Mineral Exploration

Smaller and Smarter – Efficient and Effective Exploration Economics

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SUMMARY

Recent data from the mineral resource exploration industry indicate discovery rates are declining and discovery costs are rising steeply (Richard Schodde, www.minexconsulting.com/publications.html). This, plus the struggle for exploration stocks to attract investment, adds to the challenge of exploration success. There is little doubt the mineral exploration industry is in a state of flux. It is widely believed that most economic near-surface deposits have been discovered and to find the next mine requires new tools and larger budgets. Many more giant mineral deposits undoubtedly exist but they are likely to be buried beneath surface cover. The "*tyranny of depth*" as described by Neil Williams, Geoscience Australia http://www.ga.gov.au/webtemp/image_cache/GA6970.pdf). This century requires exploration tools that can fill exploration needs while delivering both cost effective and time-saving solutions

SkyTEM has engineered the next generation of airborne geophysical electromagnetic systems designed specifically to deliver these solutions. This paper provides case studies to illustrate the economic and technical benefits gained from fast acquisition and delivery of high quality data that can serve to reduce exploration costs while maximizing exploration objectives.

INTRODUCTION

This century has witnessed the influence of knowledge to shape economies and corporations. The knowledge economy can be regarded as the latest stage of development in global economic restructuring and is marked by upheavals in technological innovations. Mineral exploration companies must rely on intellectual capabilities as well as on physical inputs or natural resources to succeed and compete globally and look beyond dated traditional methods to take advantage of new products and processes developed by the research community.

Evolutionary and Revolutionary Technologies for Mining, a study conducted by the National Research Council (https://www.nap.edu/read/10318/chapter/5#23), concluded that drilling generally represents the largest single cost associated with mineral exploration as many hundreds of drill holes may be required to define the boundaries and evaluate the quality of an orebody. The paper also states that decreasing the number of drill holes or increasing directional drilling could significantly reduce the cost of exploration.

Figure 1: The SkyTEM system

Airborne geophysical data can provide valuable input for identification of likely drill targets but acquiring geophysical data can be an expensive exercise. Aircraft costs often represent more than 50% of an airborne survey budget. It is vitally important therefore to retrieve as much information as possible from the data as quickly as possible to enhance the likelihood of exploration success. It is also important in the 21st century to develop resources in environmentally, socially, and economically sustainable ways.
This is where the SkyTEM method, a helicopter-borne time domain electromagnetic system, originates from. Developed by scientists, geophysicists and engineers, SkyTEM is this century's latest breakthrough airborne geophysical technology and is designed to satisfy the growing knowledge and financial needs of the exploration community via extremely quick acquisition and delivery of high quality data from which high value information can be extracted.

Prior to the year 2000 time-domain data was generally available only from fixed wing platforms. In the late 1990's HTEM helicopter transient electromagnetic ("HTEM") systems began to be developed and were able to resolve geology to 400 m depth or more. With this advantage over fixed wing, the market for HTEM grew rapidly. Hitherto, however, HTEM systems have never been able to collect data at the speeds of fixed wing platforms and as a result surveys typically cost more per kilometre of data acquired.

Except SkyTEM systems other high powered HTEM systems with a focus on depth of exploration are incapable of mapping the near surface and subtle or discrete geological changes. Moreover, such systems commonly employ very large carrier frames, which render the acquisition speed and thereby the cost-efficiency low.

SkyTEM systems are engineered to map at least as deep as any of the conventional HTEM systems while offering several innovations that the mineral exploration sector can derive economic benefit from. This paper describes the latest advancements in this ground-breaking technology including quick acquisition and quick delivery of high quality data at speeds approaching fixed wing platforms as well as true versatility for customization and survey cost savings.

"*Innovation is the key to solving the increasing challenges posed by geology, legislation, economics and the need to keep our employees safe. We use it to identify, develop and implement smart step-change technologies that significantly improve how we work.*"

http://www.riotinto.com/documents/Mine_of_The_Future_Brochure.pdf

THE SKYTEM METHOD – ADVANCED TECHNOLOGY AT A TIME WHEN IT IS NEEDED MOST

The 21st century has seen the introduction of the next wave of powerful HTEM systems. Launched in 2004 SkyTEM was developed specifically to map one of the most challenging of targets, buried aquifers. The company has its roots in solving demanding problems through innovation and the fresh thinking applied to the challenge resulted in the engineering of a very different HTEM method for resolving these especially difficult to image targets (Read more about our company history at http://skytem.com/electromagnetic-methods-geophysics/).

Not just a "bump-finder" SkyTEM is able to leverage this recent innovation and delivers images of subtle changes in lithology from the very near surface to depth and at a dramatic increase in data acquisition speeds. SkyTEM is recognized and praised by scientists and governments worldwide as the technically unsurpassed HTEM technology for mapping water resources (read http://skytem.com/wp-content/uploads/Mapping-Groundwater-with-SkyTEM.pdf). For over a decade SkyTEM's high quality data has been used as the foundation for a wide range of earth studies and is now applied globally for mineral exploration as the sector recognizes the exploration and economic advantages.

SkyTEM introduced the first system capable of operating in MultiMoment mode that combines high resolution near surface data (previously only available with helicopter frequency domain (HFDEM) systems) with the ability to map at depths of 400 m or more. This patented innovation allows for discrimination between weak geological contrasts giving a more complete and accurate interpretation of geology while increasing confidence in modelling deeper geological structure by illuminating any links between surface and depth. The other advantages for the exploration sector include:

- Survey speeds up to 150 kph for reduced helicopter hours and time in the field.

- Near real time data. Optional 24-48 hour 1D inversions for quick review of data.
- Dipole moment (NIA) in excess of 1,000,000 with a high signal to noise ratio for deep mapping
- One-time calibration procedure to minimize post-flight corrections for enhanced target and depth accuracy. Raw data is available for critical analysis.
- Ultra-light carbon fibre frames facilitate surveys in hot and humid conditions and increase manoeuvrability in rugged terrain.
- A suite of systems, each customizable for dipole moment, speed, and altitude to suit specific targets and terrain.
- Delivery of calculated B-field, observed IP effect and streamed data.

Partial list of recent mineral exploration clients:

- Rio Tinto
- BHP Billiton
- First Quantum Minerals
- Golder Associates
- Aurora Minerals Group
- Nuna Minerals
- Oban Mining
- SOQUEM
- BHPB Iron Ore
- Sociedade Mineira de Catoca
- Alba Minerals
- Boliden
- Sekaka Diamonds
- TMAC Resources
- Spar Resources
- Geoscience BC
- Avannaa Resources
- Anglo American
- African Nickel
- Noram Ventures
- Graphite One

CASE STUDIES

COST EFFICIENCY – SKYTEM^{FAST} : DECREASE HELICOPTER HOURS, INCREASE SPEED OF ACQUISITION

Typically fixed wing electromagnetic geophysical surveys cost less per line kilometre when compared to helicopter-borne surveys due to the higher rate of data acquisition. A high percentage of the total cost of helicopter-borne surveys is derived from helicopter hours. The challenge to reduce time in the field and increase data acquisition speed is now met with SkyTEM's fast systems, launched in 2015. This heralded the introduction of ultra-light and resilient carbon fibre carrier frames that keep system geometry rigid and stable while in fast flight. One of the first groups to take advantage of SkyTEM^{FAST} was **Geoscience BC** for their Peace Project – a subsurface mapping project designed to collect new information about geology and lithology within an 8,300 square kilometre area in northeast British Columbia. The Peace region of the province has been a focus of petroleum exploration and development since 1952 and participating partner companies included the BC Oil and Gas Commission, ConocoPhillips and Progress Energy as well as several Treaty 8 First Nations.

The main priority of the project was to map the area, comprising some 21,000 line kilometres, in fine detail and to a depth of at least 300 meters. In addition, a major project planning constraint was that the airborne data acquisition had to be completed before the hunting and trapping season began. This required the project to be completed within seven (7) weeks from start up. In order to meet this tight deadline, SkyTEM312^{FAST}, able to operate at up to 150 kph, was

selected for the data acquisition. Over 1,000 line kilometres of data were often collected during a single day, unprecedented in HTEM surveys, with total coverage completed in only forty-three (43) days.

While the initial objective was to map to at least 300 m, SkyTEM312^{FAST} resolved geology in some areas to a depths approaching 500 m.

Data, including 1D inversions, were delivered every 48 hours for quick review of the data throughout the project. One result from access to near real-time data was Geoscience BC's ability to optimize the flight plan with a focus on identified areas of particular interest.

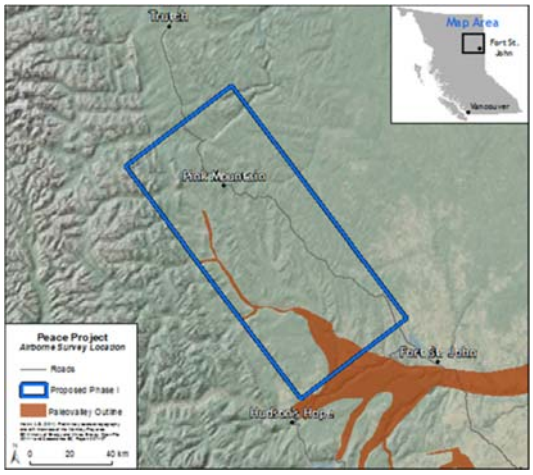

Figure 2: Peace Project Area map

COST EFFICIENCIES FORM NEAR-REAL-TIME ADVANCED DELIVERABLES

By taking full advantage of the rapid increase in acquisition speed and delivery of advanced products, exploration budgets can be reduced in a few ways. The ability to acquire over 1,000 line kilometres of data per day combined with fast data delivery allows exploration managers to consider flying an area regionally, with wide flight line spacing and greatly reduced helicopter hours. Results from each days flying can be reviewed and geological trends and anomalies identified. Areas of interest can be strategically targeted for infill lines or extended flight lines thereby reducing time in the field while maximizing exploration objectives. This is all done in one mobilization with crew and helicopter still on site as data is delivered. The combination of speed of acquisition combined with tactical selection of flight lines contributes not only to efficiency and economic benefits but also to providing exploration management with near real-time data to make appropriate management decisions.

SkyTEM is very robust and can fly in challenging weather and terrain conditions and without an on-board operator. In the Abitibi region of Quebec SkyTEM acquired 10,000 line kilometres of electromagnetic and magnetic data for a gold exploration company using SkyTEM312^{FAST}. The survey, flown during January 2016 in severe winter conditions, was completed safely within a short 3 week schedule.

Carlos Salas (Vice-President Geoscience BC) said:

"*SkyTEM312^{FAST} is an incredibly efficient system, and we are impressed by the great results we have achieved so far. Not only does the SkyTEM system map the near surface we were looking for, it now seems the system has a much greater depth of penetration than we expected for resolving much deeper geology. The ability to review high quality data several times a week was also of benefit to our program.*"

DEPTH OF PENETRATION

One of the more important issues to address in survey design is ensuring selection of an appropriate instrument for data collection. **Geoscience Australia** recently conducted field test to compare results of three helicopter-borne systems, SkyTEM312, SkyTEM312^{FAST} and the VTEM system. The conclusions, found at http://www.publish.csiro.au/ex/pdf/ASEG2016ab302, include *"At depth, there is very good agreement between the three systems.* Plus *"SkyTEM systems have a better resolution in the top 30m"* and *"This resolution is not seen in the VTEM profile."* The ability of SkyTEM to detect the more subtle conductivity contrast due to the geological structure above a deposit is significant in that it may represent an exploration indicator for the location of large deposits at depth. It also provides a shallow drill target to drill exploratory holes. The test also concluded that "*throughout the profile, there is hardly any difference between the two SkyTEM systems."* It can be seen that flying fast does not negatively affect resolution and with double the average daily acquisition of conventional systems flying fast can significantly reduce exploration budgets.

Similar results were obtained at the Caber test site in Quebec, Canada. http://skytem.com/skytem516-caber-deposits. The **Caber North zinc-copper deposit** is particularly suitable for testing helicopter-borne EM system signal-to-noise (SNR) as it is a challenging target and one that conventional ground EM systems have difficulty detecting - difficult because it is buried under more than 300 meters of conductive overburden. To resolve the deposit requires a dipole moment in the range of 1,000,000 NIA and, above all, an exceedingly low noise level. SkyTEM516 and SkyTEM512 (launched in 2014 and now replaced with an equivalent power and lighter weight SkyTEM312) were both proven to successfully detect the Caber North deposit. SkyTEM and only one other larger and heavier TDEM system have mapped the Caber zinc-copper deposit.

The SkyTEM^{FAST} advantage comes from a combination of high dipole moment, calibration, high signal to noise ratio and high depth of penetration and the economic benefits derived from reduced helicopter and crew time in the field.

BEST OF BOTH WORLDS: HIGH DIPOLE MOMENT (NIA) AND HIGH SIGNAL TO NOISE RATIO (SNR)

TMAC Resources conducted a SkyTEM survey in the summer of 2015 over their Hope Bay and Elu gold mining project areas in Nunavut. The survey required the acquisition of 15,000 line kilometres of data to supplement previous exploration carried out on the Greenstone belt. The depth to known mineralization was in the order of 500 m or more so a high-powered SkyTEM system was configured to operate with an NIA of 1,000,000. In Figure 3, the SkyTEM resistivity data (blue) is in good agreement with an area of known mineralization at a depth of approximately 500 m.

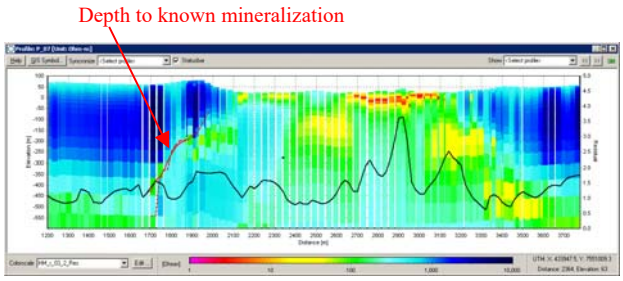

Figure 3: Resistivity data for TMAC Resources

Data courtesy of Aarhus Geophysics

The near surface was also well resolved and the shallow conductive feature (red) is interpreted to be an aquifer. The presence of readily available water in the area can be of benefit to future mine operations, or an environmental/social concern.

Low receiver noise levels play a vital role in identifying **Kimberlite** targets. They can be small with a very subtle resistivity contrast to the surrounding terrain and can remain undetected without accurate, high-resolution data from the very near surface to depth. Since 2014 SkyTEM has acquired over 110,000 line kilometres of data in Angola for diamond exploration company **Sociedade Mineira de Catoca LDA (Catoca)**.

Figure 4 shows kimberlites signatures at various near surface depths.

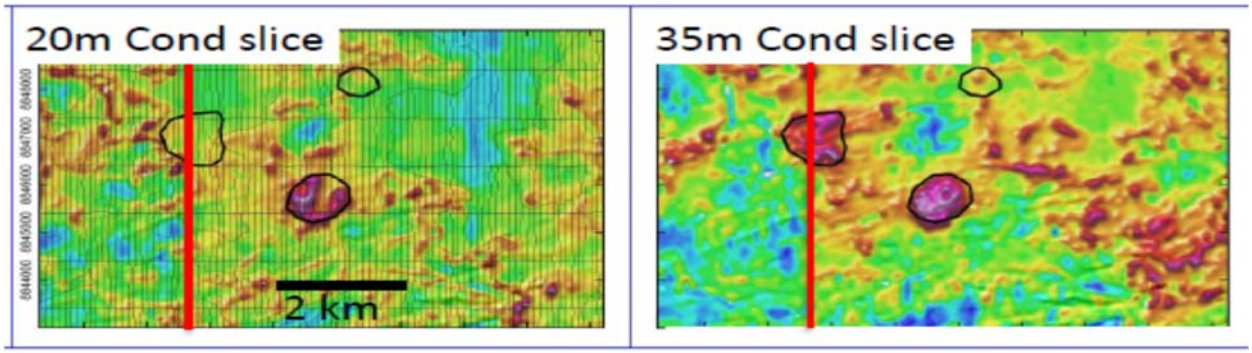

Figure 4: Catoca Kimberlte signatures from SkyTEM data

A paper by Le Roux & Steenkamp (Xcalibur Airborne Geophysics), delivered at the 2014 GSSA Kimberley Diamond Symposium paper, concluded *"One needs exceptional quality airborne data from low-flying state-of-the-art systems to resolve the subtle kimberlite signatures. We thank SkyTEM for the good data…. It is a real pleasure to work with such data!*"

Demand from the mineral exploration sector for high powered TEM systems that map increasingly deeper has been met by high power, single-moment systems that cannot adequately resolve the top 30-40 m due to their 150 *milli*second or greater first time-gate, compared to SkyTEM at 9 ***micro***seconds. Quoting again from Geoscience Australia paper referenced above*: "Moreover, looking closer, it is seen that the SkyTEM systems agree on a very near-surface well conducting layer separated from the one at 20-30m depth by a more resistive zone throughout the profile. This resolution is not seen in the VTEM profile."* Resolving – or not resolving – a potentially valuable target can have a huge impact on any mineral exploration program with a need to reduce drilling costs and maximize exploration success.

CALIBRATION, ACCURACY AND CORRELATION WITH BOREHOLES

A paper by James Reid (Geoforce Pty Ltd), describing SkyTEM results from a **uranium** mapping program said SkyTEM *"has a self-response below the natural noise level, and there is therefore no requirement for drift correction or levelling of the data. A recent SkyTEM survey at Pells Range has yielded results consistent with mapped geology and extensive regional drilling. The survey clearly identified a palaeochannel system within the Moogooloo Sandstone which is associated with known uranium mineralisation, and has provided clear targets for follow-up drilling."* From the abstract found here http://www.publish.csiro.au/ex/ASEG2007ab118

These conclusions are based on two very unique and very crucial characteristics engineered into all SkyTEM systems. (1) the two receiver coils are null-coupled to the primary transmitter resulting in a very high signal to noise ratio (SNR) and little to no bias in the received data and, (2), SkyTEM is a calibrated system. These qualities contribute significantly to data accuracy.

SkyTEM's reduced requirement for repeated high altitude flights during survey operations to check system drift reduces helicopter time while maximizing time spent on the survey line acquiring data. It also means surveys can be flown when cloud cover is low whereas conventional TEM systems wait on the ground to carry out calibration procedures. Additionally data levelling and other post flight manipulation tasks are greatly reduced or eliminated contributing to data reliability facilitating 24-48 hour delivery of preliminary inversions and other advanced products where requested by the client.

SkyTEM is a calibrated system

Denmark has established a national test site for all electromagnetic (EM) instruments including SkyTEM. The Lyngby test-site is recognised as a well-understood site with a well-described earth structure of 5 layers. The accepted electrical structure model of the site acts as the reference model and all SkyTEM systems are calibrated at Lyngby to produce consistent results across the individual electromagnetic (EM) systems in the fleet. Calibration establishes the absolute data level to facilitate precise data processing, modelling and interpretation. SkyTEM systems exhibit little to no system drift, resulting in consistent and comparable data across a property or from year to year.

Graphite One Resources employed SkyTEM to explore for **large flake graphite** over their Graphite Creek property on the Seward Peninsula, Alaska. The SkyTEM data indicated a significant increase in the size of the previously known mineralized area and based on this information Graphite One carried out a sampling and mapping program. The results confirmed the presence of graphite along the trend of conductors mapped and made it possible for Graphite One to increase the length of the known mineralized trend from 5 km to 18 km. A drill program was also carried out to determine the depth of the mineralization exposed at surface. Results from three holes (Figure 5) show an excellent correlation with the resistivity section. This in-field confirmation increased confidence in the accuracy of the inversion, resulting in an HTEM optimised drilling programme.

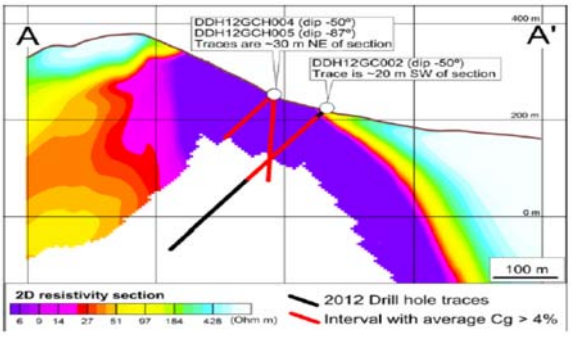

Figure 5: Graphite One Bore hole correlation

SkyTEM's high signal to noise ratio helped **Noram Ventures** discover the highest grades of **graphitic carbon** found at the Company's Jumbo flake-graphite property in the Kootenay region of south-eastern British Columbia. The press release stated "*the discovery was made on the basis of a SkyTEM survey conducted in 2012 and includes the highest grades found to date that are coincident with the strongest and most discrete SkyTEM conductive zones.*" The entire press release can be found at:
http://www.noramventures.com/News_Archive/2016/NRM_PR_06-01-16_Jumbo_Exploration_Update.pdf

SkyTEM will deliver raw data for critical analysis while conventional system providers are reluctant to do so, or simply will not.

The raw EM data are supplied with information about SkyTEM's geometry (e.g., coil con- figurations, currents, effective area, calibration factors, low-pass filters, gate times, and a waveform description), the navigation data (e.g., GPS locations, altitude, and pitch and roll).

TRULY VERSATILE – SMALLER AND SMARTER

As conventional HTEM system focus on increasing the depth of investigation, an easy way to increase dipole moment (NIA) is to increase the transmitter loop area or number of turns of the loop. This has led to increasingly heavier arrays with additional weight leading to larger, more powerful helicopters being required to maintain flight performance characteristics and safety margins. Recent SkyTEM R&D has reduced the size and weight of systems while at the same time increasing the dipole moment (NIA) and the resulting depth of investigation (DOI). All SkyTEM systems are now available on a single 341m^2 rigid and light weight frame platform. This basic building block is then fully customizable for dipole moment and survey speed to suit specific exploration targets or manage safety risks such as hot climates or steep terrain. Just as flight line planning can be modified in the field given near real time data delivery, system specifications can also be modified and customized to maximize exploration results. For example, within a day or less all SkyTEM systems can be changed - from Multi Moment to Single Moment with a focus on late time gates and greater depth of investigation to focus on deeper targets after completing a regional mapping survey, or, to a lighter configuration for flying in rugged terrain at high altitudes if the target area spans from valley floor to the tops of a mountain range.

Some clients may require ultra high-resolution hydrogeological or geotechnical information as well as geological information over different tenements in the area, and rather than deploying two systems, a configurable platform would prove more cost effective. In order to survey such widely differing exploration objectives, other contractors may have to utilize different technologies (FDEM, for example) to achieve the same result as SkyTEM. In addition, comparison of results obtained by these differing systems often makes for a more complex interpretation task.

"I had the opportunity to perform QA/QC checks on SkyTEM's preliminary data and found it to be consistent and of high quality. SkyTEM maintained excellent communication with me throughout data acquisition and delivered the data electronically in a time fashion as required in the contract"

Mel Best, President, Bemex Consulting.

"SkyTEM completed an extensive survey over rugged terrain in the SW US while holding closely to the survey specifications. The data quality was maintained as very good to excellent. The combined two frequency system mapped the project geology from the very near surface to 300+m depth. Several geologic features that were unknown were mapped quite well. In addition a few areas where the expected geology was not found were defined as targets of interest. The combined magnetic and EM data was instrumental in mapping and target definition."

Frank Fritz, Consulting Geophysicist

COMMUNITY AND ENVIRONMENT

Mining is a complex and intensive process that causes environmental and social change no matter where it occurs. Mining-related disruptions impact the physical environment (through, for instance, loss of habitat and contamination of surface and ground waters) and local communities (through, for instance, displacement of livelihoods and cultural impacts). Negative social and environmental impacts are avoidable if companies operate according to the best possible standards. Elements of such responsible mining practices include Corporate Social Responsibility (CSR) - something all mineral exploration and mining companies are becoming increasingly aware of to help build and maintain productive relations with the local communities.

Figure 6: Carlos Salas, VP, Geoscience BC reviews flight plans with local First Nations people

The earlier described Geoscience BC (GBC) Peace Project covered a vast area of northern British Columbia and included land owned by various First Nations. Care had to be taken to properly plan and communicate with local people regularly throughout the airborne survey.

Upon survey completion Reg Whitten, Community Relations Consultant on the project stated, *"In my role as community relations consultant for Geoscience in support of the Peace project, I can say that SkyTEM maintained excellent communication regarding field logistics. They were responsive to changes in flight planning to recognize First Nation community and traditional-use activities by implementing temporary no-fly zones. They were very cooperative in finding solutions and communicating changes to allow contingency plans to be quickly developed. This resulted in optimal survey coverage and timely data acquisition. SkyTEM and its partners also hosted a barbecue and a show-and tell for local communities to attend and provided an opportunity for them to see the helicopter and geophysical equipment and have questions or concerns addressed to their satisfaction. The team also accommodated additional requests for flying areas of special interest to support their water and land management planning objectives."*

GLOBAL SERVICES

SkyTEM has collected data on all seven continents and has offices and partners around the world. Please visit our website to learn more about SkyTEM people, technology and projects and to find an office near you.

http://www.skytem.com

Figure 7: Each blue dot represents a SkyTEM survey completed

Figure 8: SkyTEM Global HQ in Denmark