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ETD

EXPLORATION **TRENDS** & DEVELOPMENTS

March 2021

A geophysicist wearing a yellow hard hat, safety glasses, a green jacket, and a red safety vest is standing on a rocky mountain slope. The person is holding a yellow geophysical instrument. In the background, there are snow-capped mountains under a clear blue sky.

Advances in **GEOPHYSICAL TECHNOLOGY**

THE NORTHERN MINER

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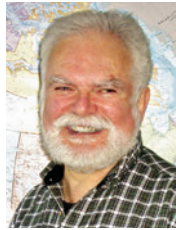
**Cover photo:**

Auston Castle, a geophysicist with Dias Geophysical, conducting a DIAS32 3D IP survey in B.C.'s Golden Triangle.

Credit: Dias Geophysical

MINERAL EXPLORATION TRENDS AND DEVELOPMENTS IN 2020

By Patrick G. Killeen Ph.D., Geophysical Consultant and retired Research Scientist, Geological Survey of Canada, Ottawa 2020



This is the fifth 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.

On a sad note, Peter J. Hood, a Geological Survey of Canada (GSC) scientist and the originator of the ETD Review, passed away in October 2020. He wrote this unbiased annual publication on trends and new developments in geophysical exploration for minerals from 1965 until 1992 (28 years) when he retired, and I began writing it (29 years). Hood led the GSC's National Aeromagnetic Program, producing the first Aeromagnetic Map of Canada, a success soon replicated by similar programs in Australia and the United States.

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; 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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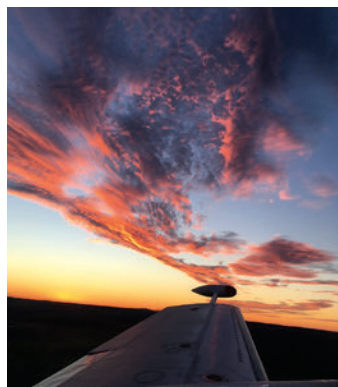
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■ Terraquest on a magnetic gradiometer survey in Missouri. Credit: Terraquest



EXPLORATION TECHNOLOGY IN 2020: COVID CLOUD'S SILVER LINING

The coronavirus pandemic negatively affected nearly all activity in 2020 except for the diversion of resources to work on R&D. On a positive note, at least two survey contractors added an aircraft to their fleet despite decreased mineral exploration activity. Many companies used this 'downtime' to conduct R&D, improve, upgrade or enhance existing technology and develop new hardware, software and methodology for airborne, ground and borehole surveys. Uniquely, one company reduced the COVID-19 effect by utilizing previously trained foreign crews to operate survey equipment, remotely manage QA/QC and minimize international travel. Another used wireless communication to operate multiple instruments (e.g. IP receivers) remotely from a single location, eliminating multiple field operators. With the internet, data acquisition could be observed and monitored for QA/QC from anywhere in the world. Use of AI and machine learning for mineral targeting increased in 2020, as did smartphone apps for control and transfer of data from geophysical instruments.

In spite of the pandemic, airborne geophysical surveys around the world resumed, cautiously and safely in the second half of 2020. Airborne geophysical survey technology saw the first commercial survey with a new SQUID-based helicopter-borne full tensor magnetic gradiometer system and development of a similar, SQUID-based system measuring both vertical and horizontal gradient; a new UAV-borne magnetic survey service; and in one case, a laser scanner mapping capability added to complement traditional airborne geophysical surveys. There is new R&D to simultaneously extract natural field EM data from TDEM data, thereby recording both NFEM and TDEM data in one survey.

Other new developments include; use of a telemetry relay network for UAV-mounted geophysical systems to conduct flights without line of sight; a UAV airborne fluxgate magnetometer platform; a helicopter-borne AFMAG and horizontal magnetic gradiometer in a towed bird; several upgrades to airborne EM systems, including: new, high speed DAS, new TDEM Tx and new Rx design for reduced noise and increased dipole moment; a UAV towed-bird VLF-EM system that records three VLF stations simultaneously; a fixed-wing VLF-EM system in development that records four VLF stations simultaneously and multiple new data parameters; a hybrid air-to-ground EM system now offered for commercial surveys; a lightweight UXO detector

for drone applications; a UAV gamma-ray spectrometer system improved with innovations including a smartphone app to view system status and data and a new generation 1024-channel airborne gamma-ray spectrometer developed by a survey contractor.

Developments in ground geophysical surveying include; portable rock property instruments using free Android apps; improved processing and imaging of EM data for real-time guidance of field crews; new transmitters with increased number of parameters recorded in AMT and MT data; and a consortium research project investigating the predictive power of machine learning algorithms in geological mapping and prospectivity analysis. In drillhole methods, gravity data from multiple boreholes and surface surveys are being inverted to estimate tonnage and reduce drilling; a new borehole gamma-ray spectrometer probe has a choice of detectors, and new revisions of borehole data processing software, including for sonic probes. A new 32-mm version of a probe has an upgraded IMU, Li-ion battery and reduced noise, to acquire magnetic or IP data.

Ground EM developments saw new EM and IP transmitters and upgraded EM receivers; an improved MMR system for borehole and surface surveys; two new versions of EM instruments for shallow depth applications; an upgraded EM system with extended ISR measurements for arid and frozen environments; several upgraded transmitters for EM with improved calibration procedures and software and two new transmitters for use with broadband EM receivers in natural and CSEM data acquisition. In gravity surveying, one company has replaced the detachable control unit for its gravity meter with enhanced software and a smartphone app.

IP developments include: new configurations for increased depth of investigation and resolution; improved daily fault diagnosis and auto-correction of in-field setup errors; new lightweight transmitters with increased power and signal-to-noise; a new Resistivity and IP receiver with 20 simultaneous channels, full wave recording and advanced signal processing; and finally, a new IP survey methodology for 3D information and improved mapping. For magnetotellurics, one company has introduced a new wideband MT system with full processing and QC software; while another has released a new generation of array-based AMT/MT survey equipment that is set up during the day with recording at night. **END**

■ CGG Multi-Physics' Tempest airborne EM system with Rx bird docked. Credit: CGG Multi-Physics



Corporate Highlights

Abitibi Geophysics of Val d'Or, Que., which offers a full range of ground and borehole geophysical services, reported increasing activity in eastern Canada during the second half of 2020. International partners, using Abitibi-trained local crews, successfully conducted surveys and minimized the need for international travel. Technologies in demand are ARMIT TDEM B-field and dB/dt with deep exploration loop configurations; 2D and 3D IP using the popular OreVision arrays, DasVision (distributed array) and borehole IP; and the company's proprietary borehole gravity with GeoTk 3D gravity inversions.

Advanced Geophysical Operations and Services (AGCOS) of Toronto continued development of EM technologies, as well as upgrades to EM receivers GEPARD-4 and GEPARD-8, sensors, EM and IP transmitters and software. The company offers sensitive integrated natural and controlled-source EM (NCSEM) surveys with multiple geophysical techniques for contract surveys to identify mineralization in challenging geology.

CGG Multi-Physics headquartered in Paris, with offices in Toronto and globally, acquires, processes, and interprets airborne and marine geophysical data for resource exploration and geological mapping. During 2020, the Helitem2 and Tempest AEM technologies and the HeliFalcon and Falcon AGG systems were deployed on resource exploration, geothermal, water, and government mapping projects. In Australia, post COVID-19 hiatus demand for airborne geophysical surveys increased primarily for gold.

ClearView Geophysics of Brampton, Ont., has focused on acquiring 'soundings' data directly below the sensor or array. GPR (ground penetrating radar), EM31, IMAGEM and CSAMT are used for geotechnical applications and mineral exploration, where both near-surface and deep penetration with high resolution are required. Utilization of GPS-synchronized multiple receivers reduces acquisition time. 1D inversion of IMAGEM and CSAMT are modelled to give better operator control and can be combined with near-surface GPR and EM31 to produce high-resolution 2D and 3D models of the subsurface.

In 2020, **Crone Geophysics & Exploration** of Mississauga, Ont., reported that while global demand dropped off due to the COVID-19 pandemic, attention was diverted to supplying Canada-wide projects with its Pulse EM system and significant resources were diverted to R&D, resulting in advances in its E-SCAN DCIP / R system, (Mark 7) which will be fully operational in 2021. Advances in software, power transmission, automation and QA/QC controls are expected to result in increased production, better discretization of targets at depth and improved confidence in data quality and interpretation. Manufacturing increased in 2020 and now Crone is well equipped to perform more surveys and to supply equipment and spares for all projects.

Saskatoon, Sask.-based **Dias Geophysical** reported additions of a new, high-power transmitter, new AMT and MT survey services, and a new cloud service for 3D inversion using the SimPEG codes. DIAS32 is a multi-parameter, distributed array

technology which has carried out over 50 3D surveys worldwide. The DIAS32 CVR technology has confirmed, on several surveys, an exploration depth of over 1 km.

Dias Airborne, also headquartered in Saskatoon, is a partnership between **Dias Geophysical** and **Supracon AG** of Germany. The company carries out and processes helicopter-borne magnetic and passive EM surveys. Both technologies employ low-temperature SQUID sensors, which provide highly sensitive measurements. The QMAGT system is a helicopter-borne full-tensor magnetic gradiometer system resulting from over 22 years of collaboration between Supracon and Anglo American. The QMAGT system delivers the six independent tensors of the magnetic field. The QAMT system measures the three components of the magnetic field with a high degree of accuracy, so the dataset can be processed to deliver three-component magnetic field data, and passive EM (AFMAG) responses. Dias Airborne completed its first QMAGT commercial survey in 2020.

Selkirk, Man.-based **EarthEx Geophysical Solutions** has been providing geophysical consulting and physical rock properties laboratory services since 2014. In 2020, the company introduced low-flying UAV magnetic surveys. The system employs a hexacopter drone with a towed-bird cesium vapour magnetometer. Its unique active collision-avoidance system from **Devbriio Geophysics** can fly with the sensor at 5 metres above ground level and easily avoid obstacles. This produces higher resolution datasets with lower terrain clearance and tighter line-spacing without oversampling. The pandemic caused a boost in desktop consulting services to review historical geophysical data. EarthEx defined new base metals targets by reviewing airborne EM data (VTEM) and precious metals targets from a compilation of detailed magnetic and IP-Resistivity data. 2020 saw increased demand for physical rock properties complementing development of robust geophysical prospecting strategies.

EON Geosciences of Montreal provides airborne high-resolution magnetic, gamma-ray spectrometric, gravity, and EM surveys using fixed-wing aircraft and helicopters. In 2020, EON added another Piper Navajo aircraft to its fleet of seven fixed-wing aircraft. EON's aviation company (**EON Airborne**) now offers commercial aircraft operation services for all survey industries (geophysics, LiDAR, aerial photography, etc.).

Richmond, B.C.-based **Ideon Technologies** (formerly CRM Geotomography Technologies) is a spin-off from TRIUMF (Canada's national particle accelerator laboratory). It has developed a cosmic-ray muon tomography solution for subsurface exploration. Muon radiography is a means of inferring density by



■ Spectrem Air's TDEM system seen from below with bird deployed.
Credit: Spectrem Air

measuring the attenuation of muon (a type of elementary particle) flux through matter. Muon tomography uses tomographic methods to derive 3D density maps from multiple muon flux measurements. The company's discovery platform consists of proprietary muon detectors, inversion technologies, and AI to provide X-ray-like visibility up to 1 km beneath the Earth's surface, identifying and imaging mineral deposits, air voids, caves, and structures with density contrasts in the subsurface. Multiple successful field trials of the technology have already been conducted. In 2021, field trials will begin and followed by commercial release of a muon detector suitable for deployment in HQ boreholes.

In 2020, Quebec City-based **Instrumentation GDD (GDD)** introduced unique IP technology add-ons to significantly decrease cost of IP surveys by optimizing

usage of the equipment, reducing field personnel and increasing productivity. New advances include real-time feedback, remote survey control and monitoring, the possibility to enhance investigation depth and data quality and avoid telluric noise, and the ability to merge multiple receiver data into one single file to ease processing and 3D inversion.

Headquartered in Montreal, and with offices in Australia, **Mira Geoscience** expanded its integrated interpretation software and consulting services for mineral exploration. The company's industry-led Geophysical Research Consortium continued making the best geophysical codes useful, practical, and effective through Geoscience ANALYST Pro Geophysics. Founding members Anglo American, Barrick Gold, Glencore, Rio Tinto, Teck and Vale were joined in 2020 by Cameco and BHP. The consortium focuses on interoperability with other geological, geophysical, and geochemical interpretation software.

Toronto-based consulting firm **Paterson, Grant & Watson Limited (PGW)** completed the interpretation of a 546,000 line-km magnetic/radiometric survey of Sierra Leone in partnership with **Xcalibur Airborne Geophysics**, for the **Ministry of Mines and Mineral Resources'** EITAP World Bank project. The nationwide survey incorporated separate 1:250,000 scale interpretations of basement lithology and structure, and of surface geology and regolith. Nationwide prospectivity maps for gold, bauxite, rutile and nickel were prepared with machine learning, in addition to target maps for kimberlite pipes and dykes, and iron ore. In 2020, PGW commenced a geophysical compilation and interpretation for the northern half of Botswana. It will characterize mineral prospectivity and hydrogeology resulting in a new edition of the national geology map and bulletin. The project is managed by

the **Botswana Geoscience Institute** and PGW is partnered with **Water Resources Consultants** of Gaborone. PGW was awarded a three-year contract from the **Ministry of Energy and Mineral Development** to supervise a 293,000 line-km magnetic/radiometric survey of the Karamoja region in northeast Uganda, followed by large airborne gravity and EM surveys.

Toronto-based **Quantec Geoscience** provides deep subsurface information in a safe manner. In 2020, due to the pandemic, the company added safety protocols and measures respecting local jurisdictions to assure its employees working in the field are safe. Quantec made several improvements to equipment and processes, including development of **QUICKLAY** automatic data processing and creation of a database of forward model studies. **TITAN 160**, a new generation of MT, was developed as well as ancillary equipment for **SPARTAN MT** surveys. Also in response to Covid-19 lockdowns, a new educational webinar series was developed to provide the following overviews for Geoscientists: Geophysics for Geologists, MT 101, DCIP 101, and DCIP 110 – Real 3D acquisition.

With headquarters in Sudbury, Ont., offices in Toronto and associates worldwide, **Ronacher McKenzie Geoscience (RMG)** provides integrated geological and geophysical consulting services for mineral exploration, ranging from desktop modelling and interpretation to field services and drill program management. Using a federal grant for women entrepreneurs, RMG finalized proof-of-concept of a machine learning tool called **Interpretable Artificial Intelligence**. Interpretable AI allows the user to annotate the output of an algorithm and answer the question “What does this mean?” explaining complex exploration data and leading to improved targeting.

Sander Geophysics Ltd. (SGL) based in Ottawa, provides worldwide airborne geophysical surveys for petroleum and mineral exploration, and geological and environmental mapping. Founded in 1956, services include high-resolution airborne gravity, magnetic, EM, radiometric, and methane sensing surveys, using fixed-wing aircraft and helicopters. Early in the pandemic, all field operations shut down and SGL quickly pivoted and offered its fleet of survey aircraft for the transport of essential supplies and cargo, and refocused operational resources onto R&D projects. The company continued to operate throughout this period following all government health and safety guide-


lines. By early summer, operations resumed in Canada, followed by Greenland and Ireland. In a major highlight for the company, the **Saudi Geological Survey (SGS)** awarded SGL an 800,000 line-km airborne magnetic gradient and radiometric survey, including data acquisition, processing and interpretation. This project is part of the Kingdom’s Vision 2030 program to diversify the Saudi economy.

Scintrex of Concord, Ont., reported that its CG-6 Autograv gravity meter continued to be a popular choice, with strong sales since its introduction in 2016. Sister company **Micro-g LaCoste** of LaFayette, Colo., introduced the SEA III marine gravity system, the latest in the long line of successful LaCoste & Romberg-based dynamic gravity systems. It represents the next generation zero length spring tension/beam velocity sensor.

Vancouver-based **SJ Geophysics** provides ground-based geophysical data acquisition and consulting services internationally, specializing in the acquisition of 2D/3D DCIP, EM (surface and borehole), MT, gravity, and magnetic surveys. In 2020, the company completed surveys in Canada, Finland, the United States and Mexico. Research efforts continued to improve the hardware and software of the Volterra Acquisition System.

SkyTEM Surveys, headquartered in Denmark, saw 2020 as a challenging period to fly airborne EM surveys with the spread of the COVID-19 virus. To adapt to the changing global business environment and travel restrictions, the company was restructured to focus on individual regions to ensure faster turnaround times. As a result, it was able to safely return to high production flying late in the second quarter, in accordance with the company’s Covid-19 policy and all local regulations.

Spectrem Air of Lanseria, South Africa, reported that after prolonged surveys in Australia, the Spectrem Plus system undertook surveys in Southern Africa. It was deployed for mineral exploration and both geological and hydrogeological mapping.

Terraquest, based in Markham, Ont., continued to provide fixed-wing and helicopter geophysical surveys in South America, the U.S. and Canada cautiously and safely during the pandemic. A Piper Navajo was added to its fleet, outfitted with horizontal gradient magnetics, radiometrics and VLF-EM, now enhanced with 2D and 3D resistivity products. The company has also added cost-effective laser scanner mapping to complement traditional airborne geophysical surveys. 



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Airborne Geophysical Surveying

EON Geosciences flew several large aeromagnetic and gamma-ray spectrometric surveys in Quebec for the **Ministry of Energy and Natural Resources (MERN)** and in United States for the **United States Geological Survey (USGS)**, as well as a horizontal gradient aeromagnetic survey in Manitoba for a private mining company. EON signed a contract with the **Geological Survey of Norway** for a large aeromagnetic, gamma-ray spectrometric, and VLF-EM survey in Norway to be flown in 2021.

Expert Geophysics, an airborne geophysical survey company based in Newmarket, Ont., reported an active year with MobileMT, its helicopter-borne EM and magnetic technology. Using natural EM fields in the frequency range 25 Hz - 20,000 Hz, the MobileMT system uses the latest advances in electronics, airborne system design, and signal processing techniques. MobileMT surveys were flown in North and South America and Asia, to explore for gold, porphyry copper, silver, and uranium. Four MobileMT systems are available for worldwide commercial operations and data processing, data inversion, and interpretation services including resistivity-depth.

Geosphair Aviation, based in Montreal, specializes in airborne survey platform operation, management, R&D and survey-aircraft modifications. Geosphair offers aircraft management services including pilots, maintenance, survey modifications and compliance with airworthiness regulations. The company's R&D continued to improve its Seaplane platform, working on stability-at-sea and various aids to seaplane pilot decisions.

Aurora, Ont.-based **Geotech**, along with its subsidiaries **Geotech Airborne** (Johannesburg, SA) and **UTS Geophysics** (Perth, WA) offer worldwide airborne geophysical surveys and consulting services using its VTEM helicopter time-domain EM and ZTEM natural field EM systems and fixed-wing and helicopter magnetic, radiometric and gravity systems. In 2020, surveys included completion of a two-year, 450,000 line-km fixed-wing magnetic and gamma-ray spectrometric survey in Cameroon. The project, for World-Bank funded PRECASEM (Projet de REnforcement des CAPacités dans le SEcteur Minier), included a training component. VTEM and magnetic surveys were completed for **Natural Resources Canada (NRCan)** for

■ NRG Exploration's Xcite TDEM system in South Africa. Credits: NRG

mapping in Saskatchewan, and VTEM ET groundwater surveys were completed for the **Cheyenne Bureau of Public Utilities** in Wyoming. A multi-year VTEM survey was continued in parts of Rajasthan and Madhya states for India's **Atomic Minerals Directorate**, in the Department of Atomic Energy.

New Resolution Geophysics (NRG), headquartered in Cape Town, South Africa, flies high-resolution helicopter magnetics and radiometrics (Xplorer), fixed-wing magnetics and radiometrics (Xact), fixed-wing gravity and magnetics (Xtract) and state-of-the-art helicopter time domain EM (Xcite) throughout Africa, the Middle East and Australasia. The company, which has nine helicopters and three fixed-wing aircraft, retained its full complement of staff throughout the 2020 pandemic by focusing on R&D. NRG conducted surveys in Myanmar and East Timor and has ongoing surveys scheduled in West Africa, Southern Africa and Australia.

Vancouver-based **Precision GeoSurveys** specializes in low-level airborne geophysical surveys in remote and mountainous terrain. The company operates its owned and chartered helicopters and fixed-wing aircraft to provide high-resolution magnetic, radiometric, and EM data in Africa, Asia, Europe, and across North America. In 2020, the company flew TDEM, FDEM, magnetic, and radiometric surveys in Europe, across Canada, and in the U.S.

Despite the pandemic's challenges in 2020, **SGL** flew airborne surveys in North America, the Middle East, Greenland

and Europe. Highlights include a fixed-wing FDEM and magnetic survey in Canada, a high-resolution helicopter gravity and magnetic survey to map fractures and bedrock morphology in the U.S., and a gravity survey in northwest Greenland to map bedrock below glaciers. The company flew several fixed-wing and helicopter gravity and magnetic surveys in North America for mineral exploration and geological mapping. Several combined magnetic and radiometric surveys, as well as a large magnetic, radiometric and FDEM survey, were also flown. In addition, SGL started flying a large magnetic gradient and radiometric survey for the **USGS** using both fixed-wing and helicopter.

In 2020, the Heli-GT helicopter georeferenced three-axis magnetic gradiometer system, developed by Toronto's **SHA Geophysics**, carried out surveys across North America, including Ontario's Ring of Fire (base metals); British Columbia's Liard mining division (VMS); La Ronge, Sask., (palladium); and Arizona (gold, copper porphyry). The Heli-GT's combination of four high-sensitivity cesium sensors in a towed bird with accurate pitch, roll and yaw determination measures total field and magnetic gradients in true east, north and vertical directions.

SkyTEM entered 2020 with a significant backlog of projects in what appeared to be potentially a record-breaking year. Despite the global pandemic reductions in travel, the company flew projects in the U.S., Canada, Europe, Africa, Australia and India. Projects included: ground water studies in South Africa with the Saldanha Bay Municipality, Hawke's Bay in New

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Zealand and in the State of Nebraska. SkyTEM also conducted work for the **Ministry of Energy, Northern Development and Mines (MENDM)** in Ontario, **Geoscience Australia** and the **National Geophysical Research Institute (NGRI)** in India. Through R&D last year, SkyTEM lowered its transmitter base frequency to 6.25/7.5 Hz, which increased the on-time duration, resulting in a higher signal response enabling recording of later off-time (~60 ms) which relates to deeper features. The waveform and duty cycle were designed to maximize the depth of penetration. A new receiver coil suspension system reduces the effect of motion-induced noise. SkyTEM, in partnership with **Emerald Geomodelling** and **Southern Denmark University**, secured 1.6 million euros in Eurostars funding over 30 months to develop a drone-based system and piloting, for the geotechnical and engineering industries. (The Eurostars program supports R&D in small and medium-sized enterprises.) Along with several Danish partners, SkyTEM also secured Innovation Fund Denmark funding of DKK 30 million to develop drone-based TEM technology and AI tools to estimate peat thicknesses.

Terraquest has provided high-resolution airborne geophysical surveys to the mining and oil and gas exploration sector for 37 years using gravimetric, total field magnetic, horizontal gradient, radiometric, proprietary Matrix VLF-EM and recently, VLF-EM Resistivity methods. The company won its fifth contract with the **USGS**, scheduled to start in January 2021.

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AIRBORNE DATA ACQUISITION AND PROCESSING

Vancouver-based **Computational Geosciences Inc (CGI)** advanced its mineral prospectivity and subsurface mapping capabilities using AI and machine learning. Recently deployed supervised and semi-supervised learning techniques were designed to integrate diverse datasets at various spatial resolutions, while incorporating extremely sparse ground-truth data. The company reviewed the sensitivity of output to inputs to improve the understanding of parameter effects through the model. This sensitivity analysis helps the user visualize which data have the most impact on predictions. CGI completed several 2D mineral prospectivity projects, a technique can be scaled up to 3D prospectivity mapping over spatial domains with high data density. CGI's AI team is processing down-hole data, monitoring real-time drilling and improving speed and reliability of its 3D EM inversion. Finally, in addition to AI services, its 3D EM inversion saw continued improvements in speed and reliability.

Geotech partnered with **Platform Geoscience** (Toronto) to provide custom 3D ZTEM Inversion, 3D MVI Magnetic inversion and machine learning-assisted integrated interpretation services. Geotech also undertook research on simultaneous extraction of ZTEM natural field EM data from streamed VTEM TDEM time-series, allowing delivery of both TDEM and NFEM data from a single survey VTEM system platform, in combination with its patented ZTEM base station.

Mira Geoscience reported that with version 3.2 release, Pro Geophysics runs UBC-GIF DCIP3D and DC/IP OcTree inversion programs, adding to its list for gravity and magnetics, DC/IP, and MT/ZTEM forward modelling and inversion codes. It is now possible to run VPmg bulk-property inversion and import VP Geophysics Suite mesh objects from VPmg, VPem1D, and VPem3D model files. 2020 saw the launch of Geoscience ANALYST's Python API, which is available via PyPI (the Python Package Index) and GitHub. Mira created the mirageoscience-app repository of geoscience applications, which will become a central repository to interfaces and applications including geophysical data processing, modelling, and inversion codes such as SimPEG. The free 3D viewer is available via MiraGeoscience.com. The company also made geophysical online content available through its YouTube channel where there are now over 30 new tutorial videos.

SGL completed a large integrated interpretation project, with 2D, 2.5D and 3D modelling of airborne data, using constraints from available geophysics, geology, and drill hole results. It also completed several forward modelling projects to assist clients with survey design. The company continues to provide the processed x and y horizontal gravity components for gravity surveys, in addition to the traditional z component, a unique capability of its AIRGrav system. The horizontal components are useful for mapping and geoid applications. Other R&D projects will enhance the resolution and accuracy of AIRGrav gravity data, and further develop EM and other systems.

Toronto-based **Geosoft** joined **Seequent**, headquartered in Christchurch, New Zealand in 2018. The merged company, with offices in Toronto, Vancouver and Denver and around the globe, continued to drive innovation in 2020. The company's

VOXI Earth modelling now offers forward and inverse modelling in 2.5D time-domain EM. Oasis montaj introduced a new Multi-Trend Gridding feature to better join linear trends in any direction with no boudinage artifacts as well as a redesign of 1D and 2D Filtering. A new Matched Filter feature was introduced enabling users to design up to four complementary matched filters to separate the equivalent magnetic response of different depth slices. Seequent has updated the Tilt Angle Derivative method for calculating the tilt depth to the magnetic layer for straightforward interpretation. It has also improved gravity interpretation through the new variable water level in Gravity Terrain Correction, standalone Latitude correction, loop-through multiple densities for Bouguer correction and improved GC-5 import. Seequent also focused on integrating applications to enable geophysicists and geologists to all contribute to an exploration project. Outputs from Oasis montaj, Target and GM-SYS 3D can be uploaded to Seequent Central (a collaborative cloud-based workspace) and used in Leapfrog (geological modelling application) via a common workflow.

The DAQNAV airborne data acquisition, navigation and magnetic compensation system, developed by **SHA Geophysics** and in service since 2013, operates on a 10" or 7" tablet. The acquisition module logs and displays data from all devices via the major communication interfaces, including Serial/USB, Ethernet and Wi-Fi. Users may view in real-time their own flight plan, background map, DTM grid and drape surface grid. A wireless module allows transmission of geophysical and navigational data. The DAQNAV system offers out-of-the-box compatibility with most geophysical sensors. The GT-Grid mapping system was developed to extract the full benefit from measured magnetic gradient information as well as the total field, ensuring accurate presentation of complex geological scenarios with multiple trend directions. In 2020, GT-Grid projects were carried out for companies in Canada and the U.S.

Founded in 2005 as a spin-off from the University of Utah,

TechnoImaging (TI), based in Salt Lake City, is an independent company that develops and provides 3D imaging solutions for geophysical methods for mineral and oil and gas exploration, and other applications. TI is interpreting several large-scale (thousands of line-kms) airborne (e.g., SkyTEM, VTEM and Magnetic) surveys in full 3D by inverting the AEM and TMI data for entire survey areas separately and jointly to derive the conductivity, magnetic susceptibility, and the magnetization vector. TI's proprietary Glass Earth technology, based on 3D imaging and inversion, renders the top kilometres of the ground entirely transparent, revealing the geophysical properties of hidden geological formations. TI also developed an advanced method of IP data inversion, based on generalized effective-medium theory of IP effect (GEMTIP). A 3D interpretation of a Spectral IP survey using a GEMTIP method over an area identified by a TI 3D inversion of a **Spectrem Air** EM survey in Saudi Arabia led to the discovery of gold mineralization.

Sydney-based **Tensor Research**, developers of ModelVision, introduced a service for magnetic rock property and depth mapping (RPD Mapping), based on a new expert system AI technology for automated building of a model of the geology across an undulating unconformity surface. Geological principles guide the AI system to build and iteratively refine the geology using unique properties of the magnetic tensor and joint inversion of the multichannel tensor data. The technology can be applied to conventional magnetic surveys or full-tensor SQUID magnetometer surveys flown with sensors developed by **Supracon** of Jena, Germany. RPD Mapping utilizes magnetic susceptibility and magnetic remanence-related information for mineral exploration targeting. Depth compensation through geologically constrained inversion of the magnetic data normalizes the properties so that outcropping targets can be easily compared with those that may exist nearby under cover. The rock property map is a magnetic proxy for the geology of the basement surface and datasets are compatible with ModelVision, which makes it sim-

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ple to focus on targets and data subsets for further refinement of the geology and target properties. A new release of ModelVision includes graphical view improvements and enhances the integration of large-scale rock property mapping within the RockMod modules.

In order to augment the base map and interpretational capabilities of airborne geophysical products, **Terraquest** now provides high-accuracy, cost-effective laser mapping using a compact and lightweight VQ-480i Laser Scanner manufactured by **Riegl**. The scanning mechanism is based on a fast-rotating, multi-facet polygonal mirror that provides fully linear, unidirectional, and parallel scan lines. Adverse atmospheric conditions and evaluation of multiple target echoes are resolved by unique echo digitization and online waveform processing.

AEROMAGNETIC SURVEYING

Devbriio Geophysics, based in Gatineau, Que., continued R&D in UAV-mounted geophysical systems. It improved its AIM LOW technology in 2020 using a new RTK-GPS unit that pro-



■ Geotech's next generation ZTEM 3D system (see page 14).

Credits: Geotech

vides real-time centimetre accuracy to consistently maintain a sensor altitude of 3 metres above obstacles at a speed of 12 m/s without prior knowledge of obstacles or terrain. This new technology was used in Newfoundland and Northern Ontario. In partnership with **Vision4K** of Quebec City, a BVLOS (beyond visual line of sight) permit was obtained to conduct a large-scale commercial magnetic survey by improving both safety and efficiency in the field. A network of telemetry relays enabled the operator to conduct flights without line-of-sight while maintaining control of the drone at all times.

Dias Airborne introduced its QMAGT, a full-tensor, helicopter-borne magnetic gradiometer (FTMG) system that uses low-temperature SQUID sensors in a 200-kg bird to measure all nine tensor components. In 2020, Dias deployed QMAGT in a new bird, significantly increasing the signal-to-noise level of the system.

EXIGE, based in Potchefstroom, South Africa, partnered with **Coleoptere** (France) to develop and offer for sale the airborne magnetic survey platform series VAMP (Versatile Automatic Magnetic Probe). The VAMP Air 'Cigale' model, which is the industry's smallest UAV-borne magnetic platform, is composed of an integrated DJI Mavic 2 Pro, DAS and a single fluxgate magnetometer, complete with sensor calibration software. A similar fluxgate magnetic system is available as a 'plug-in' for DJI M100 UAV carriers as a single or dual-sensor platform for horizontal magnetic gradient surveys.

Expert Geophysics completed the design of a new helicopter-borne AFMAG and horizontal magnetic gradiometer system (MTmgrad) with expected commercialization in 2021. It is comprised of a smaller version of the MobileMT bird towed on a 55-metre cable with two **Geometrics** 822A magnetometers with a 4-metre horizontal separation. The system provides detailed information about the apparent resistivities from surface to a depth of several hundred metres together with the magnetic horizontal and total field data.

Markham, Ont.-based **GEM Systems** has enhanced capabilities of the CARDINAL, an ultra-lightweight (1.5 km, including battery) towed-bird magnetometer system designed specifically for UAVs. The CARDINAL uses the newly designed GEM Systems GSMP-19 Optically Pumped Potassium Magnetometer, which offers the highest sensitivity of all optically pumped magnetometers. In addition, the narrow, single spectral line of Potassium minimizes heading and orientation errors; and the instrument offers low cost maintenance and high quality results in areas of high gradients. It also includes GPS for positioning, IMU for yaw, pitch and roll, tow cable, battery, GEMLink software utility and shipping case. Data are stored in internal flash memory, which can transfer data from a 30-minute flight in approximately 30 seconds or optionally in real-time via RadioLink. Two Cardinal UAV versions are available with sensitivity of 0.001nT per SqRtHz and 0.022nT per SqRtHz. All GEM optically pumped systems – ground, UAV and manned aircraft – now have the capability of sampling rates up to 1000 Hz.

NRG's Xplorer helicopter and Xact fixed-wing gradient magnetic and radiometric systems continued to operate throughout Africa and the Middle East. The low-drag, composite material of the Xplorer's magnetic "booms" produce an efficient, cost-effective survey. High speed sampling of magnetic (20 Hz) and DGPS (10 Hz) data improves the definition of short wave-length anomalies. NRG's Xplorer package offers high-resolution, full-spectrum radiometric data as a complement to its gradient-enhanced magnetic data. The reduced survey height of a helicopter platform improves signal-to-noise ratio, enabling a higher sampling rate of 2 Hz (approximately 20 metres). Up to 2048 in³ (32L) NaI detector packs are employed with full gamma-ray spectrum recording using industry-leading **Radiation Solutions** spectrometers. Full-spectral NASVD processing is applied to all radiometric data.

In 2020, Mississauga, Ont.-based **RMS Instruments** developed and qualified a comprehensive set of data capture methods as well as detection and location estimation algo-

rithms for magnetic anomaly detection (MAD). The system works seamlessly with the compensation and data acquisition instruments in the DAARC500-series. While the MAD technology is not yet commercially available, it continues to be developed in prototype for the AARC52, a dual-magnetometer, real-time compensation and data acquisition system tailored to UAV platforms. The AARC52 and its predecessor, the AARC51, have now been qualified down to -10°C operating temperature. RMS has improved the aeromagnetic compensation performance and feedback for operators to allow quick evaluation of compensation results. New hardware and firmware releases for the DAARC500 incorporate embedded barometric pressure and temperature sensors, and offer comprehensive support for fully automatic altitude-controlled calibrations (ACCs), targeted to UAVs.

Magnetic data are acquired by **Sander Geophysics** in stand-alone airborne magnetic surveys and in multi-parameter surveys including EM, radiometrics and gravity with fixed-wing aircraft and helicopters. Helicopter surveys can be flown with the magnetometer either in a stinger or a towed bird or configured for horizontal gradient measurements. Fixed-wing surveys can be flown with a single tail-mounted magnetometer, a horizontal gradient configuration with wingtip magnetometers, or a tri-axial gradient (horizontal, vertical and longitudinal) configuration with wingtip magnetometers and vertically separated tail-mounted magnetometers. The company flew several combined magnetic and gravity surveys in Canada for mineral exploration using fixed-wing aircraft and helicopters, as well as a magnetic and radiometric project for regional mapping and a large magnetic, radiometric and EM survey in Ireland.

Spectrem Air successfully completed two SQUID full-tensor magnetic surveys in Canada with its helicopter-towed vertical cryostat system. Work continued with **IPHT** and **Supracon** on the deployment of the system with a horizontal cryostat on a fixed-wing platform. The FTMG system can now be deployed in both horizontal and vertical cryostat modes on a bird or boom attached to a helicopter. Data interpretation advances now include improved levelling of the data, as well as inversion of the tensor data to produce 3D models of susceptibility distribution fully accounting for the magnetization direction. In addition, magnetic remanence direction is mapped and output, which aids in structural interpretations in magnetically complex terrains.

Terraquest has developed a dynamic point-to-point steering correction based on real-time corrected GPS positioning to achieve a preferred geographically referenced horizontal magnetic gradient. The enhanced result is used to mitigate the challenge on surveys where dykes are parallel to the flight line. The normally levelled measured magnetic data are compared with data reconstructed from the high-resolution, measured horizontal magnetic gradients. The reconstructed total field data, by definition, are not influenced by diurnal effects and therefore any anomalous features associated with the line direction can be assumed to be legitimate. By comparing the measured and reconstructed magnetic field, micro-levelling corrections are limited or eliminated for more accurate preservation of valid geologic features in the final product.

AIRBORNE ELECTROMAGNETIC SURVEYING

CGG Multi-Physics offers three unique AEM technologies, Helitem, Tempest and Resolve. The company updated its Helitem technology to create the Helitem2 system in 2019, and in 2020 a survey was flown in Spain by a European funded consortium (INFACT). These data will be published to show the use of innovative, non-invasive exploration technologies. In Australia, Helitem2 surveys were completed for iron ore development, and for base metal and gold exploration; in North America, it was mainly used for base metal exploration. The upgraded Tempest fixed-wing TDEM system spent early 2020 in Mississippi in the third and final year of a groundwater contract for the **USGS**. Later in Western Australia, it continued the regional coverage of the AusAEM series of surveys for **Geoscience Australia**, focused on the goldfields region. The program is in its third phase with CGG's Tempest contracted to survey approximately 165,000 line-km across three states. These projects illustrate the effectiveness of Tempest for large regional-scale mapping. CGG's Resolve technology continued surveys for high-precision conductivity measurements for groundwater, mineral exploration, and geological mapping in rugged environments. It is preferred for mineral exploration in resistive regimes in Canada owing to its extremely high resolution and sensitivity to small variations in resistivity.

Dias Airborne offers passive EM surveys (AFMAG) using its



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LT SQUID-based QMAGT system, towed beneath a helicopter acquiring three-component magnetic and three-component passive EM data. The passive EM system combines all three components with base station data comprising three-component B-field and two-component E-field datasets to produce a range of resistivity imaging products.

Last year, **Expert Geophysics** upgraded mTEM (formerly called MicroTEM), its innovative airborne EM system which uses a controlled-source field. It is a time-domain system for detailed near-surface (0-50 metres) investigations and is claimed to be the only system able to obtain clean data in industrial areas with EM interference.

GEM Systems' UAV-towed VLF-EM system is based on the company's fixed-wing VLF-System. The AirVLF (GSM-90AVU(B)) provides true measurements of the vertical in-phase and out-of-phase components as percentage of total field within the VLF frequency range. The system features two (or optionally three) separate sensors with three lightweight orthogonal air coils in each. This provides reduced noise and allows true in-phase and quadrature data to be gathered simultaneously (up to 10 Hz) from the VLF transmitting stations, regardless of sensor orientation (+/- 45 degrees of horizontal tilt correction).

Based on experience with its EM61-MK2, the industry's well-recognized UXO detector, **Geonics** has now developed a new lightweight version of the instrument called the EM61-Lite for drone applications.

During the exploration lull in 2020, **Geotech** increased its R&D on multiple new systems that may be introduced in 2021. Development included a new high-speed, full-waveform Streamed Data Acquisition System for its VTEM TDEM system that accompanies its new generation VTEM TDEM transmitter. The new system has a square-shaped current pulse, faster turn-off time, higher dipole-moment and extended base-frequencies. The company also developed the next generation Blackbird TDEM system prototype, with advanced lightweight composite design for greater survey speed. For its natural field EM (NFEM) systems, 2020 saw the company complete the redesign and testing of its new ZTEM-Lite receiver with modular aerodynamic construction for easier disassembly and transportability. It also tested its next generation ZTEM 3D system that combines the rotational invariance of its previous AirMT prototype and full three-axis AFMAG tipper measurements in the 22 to 30,000 Hz frequency band. The company continued to work on hybrid air-to-ground EM surveying. Buoyed by the publication in 2020 of two successful Groundfloor EM (GFEM) case studies over Vale's WD-16 nickel-copper deposit in Sudbury, Ont., and INFAC 2020-funded VMS copper deposit test sites in Spain, held by Las Cruces and Rio Tinto, **Platform Geoscience** and Geotech partnered to provide commercial GFEM and VTEM surveys in 2020. Applying EM reciprocity and On-time Step Response computation, GFEM allows the detection and discrimination of extremely high conductivity targets that would not be detectable in standard TDEM surveys.

NRG's Xcite EM system has an updated processing flow

and receiver suspension, which reduced noise. An increased dipole moment was implemented on all operating systems. The company relocated the magnetic sensor on the inflatable bird to increase the magnetic signal-to-noise ratio, ensuring collection of high-quality magnetic and EM data. The streaming data provides along-line resolution of approximately 0.5 metre with 'soundings' from shallow to very deep. There are currently six Xcite systems in operation in Africa, the Middle East and Australasia

NUVIA Dynamics of Mississauga, Ont., improved and updated its NuTEM TDEM system, which is commercially available for sale and for surveys. The helicopter-borne NuTEM system with a dipole moment of 300,000 amp-m² has new electronics for more precise discrimination of on-time and off-time gates. The receiver was completely redesigned making it lighter, larger and more efficient. Its new suspension system increased signal-to-noise ratio, improving target resolution. The company is working on miniaturization of the hand-held radiometric system (PGIS), and updating the software and electronics.

SGL continues to offer its unique four-frequency fixed-wing airborne EM system (SGFEM) for high-resolution EM surveying with the transmitter and receiver mounted on the wingtips. Without a towed bird, it is seen by aviation authorities as a safer alternative to helicopter systems for flight over built-up areas. It is also relatively unaffected by powerline noise, providing useful EM data even in areas with infrastructure. The SGFEM system can be used in combination with other sensors (gravity, magnetic, radiometric, methane, etc.) to provide multi-parameter geophysical surveys. Applications include mineral exploration, geological mapping, and environmental and geotechnical studies. Despite a Covid-19-shortened season, SGL flew another large EM, magnetic, and radiometric survey in Ireland using its SGFEM system. 2020 marked the seventh year in the **Geological Survey of Ireland's** multi-disciplinary **Tellus** program, in which SGL conducted airborne mapping of most of Northern Ireland and the Republic of Ireland, with a goal to map the entire island by 2023.

Spectrem Air had more time for R&D in 2020, and developed a new upgraded receiver system with lower electronic noise, full tracking of receiver position and rotation, and improved suspension system. A processing algorithm improvement enables fully selectable high-resolution time windows to be tailored for each survey. Collaboration with recognized EM centres and interpretation service providers expanded its offering of inversions and modelling of EM data.

Terraquest commissioned the design and production of a digital VLF-EM system using advanced circuitry and techniques adapted from EM signal research. It monitors up to four frequencies, recording full parameterization of the VLF-EM signal, including total field amplitude, vertical ellipticity (proxy for quadrature), planar ellipticity, tilt angle ellipse (proxy for in-phase), Tipper coefficient and azimuth to VLF transmitter. These data have now been inverted to produce well-defined and coherent resistivity products corroborated by IP and drilling. Final products include resistivity maps, depth slices, verti-

cal sections, 3D databases and voxels in Geosoft format, allowing user-selected visualization of the 3D model for enhanced interpretation.

AIRBORNE GAMMA-RAY SPECTROMETRIC SURVEYING

In 2020, **Radiation Solutions Inc. (RSI)** of Mississauga, Ont., reported developments and improvements – notably, reduced power consumption, scalability and connectivity across its product line. The UAV-borne spectrometer introduced in 2019, Drone Detection Spectrometer (DDS-3) uses a 3”x3” (0.39L) NaI(Tl) detector and spectrometer assembly weighing only 3 kg. The DDS-3 is designed for near-surface geological mapping and uranium exploration, and can be combined with a magnetometer or other sensors. The UAV’s autopilot feature can easily navigate more than 30 line-km per battery charge. RadMobile is a smartphone app developed to view system status, count rate and detailed isotope information. The DDS-3 is equipped with Wi-Fi, Bluetooth, Ethernet, USB download, internal GPS and onboard spectral analysis.

After several years of development, **SGL** is now routinely using its SGSpec radiometric system, which supersedes many older systems. SGSpec is a modern full-spectrum (1024 channels per crystal) digital spectrometer, which includes real-time signal processing/analysis and automatic gain control for individual crystals, multi-channel analysis and full-spectrum recording. The company flies radiometric surveys with fixed-wing aircraft and helicopters.

■ Radiation Solutions’ UAV-borne gamma-ray spectrometer.


Credit: Radiation Solutions



AIRBORNE GRAVITY SURVEYING

CGG Multi-Physics flies airborne gravity and gravity gradient surveys with its six Falcon AGG systems, designed for use in light aircraft and helicopters and engineered to isolate the instrument from aircraft noise, resulting in superior sensitivity. In 2020, Falcon surveys were flown in Australia, Africa, Indonesia, Japan, Kazakhstan and North America, predominantly for gold, oil and gas, iron ore, base metals, and geothermal resources. The Falcon Plus system and the Full Spectrum Falcon AGG technology were described in ETD 2020. The HeliFalcon system was deployed in Japan, Canada, and South America and the Full Spectrum Falcon was deployed in Australia, Indonesia, and North America.

NRG’s Xtract system offers airborne gravity globally with its twin turbine-powered fixed-wing aircraft. Based on **Canadian Micro Gravity (CMG)** gravimeters (eg. GT2A), the enhanced capabilities of the Xtract system are due to its combination with NRG’s patented Active Thermal Control System (ATCS), described in ETD 2019.

The global COVID-19 pandemic, coupled with depressed petroleum exploration activity, decreased opportunities for AIRGrav surveying by **Sander Geophysics**. However, in 2020, the company flew surveys using fixed-wing aircraft and helicopters for exploration clients and government agencies in North America, Greenland and the Middle East for mineral exploration, geological mapping, and geoid modelling. The company continued to improve its AIRGrav system, focusing on high accuracy, resolution of vertical gravity, as well as the two horizontal components. SGL has 12 AIRGrav systems, which can be flown in its dedicated survey aircraft or in suitable third-party aircraft. 

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Ground Survey Techniques



■ GF Instruments' CMD EXPLORER 6L multi-depth probe for EM conductivity measurement (see page 19). Credit: GF Instruments

PHYSICAL ROCK PROPERTIES & ELEMENTAL ANALYSIS

GDD's portable instruments, the Multi Parameter Probe (MPP) model MPP-EM2S+ and the Sample Core IP (SCIP) tester are widely used by geologists and geophysicists to determine physical properties of samples, cores, half cores, etc. GDD improved efficiency and lowered the cost of the instruments by replacing the computer with the client's Android device and two free apps – GDD MPP and GDD SCIP.

GROUND DATA ACQUISITION AND PROCESSING

Condor Consulting, with offices in Lakewood, Colo., and Vancouver experienced a Covid-challenged first half of 2020, with market conditions improving by mid-year. Work focus was split between gold and copper projects with minor activity related to zinc and nickel-PGEs. Due to pandemic protocols, utilization of virtual meetings was expanded for both client interaction and professional society involvement. In terms of techniques and technical trends, Condor reported a strong focus on the IP technique, (review of legacy data and new 3D array, surveys). It also reported a predominance of data from the **Geotech ZTEM** system but noted that data from the MobileMT technology of **Expert Geophysics** is appearing more frequently. On the processing side, requirement for resolution of shallow and deep targets lead to more joint inversions of ZTEM and MT and ZTEM-VTEM-DIGHEM datasets.

Crone Geophysics worked with **Seequent's** software tech-

nology in 2019 and 2020 to ensure that its E-SCAN Mark 7 pole-pole datasets are fully implemented in VOXI 3DIP inversion processing. Very large datasets have been successfully inverted as overlapping sub-areas and merged to present detailed wide-area true 3D imaging of DC Resistivity. The objective is to nightly update the 3D earth model inversions for quality control, and real-time guidance of field crews. In addition, MMR surveys now come with standard in-phase and quadrature analysis of the time series, new time-domain analysis of stacked data with shorter processing time and inductive responses that can be easily identified in the time-domain analysis.

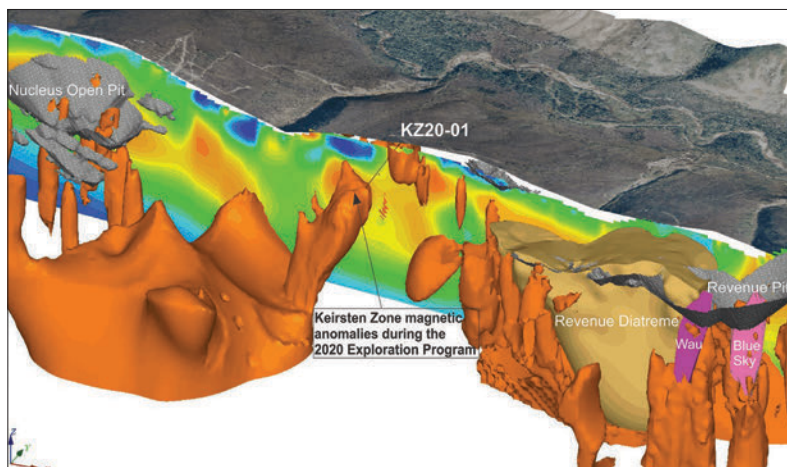
In 2020, **Dias Geophysical's** research efforts included new hardware and software. Dias introduced its GS5000 transmitter, which delivers up to 25 A of current using a maximum of 5,000 V and drawing up to 25 kW. The DIAS32 system (less than 32 kg) was upgraded to allow for AMT and MT recording. On the processing side, Dias expanded its SimPEG 3D inversion portfolio, adding MT, AMT, FTMG, Tipper, Mag and Gravity (including multiple options for sensitivity matrix calculation) to its original 2D/3D DCIP inversion capabilities. The SimPEG suite is now fully functional on Caravel, Dias' cloud computing system, and is available via the Caravel app to customers who run their own inversions. The company optimized the handling of its growing datasets by migrating its extensive processing and QC custom toolbox to Caravel, and by actively developing its AI-based time series QC capabilities.

The development of matched filter processing software,

Step Loop Processing (SLproc), for the imaging of multi-fold step loop UTEM5 data was completed by Kingston, Ont.-based **Lamontagne Geophysics** and it was applied to one survey area in 2020. The main application of SLproc is the detection of discrete massive sulphide targets in areas with complex background EM responses. A high-power computing cluster is now being assembled to reduce computation time.

In 2020, **Mira Geoscience** continued exploiting the advantages of supervised and unsupervised machine learning, by using geophysical models and data in mineral deposit targeting as well as in alteration and lithological domain prediction. Deep Learning computer vision was used to help leverage the predictive power of textures and edges in the construction of predictive models. Mira started work on the CONSOREM (a Mineral Exploration Research Consortium at the University of Quebec) project to evaluate the predictive power of different machine learning algorithms applied to geological mapping and prospectivity analysis to help the industry partners select an AI technology. The company utilized an integrated approach to geological and geophysical modelling techniques. For example at Triumph Gold's Freegold Mountain project in the Yukon, Mira identified a high-temperature hydrothermal exploration target using magnetic susceptibility. By combining the surface magnetic data and measured drillcore susceptibility data, the drill-hole-constrained inversion process successfully identified pipe-shaped magnetic anomalies interpreted to represent high heat targets. Triumph Gold confirmed in 2020 that the Keirsten Zone anomaly was associated with a mineralized hydrothermal system. This conjoint geophysicist/geologist modelling team showed the importance of understanding the mineral systems to constrain the geophysical inversion processes to better define a target.

Thanks in part to the pandemic, **Quantec** improved the efficiency of field operations and contributed to cost savings for clients. Accelerated development of "QUICKLAY" for flow control and automatic data processing eliminated the need for field processors to be physically in the field. This reduced field costs, relocated field processors to a safe environment where they could



■ Triumph Gold and Mira Geoscience case study: Drillhole and geologically constrained 3D magnetic susceptibility inversion results presented over the Freegold Mountain property. Orange bodies outline magnetic anomalies identified by the 2020 drill-hole constrained 3D magnetic inversion model.

Credit: Triumph Gold

work on multiple projects, made data QA more efficient and also remotely accessible to senior staff. The company created an extensive database of geophysical forward model studies to demonstrate the advantages and limitations of various 2D array-based IP profiling methods and 3D data acquisition geometries, which helps clients with survey design and survey optimization to achieve best exploration and budget objectives. The modelling demonstrates the significant superiority of 3D data acquisition (including cross-line dipoles) over 2D and offset pole-dipole surveys.

DRILLHOLE METHODS

Abitibi Geophysics' proprietary GeoTk inversion software combines gravity data acquired in multiple boreholes with surface surveys, processing with or without constraints, to detect excess mass and estimate tonnage. The objective is to drill fewer holes and potentially reduce exploration costs. Improvements made to H2H BHIP (hole-to-hole boreholeIP) help to map the continuity of geology between boreholes. Development of a borehole ARMIT B-field EM sensor is now ready for field testing and commercialization.



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Alpha IP
A Wireless Time Domain Distributed IP Technology



Omega MT
Ultra Wideband Magnetotelluric Technology

Alpha IP, Omega MT, TDEM, CSAMT, Gravity & Magnetics
Globally Proven for Gold, Base Metals and PGEs
Versatile, Next-Generation Technologies

Luxembourg-based **Advanced Logic Technology (ALT)** introduced the QL40-SGR-2G Spectral Gamma Probe, which has a redesigned and ruggedized mechanical assembly, electronics and gamma module, available with a CeBr3 or BGO scintillation crystal. The CeBr3 crystal has high spectral resolution and sensitivity, and is ideal for ore grade analysis. The BGO detector has very high scintillation efficiency, good energy resolution, and is mechanically rugged, making it ideal for a wide range of applications. ALT also released version 5.4 of its WellCAD Borehole Data Software. A Core Shifter workspace has been implemented into the ISI and CoreCAD modules, allowing users to depth-shift and reorient log data, and structure picks and images to align core and wireline log data. The Full Waveform Sonic Processing module has been completely upgraded with a new velocity analysis workspace, greatly improving productivity while processing sonic data. The company also made upgrades to the Basic module, including dynamic depth scaling and a tool model repository.

SJ Geophysics developed a new 32-mm version of its Volterra Borehole System to be ready for commercial surveys in 2021. The new Volterra probe features an upgraded IMU unit for borehole orientation data, integrated Li-ion batteries, reduced noise levels and is shorter and lighter, making it more portable. It can be configured with a three-component fluxgate magnetometer, an axial induction magnetometer, or a four-dipole IP cable. Two or more Volterra 32-mm probes can be connected together to acquire fluxgate and induction magnetometer data simultaneously. The company is also developing a method to acquire IP data using the Volterra BH system's ability to survey below the drill rods.

GROUND ELECTROMAGNETIC METHODS

With the choice of InfiniTEM or OmniVision transmitter loop configurations, combined with the ARMIT simultaneously measuring dB/dt and B-field sensor, **Abitibi Geophysics** can optimize survey parameters prior to acquisition to ensure target detection regardless of conductivity or geometry. The dual-

loop ARMIT InfiniTEM configuration is ideal to locate deep sub-vertical conductors beneath conductive overburden, while the triple-loop ARMIT OmniVision additionally detects conductors at any dip angle.

AGCOS developed new instrumentation in 2020 for EM, IP and MT methods. The company introduced the AT-300, a new portable, lightweight IP and EM transmitter for near-surface applications with 5A output and less than 5-microsecond turn-off times. It has wideband (50kHz - 0.01Hz) 200 frequencies, intuitive flexible scheduling, GPS and cable synchronization, full waveform recording, safety features and is powered by a standard 12V battery. The company also introduced extremely low-noise high and low frequency three-component aircoils (ATEM-20 and ATEM-50) in addition to FTEM-100, MTEM-200 and LTEM-25 airloops for TEM/TDEM methods. In addition, AGCOS upgraded its GEPARD-4 and GEPARD-8 broadband multifunction EM receivers (43,000 - 0.00001 Hz) with a new GUI interface, improving in-field DAQ setup and QA/QC processes for all 18 supported EM methods. They are supplied with new low-noise lightweight HAMT, AMT, MT and BBMT induction coils as well as three models of low-noise, non-polarizing electrodes. Contract EM surveys carried out by AGCOS with integrated natural and controlled-source EM (NCSEM) technology significantly increased the amount of data collected with a single field array with low survey costs and increased accuracy and certainty of interpretation. NCSEM technology combines elements of AMT, MT, MVP, CSAMT, FDEMS-IP, SIP, DES-IP, SP, and VLF-EM methods and can be easily adapted for most mineral exploration. NCSEM surveys carried out with AGCOS instruments and software proved the technology's exceptional sensitivity and effectiveness in challenging highly resistive environments.

Crone Geophysics provided borehole/surface MMR surveys in 2020 while continuing to make improvements to the system, including full continuous recording of the transmitted current

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waveform and custom channel configurations to reduce 60/50Hz noise in the time domain, using the CDR4 receiver.

During 2020, Mississauga, Ont.,-based **Geonics** developed new EM instruments for near-surface geophysical exploration, including the EM38-4, a multi-coil ground conductivity meter, and a truck-mounted instrument carrier for agricultural applications exploring to 1.5 metres depth. The unit is equipped with fast, real-time, two-layer inversion software. The company also developed the EM31-8 conductivity meter with two transmitter coils (dipoles) oriented perpendicular to each other (vertical and horizontal), that simultaneously generate a vertical (VD) and horizontal (HD) primary magnetic field. The instrument has four sets of two perpendicular receiver coils (i.e. four vertical, four horizontal) for each Tx dipole, with four Tx-Rx coil separations (1 metre, 2 metres, 3 metres and 4 metres) that measure the secondary vertical and horizontal magnetic field. Two components are derived from each receiver coil channel: quadrature, related to ground conductivity; and in-phase, related to ground magnetic susceptibility. The eight receiver coils at different separation and orientation, sense at eight different depths, providing information for calculating thickness of the top two layers and three apparent conductivities for a three-layer inversion model, to a depth of 6 metres. The data processing package includes fast, real-time three-layer inversion software specially developed for Geonics by **Emtomo Software Development** in Lisbon, Portugal.

In 2020, **GF Instruments** (Brno, Czech Republic) introduced its new CMD EXPLORER 6L high-resolution EM conductivity meter for multi-depth surveys ranging from 0.45 to 6.3 metres. The sensor system is equipped with six coplanar receivers for simultaneous reading of conductivity and in-phase measurements. This allows both multilayer mapping and 2D/3D data processing for imaging of conductivity sections with inversion. The instrument keeps the traditional lightweight, robust design of the CMD series of conductivity meters with simple operation from a standard CMD control unit or a smartphone app.

The range of application of the UTEM5 system for Inductive Source Resistivity (ISR) measurements was extended by **Lamontagne Geophysics** in 2020. The system can now measure three dipoles per receiver at once with up to three simultaneous transmitters. It can be used with capacitive electrodes suitable for arid or frozen environments over a range of base frequencies extending down to 0.2 Hz. The upgraded system is used for the detection of resistive targets using a simple profiling configuration or resistivity imaging when using a multi-fold configuration.

SJ Geophysics upgraded its Volterra EM Transmitter (EMTX) in 2020 to transmit both 100% and 50% duty cycle waveforms with increased timing accuracy. The power supply can be a generator or batteries. The company improved calibration procedures and software to take advantage of high sensitivity surface induction magnetometers.

Zonge International, based in Tucson, Ariz., continued to work with its new broadband EM receiver called ZEN, released in 2018 and described in ETD 2019. The high-resolution, multi-channel ZEN receiver was designed for acquisition of controlled and natural source geo-electric and EM data. In 2020, the company developed two new transmitter power sources, the ZMG-4 and ZMG-11 (MG=Motor Generator), with upgraded reliability, security features and technology. The ZMG-4 and ZMG-11 generate 4.5KVA and 12.5KVA, respectively, at an output frequency of 400Hz, and voltage of 120/208V three phase. The company announced that its new GGT-30B transmitter is now available for purchase. This high power, fast turn-off unit may be used for time/frequency domain IP, Resistivity, CR, TEM, FEM and CSAMT. TEM surveys will benefit from the advanced features and reduced weight and size of the company's new TEM inductive coil. Results at the very high and low ends of the frequency spectrum provide improved overall resolution of the subsurface and late-time data.

GRAVITY SURVEYING

GF Instruments reported its LG-1 Galileo land gravity meter was equipped with enhanced software capabilities in 2020. It can now be operated using a smartphone app instead of the detachable control unit. The ruggedness of the new fully quartz core technology of the gravity sensor has been confirmed by use in field surveys.

INDUCED POLARIZATION

Abitibi Geophysics expanded its suite of IP methods with the addition of OreVision3D and DasVision. OreVision3D utilizes in-line and cross-line dipoles to increase the depth of investigation, target resolution and geological trends between lines. This results in improved 3D IP inversion with reduced near-surface striping at a lower cost than standard 3D IP surveys. For increased depth of investigation and high resolution over large survey blocks, DasVision surveys include the possibility to inject current in boreholes located within the surface array.

In 2020, technical advances by **Crone Geophysics** included daily pinpoint fault diagnosis and auto-correction of in-field




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setup errors of E-SCAN's new Mark 7 3D mapping tools. This improved coverage of multiple square kilometres of survey area using very small field crews, while retaining true 3D data acquisition and accurate real-time 3D imaging results.

Dias Geophysical improved its DIAS32 3D IP system by adding the GS5000, a lightweight, high power transmitter, increasing the signal-to-noise levels and depth-search capabilities. It reduces risk by offering both high voltage (5 kV) for resistive contact environments and high power (25 kW) for more conductive geology and is designed for safety with remote operation.

GDD's new generation of the GDD RTE Wireless Communication Module (GDD WCM) will significantly reduce costs by replacing PDA's connected to each IP receiver and enable one on-site or remote operator to control all receivers. It will also benefit from senior geophysicist participation via portable internet. Both 2D and 3D distributed surveys can be performed by synchronizing multiple GDD IP receivers from a single operating location using a rugged Windows 10 laptop and the GDD Multi-Rx software. The WCM, provides real-time feedback, allows visualization of the transmitter current (records average or all), full waveform data, pseudosections, pin contact, and decay curves, as well as capability to change receiver configuration as needed. The GDD 2D and 3D wireless distributed acquisition system is a cost-effective solution for all scales of projects regardless of investigation depth or mineralization type and is compatible with all generations of GDD IP transmitters and receivers.

R&D by **IRIS Instruments** (Orleans, France), led to the launch of its new Elrec TERRA resistivity and IP receiver. It includes 20 simultaneous channels, full-wave data recording for advanced signal processing, a large colour display and a new lighter, more compact and robust console box. The Elrec TERRA can provide high productivity and excellent data quality in any environment.

Quantec is now deploying simultaneous single lines of RT 130 receivers with both in-line and cross-line dipole measure-

ments for IP surveys. This provides 3D information for enhanced response and improved mapping of the subsurface. While not full 3D acquisition like ORION 3D, this survey (ORION SWATH) provides enough 3D information that data can be legitimately treated with 3D inversion. Model studies indicate that by collecting data in this manner, line-cutting costs can be reduced and the response is significantly better than pole-dipole offset-current methods for collecting 3D information. The data from each transmit line may also be treated immediately in a 2D sense within a 24-hour turn-around for improved monitoring of survey progress and results. Once all the information for a grid has been collected, a 3D inversion is completed.

A number of Volterra-3DIP and Volterra-3DIP/MT surveys were completed by **SJ Geophysics** in remote and challenging environments where the Volterra system's flexibility, portability, and data quality made it an effective tool. The company is developing its next generation distributed 3DIP/MT acquisition system to expand its capabilities. Software has been developed to recalculate field-recorded Volterra-3DIP dipole data into different dipole configurations for improved 3D inversion modelling results in challenging areas.

MAGNETOTELLURIC

Dias Geophysical introduced its wideband DIASMT system in 2020, and completed its first AMT survey. The system provides sampling at up to 19.2 kHz using the DIAS32 Gen2 receivers and Metronix MFS07e coil sensors. A full processing and QC suite has been developed internally using novel methodological processes based on wavelet analysis and robust statistics, which allows a full interpretation of the MT impedance tensor. Dias has also implemented the latest SimPEG 1D, 2D and 3D inversion capabilities and offers these through its Caravel cloud service.

The new generation Ultra-Wideband Magnetotellurics (UMT) instrumentation developed by Toronto-based **Phoenix Geophysics** to replace older generations of MT equipment has been widely accepted by the MT community as more than 200 systems were shipped worldwide. This permits users to benefit

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from modern MT features that reduce operating costs and improve data reliability, at regional and deposit scales. The company's latest advance is networking receivers to transfer data in real time to a remote server for QA/QC either at the field camp or the office. UMT stations can be turned into monitoring stations for volcanic research or set up as permanent base stations for commercial surveys. The company now leases UMT systems in North America with field assistance, online training courses and a 24/7 uninterrupted technical support line. In 2020, deep controlled-source systems have been in high demand. The TXU-30A high-power transmitter was used for deep gold surveys in eastern Canada and southwestern U.S. It can be powered by a three-phase motor generator and supports FDEM, TDEM, SIP, TDIP, CSAMT and CSEM applications. Synchronized by GPS timing, the TXU-30A can be used with Phoenix systems or almost any other EM / DCIP receivers that can supply a timing signal.

Along with three available CSAMT systems, **Quantec Geoscience** now provides TITAN 160 as a new generation of array-based AMT and MT surveys. Deployment of TITAN 160 MT allows high-resolution resistivity sections and optimal acquisition strategies. The survey line is set up during the day and data are collected overnight ensuring the strongest available natural signal. The 160 data logger can capture natural frequencies from 10,000 Hz down to 0.0001 Hz providing significantly deeper resistivity information than a CSAMT survey while providing high resolution. The TITAN 160 MT system allows the acquisition of cross line dipoles and therefore the tensor data can be inverted in 3D to provide superior subsurface resistivity information. The company's SPARTAN MT was selected by Laurentian University for the **Metal Earth** phase 2 geoscience program, described in ETD 2020. In 2020, MT was used to investigate



■ Quantec Geoscience conducting an MT survey in Ontario's Red Lake mining region.
Credit: Quantec Geoscience

deep crustal information and its relation to mineral endowment in Ontario's Red Lake and Timmins mining regions. Quantec recently developed a "smart spider" system that acts as an interface between Quantec's Q-RT 160 Data Recorder system and the magnetic sensors deployed for a survey. This tool for modern broadband coils, captures serial number and other coil installation parameters per channel and automatically resets any sensors that may have entered a locked or unstable condition due to a signal overload, greatly improving data quality in the field.

Multiple MT and combined 3DIP/MT surveys were carried out by **SJ Geophysics** in 2020. MT data acquisition with high bandwidth induction magnetometers is now offered in both scalar and tensor configurations. Improvements to the MT signal processing software decreases processing time, streamlines the processing workflow in the field, and improves QC visualization tools. **EMD**



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Lamontagne Geophysics: www.lamontagnegeophysics.com	Xcalibur: www.xagsa.com
	Zonge International: www.zonge.com

Abbreviations (for acronyms used in the text)

A	Ampere	DMEC	Decennial Mineral Exploration Conferences	kW	kiloWatt	SIP	Spectral IP
AEM	Airborne EM	DTM	Digital Terrain Model	LiDAR	Light Detection And Ranging	SP	Self Potential
AFMAG	AMT	EITAP	Extractive Industries Technical Assistance Project	MAD	Magnetic Anomaly Detection	SqRtHz	Square Root Hertz
AI	Artificial Intelligence	EM	Electromagnetic	MMR	Magnetometric Resistivity	SQUID	Superconducting Quantum Interference Device
AMT	Audiofrequency MT	FDEM	Frequency Domain EM	ms	millisecond	TDEM	Time Domain EM
B	Magnetic Field	FEM	FDEM	MT	MagnetoTelluric	TEM	Transient EM (= TDEM)
BBMT	Broadband MT	GIF	Geophysical Inversion Facility	MVP	Magnetovariational Profiling	TMI	Total Magnetic Intensity
BGO	Bismuth Germanate	GPR	Ground Probing Radar	Nal	Sodium Iodide	Tx/Rx	Transmitter/Receiver
BH	BoreHole	GPS	Global Positioning System	NASVD	Noise-Adjusted Singular Value Decomposition	UAV	Unmanned Airborne Vehicle (Drone)
CeBr3	Cerium Bromide	GUI	Graphical User Interface	NCSEM	Natural and CSEM	UBC	University of British Columbia
CSAMT	Controlled Source AMT	HAMT	Hybrid-Source AMT	NFEM	Natural FEM	USB	Universal Serial Bus
CSEM	Controlled Source EM	HQ	Borehole diameter of 96 mm	nT	nanoTesla	UXO	Unexploded ordinance
CVR	Common Voltage Reference	Hz	Hertz = cycles per second	PDA	Personal Data Assistant	V	Volt
DAS	Data acquisition system	IMU	Inertial Measurement Unit	QA	Quality Assurance	VLF	Very Low Frequency
DAQ	DAS	IP	Induced Polarization	QC	Quality Control	VMS	Volcanogenic Massive Sulphide
dB/dt	rate of change of B with time	kHz	kiloHertz	R	Resistivity	VTOL	Vertical Take Off & Landing
DC	Direct Current			SimPEG	Simulation and Parameter Estimation in Geophysics		
DGPS	Differential GPS						

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