgeo.com
Discovery Int'l Geophysics: www.discogeo.com
DMEC: www.dmec.ca
DNRME: www.dnrme.qld.gov.au
EMI-Dayk-Foto: www.dayk.com
EMIT: www.electromag.com.au
EON Geosciences Inc: www.eongeosciences.com
Expert Geophysics: www.expertgeophysics.com
ExplOre European Exploration Project: https://ec.europa.eu/growth/tools-databases/eip-raw-materials/en/content/european-exploration-project
Flying-Cam: www.flying-cam.com
Gap Geophysics: www.gapgeo.com
GDS: www.geodatasolutions.ca
Gedex Systems: www.gedex.com
GEM Systems: www.gemsys.ca
Geological Survey of Canada: www.nrcan.gc.ca/earth-sciences
Geological Survey of Finland: www.gsf.fi
Geological Survey of India: www.gsi.gov.in
Geological Survey of Sweden: www.sgu.se
Geometrics: www.geometrics.com
Geonics: www.geonics.com
Geophysics GPR International: www.geophysicsgpr.com
Georadis: www.georadis.com
Geoscience Australia: www.ga.gov.au
Geoserve Tomography: www.geoserve-kiel.de
Geosoft: www.geosoft.com
Geosphair Aviation: www.geosphair.com
Geotech: www.geotech.ca
Geotechnologies: www.geotechnologies-rus.com
Girdit: www.girdit.com
Gondwana: www.gondwana.co.mz
Horizon 2020 Project: https://ec.europa.eu/programmes/horizon2020/what-horizon-2020
IGME: www.igme.es
IGS: www.igsint.com
iMAR: www.imar-navigation.de
Instrumentation GDD Inc.: www.gddinstrumentation.com
Intergeo: www.intergeo.org
IRIS Instruments: www.iris-instruments.com
KTTM Geophysics: www.geofisicakttm.com
Lake Central Air Services: www.lakecentral.com
Lamontagne Geophysics: www.lamontagnegeophysics.com
Medusa Radiometrics: www.medusa-radiometrics.com
Micromine: www.micromine.com
Mira Geoscience: www.mirageoscience.com
MNDM (Ontario): www.mndm.gov.on.ca
Monex GeoScope: www.monexgeoscope.com.au
Mount Sopris Instruments: www.mountsopris.com
MPX Geophysics: www.mpxgeo.com
MTA: www.mta.gov.tr
NASA's Ice Bridge project: espo.nasa.gov/oib
Natural Resources Canada: www.nrcan.gc.ca
NDSWC: www.swc.nd.gov
NexGen Energy: www.nexgenenergy.ca
NF VSEGEI: www.nfvsegei.com
NRG: www.airbornegeophysics.com
NTGS: https://core.nt.gov.au/resources/nt-geological-survey
New-Sense: www.new-sense.com
Nuvia Dynamics: www.nuvia-dynamics.com
Ontash & Ermac: www.ontash.com
Paterson, Grant & Watson: www.pgw.ca
Petroseismic: www.petroseismicservices.com
Phoenix Geophysics: www.phoenix-geophysics.com
PicoEnvirotec: www.picoenvirotec.com
Precision GeoSurveys: www.precisiongeosurveys.com
Quantec Geoscience: www.quantecgeoscience.com
RMIT University: www.rmit.edu.au
RMS Instruments: www.rmsinst.com
Ronacher & McKenzie: www.rmgeoscience.com
Rutgers University: www.newark.rutgers.edu
Sander Geophysics: www.sgl.com
Scintrex: www.scintrexltd.com
Scott Hogg & Associates: www.shageophysics.com
Seequent: www.seequent.com
Sensors & Software: www.sensoft.ca
SISPROBE: www.sisprobe.com
SJ Geophysics: www.sjgeophysics.com
SkyTEM Surveys: www.skytem.com
Southern Geoscience Consultants: www.sgc.com.au
Spectrem Air: www.spectrem.co.za
Starfire Industries: www.starfireindustries.com
Supracon: www.supracon.com
Technoimaging: www.technoimaging.com
Tellus: www.tellus.ie
Tensor Research: www.tensor-research.com.au
Terraplus: www.terraplus.ca
Terraquest: www.terraquest.ca
Thomson Aviation: www.thomsonaviation.com.au
Triumph Instruments: www.itriumph.ca
Tundra Airborne Surveys: www.tundraair.com
University of British Columbia: www.ubc.ca
US Geological Survey: www.usgs.gov
VeriDaaS: www.veridaas.com
Vinci Construction: www.vinci-construction.com
Xcalibur: www.xagsa.com
Zonge International: www.zonge.com

ABBREVIATIONS & ACRONYMS

A	Ampere
ADC	Analog-to-Digital Converter
AEM	Airborne EM
AFMAG	AMT
AI	Artificial Intelligence
AMT	Audiofrequency MT
ARCN	Airborne Survey and Remote Sensing Center of Nuclear Industry
B	Magnetic Field
BGO	Bismuth Germanate
BH	BoreHole
BRGM	Bureau de Recherches Géologiques et Minières
CMIC	Canadian Mining Innovation Council
CSAMT	Controlled Source AMT
CSIC	Consejo Superior de Investigaciones Científicas
CSIRO	Commonwealth Scientific and Industrial Research Organization
CVR	Common Voltage Reference
DAS	Data Acquisition System
dB/dt	rate of change of B with time
DC	Direct Current
DEM	Digital Elevation Model
DNRME	Department of Natural Resources, Mines and Energy, Queensland Government
EM	Electromagnetic
ERT	Electrical Resistivity Tomography
FFT	Fast Fourier Transform
FOM	Figure of Merit
GIF	Geophysical Inversion Facility
GIS	Geographic Information System
Gondwana	Gondwana Exploration and Mining Consultants
GPS	Global Positioning System
Hz	Hertz = cycles per second
HZDR	Helmholtz-Zentrum Dresden-Rossendorf
IGME	Instituto Geológico y Minero de España
IGS	International Geoscience Services Ltd
IMU	Inertial Measurement Unit
IP	Induced Polarization
kHz	kiloHertz
kW	kiloWatt
LiDAR	Light Detection And Ranging
LP	Long Period
MAGTAP	Mining and Gas Technical Assistance Project
MEMS	Micro Electro Mechanical System
MeV	Million electron Volts
MHz	Mega Hertz
MT	MagnetoTelluric
MVP	Magnetovariational Profiling
NaI	Sodium Iodide
NASA	National Aeronautic and Space Administration
NIA	Dipole Moment of EM loop
nT	nano Tesla
NTGS	Northern Territory Geological Survey
OGP	Obvious Geological Potential
PADSEM	Projet d'Appui au Développement du Secteur Minier
PDA	Personal Data Assistant
PNG	Papua New Guinea
PROMINES	Projet d'Appui au Secteur Minier
pT	pico Tesla
QA	Quality Assurance
QC	Quality Control
R	Resistivity
RMS	Root Mean Square
ROV	Remotely operated Vehicle
SANRAL	South African National Roads Agency
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
UV	Ultra Violet
V	Volt
VLF	Very Low Frequency
W	Watt
Xcalibur	Xcalibur Airborne Geophysics

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Precision GeoSurveys
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SkyTEM Canada Inc.
Southern Geoscience
TechnoImaging
Tensor Research
Terraquest Ltd.
Zonge International

CANADIAN COMPANIES OFFERING AIRBORNE GEOPHYSICAL SURVEYS AS A CONTRACT SERVICE 2019

Compiled by P.G. Killeen, 9759 Hwy 509, Ompah, ON K0H 2J0 **(**27/May/2019**)**

COMPANY (President or Senior Officer)	ADDRESS OF MAIN OFFICE	TELEPHONE NO/FAX NO, E-MAIL/WEBSITE	TYPES OF SURVEY OFFERED*
CGG Canada Services (Davin Allen)	2505 Meadowvale Blvd. Mississauga ON L5N 5S2	Tel: 905-812-0212 Fax: 905-812-1504 davin.allen@cgg.com www.cgg.com/en/what-we-do/multiphysics	H: AM, TEM, CAM/TEM, CAM/AR, CAM/TEM/AR, AGG (HeliFALCON), CAM/AGG, FEM, CAM/FEM, CAM/FEM/AR, Gradient AM (MIDAS) FW: AM, CAM/TEM, CAM/TEM/AR, CAM/AR AGG (FALCON, FALCON PLUS, FULL SPECTRUM FALCON), AG, CAM/AGG, CAM/AG
DIAS Airborne (Jonathan Rudd)	Unit 2 Miller Avenue Saskatoon, SK, S7K 6N3	Tel: 416-795-1263 sales@diasgeo.com	H: AM (Full tensor magnetic gradiometer)
EON Geosciences Inc. (Khaled Moussaoui)	2021 Cote-de-Liesse St-Laurent QC H4N 2M5	Tel: 514-341-3366 Fax: 514-341-5366 info@eongeosciences.com www.eongeosciences.com	FW: AM, AG, CAM/AR, VLFEM Horizontal Gradiometer H: AM, AG, FEM, TEM, CAM/AR, VLFEM CAM/AEM/AR, CAM/AEM
Expert Geophysics Ltd. (Andrei Bagrianski)	19 Lionel Heights Cres., Toronto ON M3A 1L8	Tel: 647-402-8436 info@expertgeophysics.com www.expertgeophysics.com	Natural Field EM: MobileMT, CAM/AEM
Geodata Solutions Inc. (Mouhamed Moussaoui)	1054 des Pervenches Laval QC H7Y 2C7	Tel: 514-867-9990 Fax: 450-689-1013 mmoussaoui@geodatasolutions.ca www.geodatasolutions.ca	FW: AM, CAM/AR H: AM, CAM/AR
Geophysics GPR International Inc. (Claude Robillard)	2545 Delorimier Street, Suite 100 Longueuil QC J4K 3P7	Tel: 450-679-2400 Fax: 514-521-4128 Claude.Robillard@GeophysicsGPR.com www.GeophysicsGPR.com	H: AM, AR, Transverse, Longitudinal, Vertical Gradiometry VLFEM, Geophex FEM, GPRTEM

***NOTATION: AM - Aeromagnetic; CAM/AEM - Combined Aeromagnetic/Airborne EM; CAM/AR - Combined Aeromagnetic/Airborne Radiometric etc.; VLFEM - Very Low Frequency EM, AG - Airborne Gravity, AGG-Airborne Gravity Gradiometry, FEM - Frequency Domain EM, H-Helicopter, FW-Fixed Wing, TEM - Time Domain EM, UAV - Unpiloted Airborne Vehicle**

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Geosphair Aviation Inc. (Olivier Ayotte)	767 Mont-Royal East Montreal QC H2J 1W8	Tel: 514-585-4314 Fax: 514-527-6726 Olivier_Ayotte@yahoo.com www.Geosphair.com	FW: AM, CAM/AR,VLFEM
Geotech Ltd. (Ed Morrison)	245 Industrial Parkway N Aurora ON L4G 4C4	Tel: 905-841-5004 Fax: 905-841-0611 info@geotech.ca www.geotech.ca	H-TEM: VTEM, AeroTEM Natural Field EM (AFMAG): ZTEM, AirMt, H-FEM: Impulse, CAM/AEM, CAM/AEM/AG, CAM/AR FW: CAM/AG, CAM/AR, CAM/ZTEM/AG, ZTEM Transverse, Longitudinal and Tri-Axial Magnetic Gradiometer
GeoVision Geosciences Inc. (Richard Osmond)	23678 108th Loop, Maple Ridge, BC, V2W 1B2	Tel: 604-466-0425, Cell: 604-805-0314 rosmond@shaw.ca	H: CAM/VLFEM
MPX Geophysics Ltd. (Daniel McKinnon)	355 Harry Walker Parkway Newmarket ON L3Y 7B3	Tel: 905-947-1782 Info@ MPXGeo.com www.MPXGeo.com	FW: AM, CAM/AR, VLF-EM H: AM, CAM/AR,VLF-EM,AG FEM TEM
New-Sense Geophysics Ltd. (Glenn Slover)	195 Clayton Drive Unit 11 Markham ON L3R 7P3	Tel: 905-480-1107 Fax: 905-480-1207 info@new-sense.com www.new-sense.com	FW: Horizontal AM, CAM/AR, VLFEM H: CAM/AR, VLFEM
Novatem Inc. (Pascal Mouge)	1087, Chemin de la Montagne Mont-Saint-Hilaire QC J3G 4S6	Tel: 450-464-1655 Cell: 514-966-8000 Mouge@NOVATEM.com www.NOVATEM.com	H: COLIBRI AM, CAM/AEM, CAM/AR, CAM/AEM/AR; NOVATEM TEM & Resistivity FW: CAM/AR

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Precision GeoSurveys Inc. (Harmen Keyser)	Hanger 42, Langley Airport 31330 56th Ave. Langley BC V2Y 0E3	Tel: 604 484 9402 Fax: 604 669 5715 info@precisiongeosurveys.com www.precisiongeosurveys.com	H: AM, CAM/AEM, CAM/AR, UAV AM Biaxial & Tri-axial Gradiometer, TEM, FDEM FW: AM, CAM/AR, VLFEM
Prospectair Geosurveys Inc. (Alain Tremblay)	15 chemin de l'Étang Gatineau QC J9J 3S9	Tel: 819-661-2029 Fax: 866-605-3653 contact@prospectair.ca www.prospectair.ca	H-TEM: ProspecTEM H: AM, AR, CAM/TEM, CAM/AR, CAM/TEM/AR
Sander Geophysics Ltd. (Stephan Sander & Luise Sander)	260 Hunt Club Road Ottawa ON K1V 1C1	Tel: 613-521-9626 Fax: 613-521-0215 surveys@sgl.com www.sgl.com	FW: AM, AR, AG, FEM, VLFEM, CAM/AR, CAM/AG, CAM/AG/AR, CAM/FEM, CAM/AG/FEM, CAM/AR/FEM, CAM/AG/AR/FEM, CAM/AR/VLFEM Scanning LiDAR, Methane Sensing Transverse, Longitudinal, Vertical & Triaxial Gradiometer H: AM, AR, AG, VLFEM, CAM/AR, CAM/AG, CAM/VLFEM, Scanning LiDAR, Methane Sensing, Transverse & Vertical Gradiometer
Scott Hogg & Assoc. Ltd. (Scott Hogg)	85 Curlew Drive, #104 Toronto ON M3A 2P8	Tel: 416-444-8245 Fax: 416-444-4409 scott@shageophysics.com www.shageophysics.com	H: CAM-AR-VLFEM, Triaxial Magnetic Gradiometer
SkyTEM Canada Inc. (Bill Brown)	38 Union St East. Waterloo ON N2J 1B7	Tel: 519-502-1436 bb@skytem.com www.skytem.com	H: SkyTEM 101, 304, 508, AM, CAM/AR, CAM/AEM, Dual Moment TEM
Terraquest Ltd. (Howard A. Barrie)	301-2900 John Street Markham ON L3R 5G3	Tel: 905-477-2800 Fax: 905-477-2820 info@terraquest.ca www.terraquest.ca	FW: AM, Transverse, Longitudinal, Vertical Gradiometer/CAM/AR, VLFEM (Matrix), AG (CMG GT2A) H: AM, CAM/AR, VLFEM (Matrix), CAM/AEM-HyRez TEM

***NOTATION: AM - Aeromagnetic; CAM/AEM - Combined Aeromagnetic/Airborne EM; CAM/AR - Combined Aeromagnetic/Airborne Radiometric etc.; VLFEM - Very Low Frequency EM, AG - Airborne Gravity, AGG-Airborne Gravity Gradiometry, FEM - Frequency Domain EM, H-Helicopter, FW-Fixed Wing, TEM - Time Domain EM, UAV - Unpiloted Airborne Vehicle**

CANADIAN COMPANIES OFFERING AIRBORNE GEOPHYSICAL SURVEYS AS A CONTRACT SERVICE 2019
Compiled by P.G. Killeen, 9759 Hwy 509, Ompah, ON K0H 2J0 **(27 May 2019)**

COMPANY (President or Senior Officer)	ADDRESS OF MAIN OFFICE	TELEPHONE NO.,/FAX NO, E-MAIL/WEBSITE	TYPES OF SURVEY OFFERED*
Tundra Airborne Surveys Ltd. (John Charlton)	65 Dorchester Blvd. Unit 48, St Catharines ON L2M 7T7	Tel/Fax: 289-362-1609 Mobile: 416-432-9657 Info@ TundraAir.com www.TundraAir.com	FW: AM, CAM/AR/VLFEM, Transverse & Longitudinal Gradiometer

***NOTATION: AM - Aeromagnetic; CAM/AEM - Combined Aeromagnetic/Airborne EM; CAM/AR - Combined Aeromagnetic/Airborne Radiometric etc.; VLFEM - Very Low Frequency EM, AG - Airborne Gravity, AGG-Airborne Gravity Gradiometry, FEM - Frequency Domain EM, H-Helicopter, FW-Fixed Wing, TEM - Time Domain EM, UAV - Unpiloted Airborne Vehicle**

CAPABILITIES OF AIRBORNE GEOPHYSICAL SURVEY CONTRACTORS 2019
Compiled by P.G. Killeen, 9759 Hwy 509, Ompah, ON K0H 2J0 **(27 May/2019)**

COMPANY (Country) Telephone No. Web site	AIRCRAFT Fixed Wing = FW Helicopter = H Unpiloted Aerial Vehicle = UAV (Positioning)	AEROMAGNETIC T=Total Field, G=Gradient L, TT, V=Longitudinal, Transverse & Vertical	AIRBORNE ELECTROMAGNETIC (Time domain = TD) (Frequency domain = FD)	AIRBORNE RADIOMETRIC (R), GRAVITY (G) & GRAVITY GRADIENT (GG) Remote Sensing (RS)
Aerogeophysica Inc. (Russia) T: 7-495-641-1230 www.aerogeo.ru	Antonov-An-26,An-2 FW Ilyushin-Il14 Kamov-KA25,26 H (Ashtec GPS/Glonass)	Scintrex & Geometrics Cs Vapour (T, VG, LG)	6 Freq. Coax/coplanar FW AGP AEM H Towed Bird 4 Freq. Explorer HEM	Picodas PGAM 1000 R (50 l) Picodas/PEI GRS 410 (33.6 l) AGP G
Aerophysics (Mexico) T: 52-555-590-9928	Cessna 206, FW Piper PA-31 Navajo Leased H (PNAV-GPS + Video)	Cs Vapour Helimag PMAG 3000 (T)	Explorer HEM H Towed Bird 5 Freq. Coaxial/coplanar	Picodas PGAM 1000 R 256 chan (16 l or 33 l down, 4 l up)
Bell Geospace, Inc. (USA) T: 281-591-6900 www.bellgeo.com	Basler BT-67 FW Cessna 208B	Geometrics G822A Cs Vapour (T)	NA	Lockheed Martin FTG GG Full Tensor Gravity

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CGG Canada Services (Canada) T: 905-812-0212 www.cgg.com/en/what-we-do/multi-physics	Cessna 208B FW Basler BT 67 Chartered Helicopters H (DGPS, RT-DGPS, DVideo)	CGG DAS FW Scintrex & Geometrics Cs Vapour (T, LG, TTG, VG, Triaxial) (T, LG, TTG, VG, LTTVG H Triaxial)	TD; TEMPEST FW TD; HELITEM 30C H 3 axis (x-y-z), concentric, 5.3ms pulse width, 25/30 Hz, 560k NIA) HELITEM 35C 3 axis (x-y-z), concentric, 4-33 ms pulse width, ½ sine or square tx waveform; 7.5-30 Hz 600k-1.2M NIA) MULTIPULSE FD; RESOLVE (6 Freq. 400 Hz - 140,000 Hz, 1 coaxial & 5 coplanar coil sets) or RESOLVE (5 freq. 900 Hz – 56,000 Hz, 2 coaxial & 3 coplanar coil sets)	Exploranium GR 820 FW R RSI RS-500 (256/512 chan) Exploranium GR 820, H R RSI RS-500 (256/512 chan) FALCON, FALCON FW GG PLUS, FULL SPECTRUM FALCON CMG GT-1A, GT-2A FW G FALCON H GG
DIAS Airborne (Canada) T :416-795-1263 sales@diasgeo.com	Chartered helicopters H	T,G Full tensor	NA	NA
EDCON-PRJ Inc. (USA) T: 303-980-6556 www.edcon-prj.com	Dragon Fly Ultralight FW Leased H	Geometrics Cs Vapour (T)	NA	NA

CAPABILITIES OF AIRBORNE GEOPHYSICAL SURVEY CONTRACTORS 2019
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EON Geosciences Inc. **(Canada)** **T: 514-341-3366** **www.eongeosciences.com**	**Piper PA-31 Navajo; FW** **King Air A90** **Cessna 206** **Piper Cheyenne II** **Leased H** **(DGPS, RT-DGPS, Digital Video)**	**Scintrex & Geometrics** **Cs Vapour** **(T, TTG)**	**E-THEM TD H** **Hummingbird FD** **Herz Totem-2A VLFEM**	**RSI RSX-5 1024 chan R** **(32 l down, 8 l up)** **CMG GT-1A/GT-2A G**
Expert Geophysics Ltd. **(Canada)** **T: 647-402-8436** www.expertgeophysics.com	**Leased H**	**Geometrics Cs Vapour** **(T)**	**Natural Field EM: H** **MobileMT**	**NA**
Geo Data Solutions Inc. **(Canada)** **T: 514-867-9990** **www.geodatasolutions.ca**	**Piper PA-31 Navajo; FW** **ASTAR 350, Bell 206 H** **Robinson R44** **(RT-DGPS)**	**Geometrics & Scintrex** **Cs Vapour** **(T, TTG)**	**Totem-2A VLFEM**	**RSI RSX-5 R** **(16 l down, 4 l up)**
Geophysics GPR **International Inc.** **(Canada)** **T: 450-679-2400** **www.geophysicsgpr.com**	**Hughes 300 H** **R44** **Bell 206B/L** **ASTAR BA, B2, B3, Lama**	**Geometrics** **Cs Vapour** **(T, LG, TTG, VG)**	**GEOPHEX HEM H** **GEM-2A Towed Bird** **Multi Freq.** **Coaxial/Coplanar VLFEM** **GPRTEM**	**Pico Envirotec R** **(16 l)**
Geosphair Aviation Inc. **(Canada)** **T: 514-585-4314** **www.geosphair.com**	**Piper PA-31 Navaho x 1; FW** **Super-Cub x 1** **(DGPS, RT-DGPS, DVideo)**	**GEM System K Vapour** **(T,TTG,VG)**	**Totem-2A VLFEM**	**Medusa MS-4000 R**

CAPABILITIES OF AIRBORNE GEOPHYSICAL SURVEY CONTRACTORS 2019
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Geotech Ltd. (Canada) T: 905-841-5004 www.geotech.ca	Cessna 206 x 1 FW Cessna 208B x 4 PAC750-XL x 1 Koala AW119 x 2 H AS350-B3 x 13 (DGPS,GLONASS + DVideo)	Geometrics G823A Cs Vapour (T, LG, TTG) FW (T,LG, Triaxial) H	Geotech VTEM TD H (systems configured for shallow to deep penetration) AFMAG ZTEM FW/H AirMt AeroTEM TD H IMPULSE FD H	RSI RSX-5 1024 chan R (32 l down, 8 l up) CMG GT-2A G
GeoVision Geosciences Inc. (Canada) T: 604-466-0425	Leased H	GEM System GSMP-30A	VLFEM	NA
GyroLAG (South Africa & Botswana) T: NA www.gyrolag.com	Maule M5-235C X 1 FW Trojan (1) Sycamore (1), Geoduster (1)-gyrocopter Agnav Guia/Linav (2) Novatel-DGPS (3)	Fluxgate (T, Vectors, TTG)	'SP' experimental device	MS 4000 (4 l CsI) R TAGS-6 G NIR,VIS,TIR, LiDAR RS
MagSpec Airborne Surveys Pty Ltd (Australia) T: 61-8-6260-2041 www.magspec.com.au	Cessna 210 FW Cessna 206 PAC750XL Leased H (Novatel L1/L2 + GLONASS)	Geometrics G822A Cs Vapour (T, G, TTG)	N/A	RSI RS-500 R CMG GT-2A G

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Microsurvey Aerogeofísica e Consultoria Científica Ltda (Brazil) T: 55-21-2445-1773 www.microsurvey.net	Cessna 208B FW EMB 820C x 2 Piper PA-31 Navajo	Scintrex Cs Vapour (T, G)	Ms Relief VLFEM SP-4 MT with 3 Coils	Picodas/PEI GRS 410 R (33.6 l) RSI RS-500 256-512 chan (16 l down, 4 l up) Exploranium GR-820 256 chan (16 l, 32 l or 48 l) Lockheed Martin FTG GG Full Tensor Gravity
MPX Geophysics Ltd. (Canada) T: 905-947-1782 www.mpxgeo.com	Cessna 206 FW Piper PA-31 Navajo Piper Aztek Leased H (DGPS RT-DGPS, Video)	Scintrex & Geometrics Cs Vapour (T, G, TTG)	PTHEM TD MICROTEM TD	RSI RS-500 R 256-512-1024 chan (50.4 l down, 12.6 l up)
New Resolution Geophysics (South Africa) T: 27-21-789-0509 www.airbornegeophysics.com	Pilatus PC6 x 2 FW AS350 series x 8 H (DGPS)	Scintrex CS-3 (T,LG,TTG,VG)	Xcite TD H	RS-500 x 8 R CMG GT-2A x 2 G
New-Sense Geophysics (Canada) T: 905-480-1107 www.new-sense.com	Leased: Piper PA-31 Navajo FW Cessna 206 Leased Bell 206 (stinger) H ASTAR (stinger)	Scintrex CS-3 (T, LG)	NA	RSI RSX-5 x 7 R
Novatem Inc. (Canada) T: 450-464-1655 C: 514-966-8000 www.novatem.com	Cessna 208 Caravan FW Piper PA-31 Navajo x 4 Leased ASTAR series H	Geometrics Cs Vapour (T, LG, VG)	NOVATEM TD H	RSI RSX-5 x 7 R (16 l down, 4 l up)

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Precision GeoSurveys Inc. (Canada) T: 604-484-9402 www.precisiongeosurveys.com	Cessna 206 FW Piper PA-31 Navajo Bell 206, Airbus AS-350 H (GPS, DGPS) UAV	Scintrex & Geometrics Cs Vapour, & GEM K Vapour (T,G) (with attitude correction)	VLFEM FW "1TEM" TD H FDEM	Pico Envirotec R GRS-10 Spectrometer 256-512 chan Exploranium GR820
Prospectair Geosurveys Inc. (Canada) T: 819-661-2029 www.prospectair.ca	EC120B, R44 H (RT-DGPS)	Geometrics Cs Vapour (T,G)	ProspecTEM TD H	RSI RSX-500 R (16 l down, 4 l up)
Prospectors A. S. Ltda. (Brazil) T.: 55-21-2502-2526 www.prospectorsbr.com	Piper Chieftain x 2 FW Cessna 208B x 2 Leased H	Geometrics Cs Vapour (T, LG, TTG)	AeroTEM TD H	RSI RS-500 R 3 x (40 l down, 8 l up) CMG GT-2A G
Sander Geophysics Ltd. (Canada) T: 613-521-9626 www.sgl.com	Cessna 208B x 8 FW BN Islander x 2 DHC6 x 1 Airbus AS-350B3 x 2 H (DGPS, RT-DGPS + DVideo)	Geometrics Cs Vapour Sander SGMAG (T, LG, TTG, VG, Triaxial) FW (T,TTG, VG) H	SGFEM FD FW Herz Totem-2A VLFEM	Exploranium GR820 R (256 chan) (60 l) RSI RS-500 256-512 chan 50 l down, 8 l up Sander AIRGrav G
Scott Hogg & Assoc. Ltd. (Canada) T: 416-444-8245 www.shageophysics.com	Leased H (GPS)	Scintrex CS-3 Cs Vapour (T, LG, TTG, VG, Triaxial)	Totem 2A VLFEM	Pico Envirotec R 256 chan (32 l down, 4 l up)
SkyTEM Canada Inc. (Canada) T: 519-502-1436 www.skytem.com	Leased H (GPS)	Geometrics Cs Vapour sensors (T)	SkyTEM 101-7K NIA, 304-150K NIA, 508-500K NIA [dual moment available for 304 & 508]	Radiation Solutions R Medusa 256-512 chan; (16 l down, 4 l up)

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Spectrem Air (RSA) T: 27-11-659-1518 www.spectrem.co.za	Basler BT-67 FW (DGPS + DVideo)	Scintrex Cs Vapour (T)	Spectrem2000 TD FW	Exploranium GR820 R (32 l)
Terraquest (Canada) T: 905-477-2800 www.terraquest.ca	King Air C90 FW Cessna 206 Navajo 325 Leased H (DGPS + DVideo)	Scintrex & Geometrics Cs Vapour (T, LG, TTG, VG)	Matrix digital FW/H VLFEM HyRez TD H	RSI RSX-500 R Pico Envirotec (4 l down, 2 l up) CMG GT-2A G
Thomson Aviation (Australia) T: 61-2-6960-3800 C: 61-4-9999-1963 www.thomsonaviation.com.au	PAC 750XL x 2 FW Cessna 210 x 4 Cessna 208B Fletcher FU24 Piper PA-31 Navajo x 2 UAV FW/H; Leased H (NovAtel OEMV-1VBS)	Geometrics G822A & G823A Cs Vapour (T, G)	BIPTEM TD H	RSI RS-500 R (up to 67.2 l) CMG GT-2A G
Tundra Airborne Surveys (Canada) T: 289-362-1609 www.tundraair.com	Diamond DA-42 Twin Star FW Piper PA-31 Navajo x 2 Leased H (DGPS + RT-DGPS + DVideo)	Scintrex & Geometrics Cs Vapour Scin= (T, LG, TTG) Geo= (T,LG,TTG,VG,Triaxial)	Totem 2A VLFEM H	Pico Envirotec R 256 chan (32 l down, 4 l up)
UTS Geophysics (Australia) T: 61-8-9479-4232 www.uts.com.au	Same aircraft as Geotech Ltd. (DGPS,GLONASS + DVideo)	Geometrics G823A Cs Vapour (T, LG, TTG) FW (T,LG, Triaxial) H	Geotech VTEM TD H (systems configured for shallow to deep penetration) AFMAG ZTEM FD FW/H AirMt FD AeroTEM TD H IMPULSE FD H	RSI RS-500 R 1024 chan (32 l down, 4 l up) CMG GT-2A G

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Xcalibur Airborne Geophysics (PTY) Ltd. (RSA) T: 27-12-543-2540 www.xagsa.com	Turbo Islander x 3 FW Airtractor x 2	Geometrics Cs Vapour (T, LG, TTG)	NA	Exploranium GR-820 R RSI RS-5OO

COMMERCIALLY-AVAILABLE INDUCED POLARIZATION (IP) EQUIPMENT 2019
Compiled by P.G. Killeen, 9759 Hwy 509, Ompah, ON K0H 2J0 **(27/May/2019)**

Manufacturer (Country)	(TD=Time Domain FD=Freq. Domain ϕ =Phase S=Spectral)	Transmitter Model No.	Cycling Time or Frequency	Trans-mitted Power	Transmitter Power Source (MG=Motor Generator)	Trans-mitter Weight	Receiver Model No.	Sensitivity or Accuracy	Voltage Range	Microprocessor Controlled/Data Memory	Receiver Weight
Advanced Geophysical Operations and Services Inc. (Canada)	TD, FD, ϕ IP & SIP	AT-100	DC - 50kHz, 50% & 100% duty	100 W	12V battery	4 kg	GEPARD-4 (4ch) GEPARD-8 (8ch)	0.1μV / 1% typical	0.1μV to 10V	Intuitive GUI/SD Card up to 128Gb	7 kg with internal battery
	TD, FD, ϕ IP & SIP	KR-10	DC - 50kHz, 50% & 100% duty	500W	12V-60V battery	5 kg	GEPARD-4 (4ch) GEPARD-8 (8ch)	0.1μV / 1% typical	0.1μV to 10V	Intuitive GUI/SD Card up to 128Gb	7 kg with internal battery
	TD	AT-3000	DC-30Hz, 50% duty	3kW	12V-150V battery	12 kg	GEPARD-4 (4ch) GEPARD-8 (8ch)	0.1μV / 1% typical	0.1μV to 10V	Intuitive GUI/SD Card up to 128Gb	7 kg with internal battery
	TD, FD, ϕ IP & SIP	KR-30	DC - 50kHz, 50% & 100% duty	37kW	3-phase MG	35 kg	GEPARD-4 (4ch) GEPARD-8 (8ch)	0.1μV / 1% typical	0.1μV to 10V	Intuitive GUI/SD Card up to 128Gb	7 kg with internal battery
	TD, FD, ϕ IP & SIP	KR-75	DC - 50kHz, 50% & 100% duty	75kW	3-phase MG	55 kg	GEPARD-4 (4ch) GEPARD-8 (8ch)	0.1μV / 1% typical	0.1μV to 10V	Intuitive GUI/SD Card up to 128Gb	7 kg with internal battery
	TD, FD, ϕ IP & SIP	KR-175	DC - 50kHz, 50% & 100% duty	175kW	3-phase MG	205 kg	GEPARD-4 (4ch) GEPARD-8 (8ch)	0.1μV / 1% typical	0.1μV to 10V	Intuitive GUI/SD Card up to 128Gb	7 kg with internal battery
IRIS Instruments (France)	TD & FD	VIP 3000		3000 W	45 - 450 Hz 1 phase	16 kg					
	TD & FD	VIP 4000	0.0625 - 4 Hz	4000 W	45 - 450 Hz 1 phase	16 kg	ELREC 6	0.01 mV/V0.6% typ. accuracy	10μV to 10V	Yes/2500stations	8 kg
	TD & FD	VIP 5000		5000 W	45 - 800 Hz 1 or 3 phases	23 kg	ELREC 10	0.01 mV/V0.6% typ. accuracy	10μV to 15V	Yes/3200stations	9 kg
	TD & FD	VIP 10000		10000 W	45 - 800 Hz 1 or 3 phases	35 kg					
Instrumentation GDD Inc. (Canada)	TD	Tx III-4800V-10A	DC 1,2,4,8 and 16 seconds	1800 W	120 V, 50-60 Hz	27 kg	GRx2-2 channels	Voltage: Resolution 1 μV, Accuracy ≤ 0.15%	±10μV to ±15V for any channel	Archer 2 PDA-512Mb RAM Allegro 2 PDA-512Mb RAM	1.6 kg

Manufacturer (Country)	(TD=Time Domain FD=Freq. Domain ϕ =Phase S=Spectral)										
Instrumentation GDD Inc. (Canada) CONT.	TD	Tx II-4800V-15A	DC 1,2,4,8 and 16 seconds	3600 W	240 V, 50-60 Hz	32 kg	GRx8mini-4 or 8 channels		±10µV to ±15V for any channel	Archer 2 PDA-512Mb RAM Allegro 2 PDA-512Mb RAM	3.1 kg
	TD	Tx4-4800V-20A	DC 1,2,4,8 and 16 seconds	5000 W	240 V, 50-60 Hz	40 kg	GRx8-32-8,10,16,24 or 32 channels	Chargeability; 1 µV/V, Accuracy ≤ 0.4%	±10µV to ±15V for any channel	Archer 2 PDA-512Mb RAM Allegro 2 PDA-512Mb RAM	7.0 kg
	TD	Tx4-4800V-20A	DC 1,2,4,8 and 16 seconds	10000 W	240 V, 50-60 Hz	2 x 40 kg	Post-processing IP software				
	TD	Tx4-4800V-20A	DC 1,2,4,8 and 16 seconds	20000 W	240 V, 50-60 Hz	4 x 40 kg					
	TD	EM-IP Tx Controller	1 second on and above		2 X Li Ion batteries	4 kg					
	TD	TRM	Higher frequencies								
Phoenix Geophysics (Canada)	TD, FD, ϕ IP	T3	TD: 0.0625 Hz -30 Hz , FD: 0.125 Hz to 10 kHz TD: 50% FD: 100% duty cycle, external drive optional	3000 W	Battery or any single phase generator	12 kg, mounted on backpack					
	TD, FD, ϕ IP & SIP	TXU-30	TD: 128 s -30 Hz , FD: 256 s to 10 kHz TD: 50%, 33%, 25%, bi-polar, single pole FD: 100 %, 55.55%	20 Kw	Any 200-240 V commercially available 3 phase generator external drive optional	NA					
	TD, FD, ϕ IP & SIP	T4	TD: 0.0625 Hz -30 Hz , FD: 0.125 Hz to 10 kHz TD: 50% FD: 100% duty cycle, external drive optional	2.8 kW, max 130 V input, fast turn-off for EM operations	Low Voltage battery	9.0 kg , mounted on backpack					
Walcer Geophysics Ltd. (Canada)	TD & FD	IPT-1 & TX KW10	IPT-1: FD: "A" & "B" Models DC - 4 Hz TD: "A" Model- 2 sec. on / 2 sec. off "B" Model - Seconds on / off; in 1,2,4 & 8 seconds TX KW10: 1 sec., 2 sec., 4 sec., 8 sec.	IPT-1 75 - 1200V in 5 steps 3 mA - 10 Amps TX KW10 100 - 3200V in 10 steps 0.05 - 20 Amps Tested to 10.5 kVA	MG-1, MG-2, MG-6 and MG-12 Variable power 400 Hz/3 phase	IPT-1 18 Kg TX KW-10 44 kg					

COMMERCIALLY-AVAILABLE INDUCED POLARIZATION (IP) EQUIPMENT 2019
Compiled by P.G. Killeen, 9759 Hwy 509, Ompah, ON K0H 2J0

(27/May/2019)

Manufacturer (Country)	(TD=Time Domain FD=Freq. Domain ϕ =Phase S=Spectral)	Transmitter Model No.	Cycling Time or Frequency	Transmitted Power	Transmitter Power Source (MG=Motor Generator)	Transmitter Weight	Receiver Model No.	Sensitivity or Accuracy	Voltage Range	Microprocessor Controlled/Data Memory	Receiver Weight
Zonge (USA)	TD & FD ϕ IP & SIP	GGT-3	DC to 8 kHz	3 KVA	3 Kw MG 400 Hz	30 kg					
	TD & FD ϕ IP & SIP	GGT-10	DC to 8 kHz	10 KVA	5, 7.5 & 10 Kw MG 400 Hz	51 kg					
	TD & FD ϕ IP & SIP	GGT-30	DC to 8 kHz	30 KVA	32 KVA MG 400 Hz	93 kg	GDP-32$_{II}$ 6 channel	0.03 µV	0.1 µV to 32 V AGC	Yes/32 MB/RAM 4 GB/HD	13.2 kg incl. batt.
	TD & FD	NT-20	DC to 512 kHz	480 W	Batteries	5 kg	GDP-32$_{II}$ 16 channel	0.03 µV	0.1µ V to 32 V AGC	Yes/32 MB/RAM 4GB HD	19 kg incl. batt.
	TD & FD	ZT-30	DC to 512 Hz	3.6 Kw	Batteries	8 kg					

Manufacturers and Principal Distributors of Mining Geophysical Equipment & Software in Canada 2019;
Compiled by P.G. Killeen, 9759 Hwy 509, Ompah, ON K0H 2J0 (27/May/2019)

COMPANY	TELEPPHONE (FAX)	E-MAIL/WEBSITE	SENIOR OFFICER
Advanced Geophysical Operations and Services Inc. (AGCOS) 162 Oakdale Road, North York, ON M3N 2S5	416-747-8800 (416-747-5761)	info@agcos.ca www.agcos.ca	Igor Ingerov
CRONE GEOPHYSICS & EXPLORATION LTD 2135 Meadowpine Blvd. Mississauga ON L5N 6L5	905-814-0100 (905-814-8617)	info@cronegeophysics.com www.cronegeophysics.com	William (Bill) Ravenhurst
DUALEM INC. 540 Churchill Ave Milton ON L9T 3A2	905-876-0201 (905-876-2753)	inbox@dualem.com www.dualem.com	Rick Taylor
EXPLORANIUM 60 Queen St, Suite 1516 Ottawa ON K1P 5Y7	613-563-7242 (613-563-3399)	bryan.d.rockwood@saic.com www.saic.com/products/security	Bryan Rockwood
GEM SYSTEMS INC. 135 Spy Court Markham ON L3R 5H6	905-752-2202 (905-752-2205)	info@gemsys.ca www.gemsys.ca	I. Hrvoic
GEONICS Limited Unit 8, 1745 Meyerside Dr Mississauga ON L5T 1C6	905-670-9580 (905-670-9204)	geonics@geonics.com www.geonics.com	Miro Bosnar
GEOSENSORS INC. 66 Mann Ave Toronto ON M4S 2Y3	416-483-4691 (416-483-9909)	scott.holladay@geosensors.com	Scott Holladay
GEOSOFT-SEEQUENT INC. 207 Queens Quay West-Suite 810 Toronto ON M5J 1A7	416-369-0111 (416-369-9599) 1-800-363-6277	info@geosoft.com www.geosoft.com	
GEOTECH LTD. 245 Industrial Parkway North Aurora ON L4G 4C4	905-841-5004 (905-841-0611)	info@geotech.ca www.geotech.ca	Ed Morrison
ICEFIELD TOOLS CORP. P.O. Box 30085 Whitehorse YK Y1A 5M2	867-633-4264 (867-633-4217) 1-877-423-3435	info@icefieldtools.com www.icefieldtools.com	Erik Blake
IFG CORPORATION 26 Bramsteele Rd, Unit 2 Brampton ON L6W 1B3	905-451-5228 (905-451-2877)	info@ifgcorp.com www.ifgcorp.com	Detlef Blohm
INSTRUMENTATION GDD INC. 860 Boulevard de la Chaudière, St. 200 Québec QC G1X 4B7	418-877-4249 (418-877-4054)	gdd@gdd.ca www.gdd.ca	Pierre Gaucher
KROUM VS INSTRUMENTS LTD. 2206-701 Don Mills R Toronto ON M3C 1R9	416-421-6313	kroum@kroumvs.com www.kroumvs.com	Kroum Stamenkov
LAMONTAGNE GEOPHYSICS LTD. 115 Grant Timmins Dr Kingston ON K7L 4V4	613-531-9950 (613-531-8987)	lamont@kos.net www.lamontagnegeophysics.com	Yves Lamontagne
MARINE MAGNETICS 135 Spy Court Markham ON L3R 5H6	905-709-3135 (905-479-9484)	info@marinemagnetics.com www.marinemagnetics.com	Melissa Marlowe
MIRA GEOSCIENCE LTD #309 – 310 Victoria Avenue Westmount, Quebec, H3Z 2M9	514-489-1890 (514 489-5536)	info@mirageoscience.com www.mirageoscience.com	John McGaughey
NUVIA DYNAMICS INC. 222 Snidercroft Rd Concord ON L4K 2K1	905-760-9512 (905-760-9513)	info@nuvia-dynamics.com www.nuvia-dynamics.com	Sandip Goswami
PATERSON, GRANT & WATSON LTD. 155 University Ave, St. 1710 Toronto ON M5H 3B7	416-368-2888 (416-368-2887)	pgw@pgw.ca www.pgw.ca	Stephen Reford
PHOENIX GEOPHYSICS LTD. Unit 3, 3781 Victoria Park Ave Scarborough ON M1W 3K5	416-491-7340 (416-491-7378)	yavram@phoenix-geophysics.com www.phoenix-geophysics.com	Yann Avram

Manufacturers and Principal Distributors of Mining Geophysical Equipment & Software in Canada 2019;
Compiled by P.G. Killeen, 9759 Hwy 509, Ompah, ON K0H 2J0 (27/May/2019)

COMPANY	TELEPHONE (FAX)	E-MAIL/WEBSITE	SENIOR OFFICER
RADIATION SOLUTIONS INC. 5875 Whittle Road Mississauga ON L4Z 2H4	905-890-1111 (905-890-1964)	sales@radiationsolutions.ca www.radiationsolutions.ca	Jens Hovgaard
RMS INSTRUMENTS LTD. 6877-1 Goreway Dr Mississauga ON L4V 1L9	905-677-5533 (905-677-5030)	rms@rmsinst.com www.rmsinst.com	Onorio Rocca
SCINTREX LTD. 222 Snidercroft Rd Concord ON L4K 2K1	905-669-2280 (905-669-6403)	Scintrex@scintrexltd.com www.scintrexltd.com	Timothy Niebauer
SCOTT HOGG & ASSOC. 85 Curlew Drive, #104 Toronto ON M3A 2P8	416-444-8245 (416-444-4409)	scott@shageophysics.com www.shageophysics.com	Scott Hogg
SENSORS & SOFTWARE INC. 1040 Stacey Court Mississauga ON L4W 2X8	905-624-8909 (905-624-9365) (1-800-267-6013)	sales@sensoft.ca www.sensoft.ca	Peter Annan
W. SODIN (GRAVITY) LTD. Unit 18, 95 West Beaver Creek Rd Richmond Hill ON L4B 1H2	905-886-8632 (905-886-4477)		Wolf Sodin
SOUTHERN GEOSCIENCE CONSULTANTS (SGC) 15 Toronto Street-Suite 401 Toronto ON M5C 2E3	416-407-6355	Robert.Hearst@SGC.com.au www.sgc.com.au	Robert Hearst
TERRAPLUS INC. Unit 12, 52 West Beaver Creek Rd Richmond Hill ON L4B 1L9	905-764-5505 (905-764-8093)	sales@terraplus.ca www.terraplus.ca	Claude B. Meunier
WALCER GEOPHYSICS LTD. 2106 Regional Rd 3 Enniskillen ON L0B 1J0	905-263-8767 (905-263-8766)	awalcer@rogers.com www.walcergeophysics.com	Alex Walcer

MINING GEOPHYSICAL EQUIPMENT AND SOFTWARE COMMERCIALLY AVAILABLE IN CANADA 2019

Compiled by P.G. Killeen, 9759 Hwy 509, Ompah, ON K0H 2J0 (27/May/2019)

AIRBORNE EQUIPMENT					ELECTROMAGNETIC			GROUND EQUIPMENT Sus=susceptibility/G Meter=Gravity Meter						
COMPANY	Data Acquisition	Magnetometers	EM	Scint. Spectro-meters	Drill hole	VLFEM	EM	Scint. Spectro-meters	IP	Magnetometers	Resistivity	G Meter	Suscept Meters	Other & Software
ADVANCED GEOPHYSICAL OPERATIONS AND SERVICES INC. (AGCOS)						GEPARD-4 & 8	Receivers: GEPARD-4 & 8 Transmitters: AT-100, AT-3000, KR-10, KR-30, KR-75 and KR-175 Electrical Sensors ACE-84, ALCE-84A, ASCE-84AG. Induction Coils: AMS-15, AMS-27 AMS-37 & AMS-47 TDEM Loops: MTEM-200, FTEM-100 & LTEM-25 Precision Tripods: TRI-3/30, -3/50, -1/30, -1/50, -1/30/1, -1/50/1		GEPARD-4 & 8 AT-100, AT-3000, KR-10, KR-30, KR-75, KR-175	AMS-15, AMS-27, AMS-37, AMS-47	GEPARD-4 & 8 AT-100, KR-10, KR-30, KR-75, KR-175			1. EM and Seismic software for modeling, data processing, editing, visualization and interpretation 2. Shallow Marine EM Receivers 2AUSS-07A (2Ch) and 5AUSS-07A (5ch) and, SMMT (2ch) 3. Precision Field Tripods for induction mag sensors
DUALEM							DUALEM-1, 2, 21, 4, 42, 421 and 642							

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COMPANY	Data Acquisition	Magnetometers	EM	Scint. Spectro-meters	Drill hole	VLFEM	EM	Scint. Spectro-meters	IP	Magnetometers	Resistivity	G Meter	Suscept Meters	Other & Software
EXPLORANIUM				GR-660 GR-820				GR-135						
GEM	GEM-DAS (Real time data display & Acquisition Software Compensation (post-processing or real-time)	Manned aircraft: GSMP-35A Complete Towed Birds: GSMP-35A(B) (MagBIRD) GSMP-35GA(B) (GradBIRD) GSMP-35GA3(B) (Tri-AxialBIRD) UAV: GFMP-35U (DRONEMag) GFMP-35U(B) (AirBIRD) GFMP-35UG(B) (AirGRAD)	Manned aircraft: GSM-90AV			GSMV-series: (VLF only) 19, 19W GSM-P series: (VLF attachment) 35V, 35GV (GSMP=potassium) GSM-series: (VLF attachment) 19V, 19WV, 19GV, 19GWV (19= Overhauser) 19TV, 19TWV,19TVG,19TGWV (19T=proton) (G=gradiometer; W=walking mode)								

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COMPANY	Data Acquisition	Magnetometers	EM	Scint. Spectro-meters	Drill hole	VLFEM	EM	Scint. Spectro-meters	IP	Magnetometers	Resistivity	G Meter	Suscept Meters	Other & Software
GEONICS					BH 43 BH 43-3D EM 39 EM 39S MAG 43-3D	EM-16 Tx27	PROTEM 67,47,57-MK2, CM, 67-Plus CMX EM42 EM61-MK2 EM61-MK2-HP EM61-HH-MK2 EM61-MK2A EM61-LX2 EM61 BLU26 ARRAY EM63-3DMK2 EM63 Flex Array GTEM				EM16R EM31- MK-2 EM34-3 EM31-S EM38DD EM38B EM38-MK2			DAT(31,34,39 ,38Mk2,61Mk 2) DAS 70-AR2 Logger EM61LX2
GEOSENSORS	Custom	Multi-channel High Rate Processors	Custom FDEM, TEM Helicopter Towed Bird & Fixed Mount				EM Sensors							
GEOSOFT- SEEQUENT														S
ICEFIELD					MI-03, MI-03N Borehole Surveying & Magnetics									

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IFG					Resistivity Conductivity IP Magnetic Temperature Gamma Density Caliper Tilt Orientation Systems									
INSTRUMENTATION GDD INC.					Resistivity Conductivity IP Magnetic Temperature Gamma Density Caliper Tilt Orientation Systems SSW System: Probes 25 mm+ EM Conductivity		TDEM Rx 3 or 8 channels EM-IP Tx controller TRM+Tx4 5Kw 2400V-20A Beep Mat		Tx: Tx III 1.8Kw Tx II 3.6Kw Tx 4 5,10,20 Kw EM-IP Tx controller TRM (higher frequencies) Rx: GRX 2-32 channels SCIP Tester: Resistivity and chargeability				MPP-Probe: Mag suscept. and EM conduct	IP and EM post processing software

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COMPANY	Data Acquisition	Magnetometers	EM	Scint. Spectro-meters	Drill hole	VLFEM	EM	Scint. Spectro-meters	IP	Magnetometers	Resistivity	G Meter	Suscept Meters	Other & Software
INSTRUMENTATION GDD INC. CONT.					Mag Suscept For Ni, Fe, etc.				Borehole option					
KROUM VS INSTRUMENTS	KANA8 SDAS1-PPC	KMAG4												
LAMONTAGNE GEOPHYSICS														S
MARINE MAGNETICS					Magnum Magnetometer					Sentinel Base Stn. Mag.				
MIRA GEOSCIENCE LTD.														GOCAD Mining Suite Geoscience ANALYST Geoscience INTEGRATOR VP suite inversion codes UBC-GIF inversion codes Training
NUVIA DYNAMICS INC	IMPAC	IMPAC-M (integrated) PEICOMP-magnetic compensation	P-THEM	AGRS				PGIS-2 PGIS-2-1 PGIS-2-2 RADScout(drone		PBM (diurnal variation station)				Praga4 (Spectrometer Processing) EMDataView MAPConvertD

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COMPANY	Data Acquisition	Magnetometers	EM	Scint. Spectro-meters	Drill hole	VLFEM	EM	Scint. Spectro-meters	IP	Magnetometers	Resistivity	G Meter	Suscept Meters	Other & Software
NUVIA DYNAMICS INC.. CONT.								installation)						ATAView
PATERSON, GRANT & WATSON LTD.														S
PHOENIX GEOPHYSICS LTD.							MTU-8A (AMT-MT) V8 (TDEM/FDEM /CSAMT/IP) T3 (IP/FDEM TX) T4 (TDEM TX) TXU-30		V8 T3 TX TXU-30 TX (high powered)					EM power S
RADIATION SOLUTIONS INC. (RSI)				RS-500 series RSX-4 (16L) RSX-5 (16L + 4L) RS-501 I/F Console RS-700 series RSX-1 (4L) RSX-3 (6L) RS-701 I/F				Handheld: NaI: RS-111, RS-111T RS-120, RS-120T, RS-121, RS-121T, RS-125, RS-125T, RS-230BGO Portable:						

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COMPANY	Data Acquisition	Magnetometers	EM	Scint. Spectro-meters	Drill hole	VLFEM	EM	Scint. Spectro-meters	IP	Magnetometers	Resistivity	G Meter	Suscept Meters	Other & Software
RADIATION SOLUTIONS INC. (RSI) CONT.				Console RS-705 I/F Console RS-607				RS-330NaI RS-332BGO RS-350NaI Vehicle Mount: RS-700 Series RSX-1 (4L) RS-701 I/F Console RS-705 I/F Console						
RMS INSTRUMENTS	DAARC 500 DAS 500 PDU 500 GP 300	DAARC 500 AARC 500 AARC 510, AARC 51/52(UAV) Compensator Geometrics-Cs mags	Herz Totem-2A (VLFEM)			Herz Totem-2A (VLFEM)				Geometrics Cs & Proton Mags				S ExportDARRC Support GP 300 Graphic Printer & Chart Recorder GP300 Support software
SCINTREX		CS-3 CS-VL								ENVI-CS		CG-6 RG-1 Gravilog		Training Custom/Design-Consulting S

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COMPANY	Data Acquisition	Magnetometers	EM	Scint. Spectro-meters	Drill hole	VLFEM	EM	Scint. Spectro-meters	IP	Magnetometers	Resistivity	G Meter	Suscept Meters	Other & Software
SCINTREX CONT.												A10 FGL FG-5X gPhone-X		
SCOTT HOGG & ASSOC.	DAQNAV acquisition & navigation													S magnetic comp; AGG mag modeling
SENSORS & SOFTWARE							GPR: PulseEKKO/ PulseEKKO-Borehole NOGGIN BackTrak IceMap							S
SODIN												100 100T 200 200T		
SOUTHERN GEOSCIENCE CONSULTANTS														ImageRobot S
TERRAPLUS		Gradient mag UAV/Drone	GSM-90 AV VLF	RS-500	QL40 Series ABI-2G, OBI-2G	GSMV-19 GSM	ProEx-GPR GroundExplorer-	RS-111 RS-120	Elrec Pro Elrec 6	GSM-19 GSM-19W	Syscal Kid Syscal Junior		KT-10 v2 KT-10	Geode ES-3000

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TERRAPLUS CONT.		System			FWS, GR, SGR ELOG, IP, DLL3, CAL, DEV, OCEAN, FTC, IND, MGS, SFM Heat Pulse Flow Meter, GyroShot MI5 RCAM-1000	Series 19V, 19WV, 19GV, 19GWV, 19TV, 19TWV, 19TGV 19TWGV	GPR GDP-3224 GGT-3, -10, -30 XMT-32 AMT/6 TEM/3 Stratagem Numis Lite, -Poly GEM-2 Promis	RS-121 RS-125 RS-230 RS-330 RS-700 RT-50 oreXpress PSR+	Distributed IP System Tipix VIP-3000 VIP-4000 VIP-5000 VIP-10000 IP/L QL-ELOGIP KT-20 IP	GSM-19G GSM-19GW GSM-19T GSM-19TW GSM-19TG GSM-19TGW GSMP-35 GSMP-35G	Syscal R1 Syscal Pro Ohm-Mapper		Plus v2 KT-10R v2 KT-10R Plus v2 KT-10S/C KT-10 Plus S/C KT-10R Plus S/C KT-10R S/C KT-20 KT-20 Plus KT-20 S/C KT-20 Plus S/C	StrataVisor SeisImager WellCAD Reflex Res2DINV Res3DINV Full Wave Designer Full Wave Viewer RadExplorer Object Mapper IX1D Surfer