The end of the Bronze Age for IP surveys

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ABSTRACT

During the past decade, significant improvements have been made relating to Resistivity and Induced Polarization (IP) surveying, largely due to more flexible instrumentation and software, full wave recording, GPS synchronisation amongst others. Such developments have allowed new ways of organizing transmitter and receiver dipoles resulting in very flexible arrays and methods providing better signal, coverage and processing options than previously available. Geophysicists are now able to be more creative in designing arrays to meet targeting and budgetary aims and overcome difficult surveying conditions. The collection of accurately synchronised full wave data alone provides improved capability to remove noise, glean additional data, interpret unwanted effects and improve data quality.

3D AND OTHER ARRAY TYPES

The key changes in the IP and resistivity method in the last 10 years have come from the development of instrumentation and software that allows achievable flexibility in data collection and interpretation. Into the early 2000's, many IP surveys tended to follow a very standard collinear design with very similar dipole spacing and n-spacing (depth). They were largely dictated by the number of channels available on a receiver, strength of primary signal or practicality in deploying wires over long distances. The last 10 years has seen the relative cost per channel of receivers drop significantly. This has provided geophysicists a vastly increased array of options: from receivers with many channels, to those with single or few channels for distributed use. Improved access to high quality recording hardware and modelling codes have led to a widespread push to increase the number of deployed channels which has led to examples such as the Search 96-channel IP receiver (Search) to the single channel DIAS32 receiver (Dias).

Perhaps the most significant improvement to survey design is that of increased flexibility in receiver placement. The availability of higher number of receiver channels, increased power or distributed systems meant that survey design became limited only by useable signal strength. Geophysicists are now able to plan and execute a survey that captures both desired resolution, increased depth and target geometry (offset arrays). The ease of placing significant numbers of receiving electrodes over the survey area led to improved resolution, depth of investigation, 3D data collection and subsequently more realistic modelling.

During the same period of time, significant improvements have been achieved regarding resistivity / IP data (DCIP) inversion. Thanks to significant advances with global computational capabilities, numerical inversion is now easily accessible and commonly used to generate a 3D image of the resistivity and chargeability's distribution underground. The increased computational capabilities and availability of more algorithms and software (such as DC3DIP (UBC), RES3DINV (Geotomo), VOXI (Geosoft), ZonRes3d (Zond), ERTlab64 (MPT)) have played a significant role in helping geoscientists enhancing their geophysical data compilation, refining their targeting sessions and increasing their drilling success rate. But most of all, the capability of running three-dimension DCIP inversion has also had a significant impact on the way data is now collected in the field. Geophysicists have rapidly realised that running a 3D inversion over a 2D dataset in some instances would not yield improved models and may in some cases created artefact and false anomalous signatures.

The greater access to 3D inversion has definitely driven the service companies and indirectly, the manufacturers, for practical survey flexibility in order to better constrain these 3D models. This is now commonly done using offset arrays which, to varying degrees, better constrain off-line responses when compared to collinear surveying (Figure 1). Co-parallel or "offset" configurations with transmitter and receiver electrodes often on parallel lines offer an increased sensitivity between the four (4) active electrodes and have become more conventional nowadays.

The offering of offset geometries allowing improved 3D interpretation is now commonplace and most or all contractors are now likely to be capable of providing this. 2D or collinear surveying continues to be an important tool for early target evaluation however, the costs of performing 3D surveying and the experience required to plan and perform them efficiently has improved considerably. 2D surveying is still commonly performed and the resolution and depth of investigation for collinear arrays have also improved considerably.

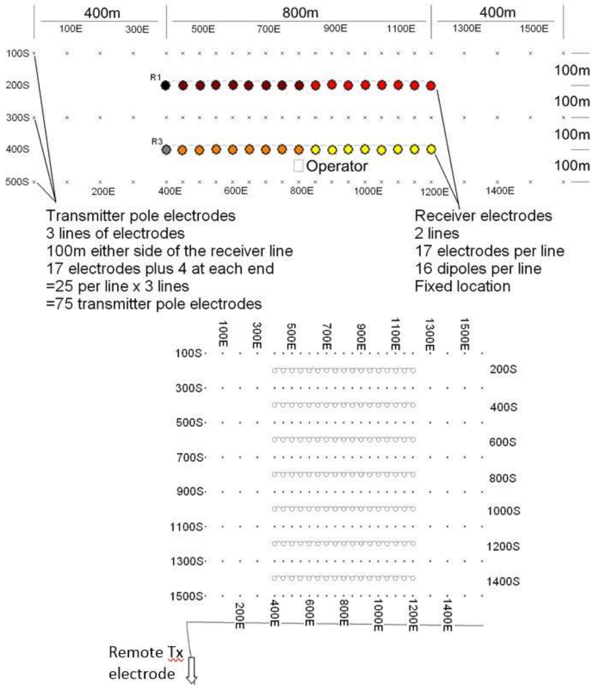

Figure 1. Example of an offset Resistivity / IP survey configuration

Early development of distributed systems has led the way since the early 2000’s and over the last 10 years, the exploration industry has seen numerous distributed receiver systems developed for IP acquisition (see "Full wave Recording" section). In some instances, these instruments, due to their longer term deployment and sufficiently sampled time series recording, are also suitable for MT (or EM) acquisition albeit with often spatially sparse magnetic field measurements. The benefits of a distributed system include survey flexibility in positioning, less complicated wiring and efficiencies at larger scales. Nevertheless, multichannel receivers (such as the GRx8-32 receiver from Instrumentation GDD) continue to have a strong presence in IP surveying. The use of efficient multicore cabling and the recent introduction of switching systems for Rx electrodes, commonly used for smaller-scale environmental surveys (e.g. Iris Instrument), also provide excellent survey efficiency and real time operator feedback on incoming data.

The last 10 years has also seen the offering of very large scale IP arrays generally in the form of gradient arrays. High power transmitters, usually in excess of 50kW are used to energise a dipole many kilometres in size (may be over 20 km) which provides both a deeper flow of primary current as well as a very large area over which efficient data collection is possible. Other means of efficient surveying over large areas include existing vector or reconnaissance IP methods. Large dipoles pose specific safety issues and may lead to significant EM coupling in some cases.

GPS SYNCHRONIZATION

There are many ways to synchronize one or more receivers to the signal of a transmitter: with a direct cable connection, through Radio-Frequency (RF) signal, using crystal clock timing or by automatic recognition of incoming transmitter signal. Commonly, resistivity / IP receivers have achieved synchronization by sensing the transmitter ground signal. Signal recognition algorithms in the receiver allow accurate identification of the beginning of the transmission cycle which is key to correctly recording secondary voltages (Vs) and calculation of chargeability. About a decade ago, evolving technologies have allowed the introduction of GPS synchronization between receivers and transmitters.

GPS synchronisation implies that both the transmitter and the receiver are synchronised to the same time reference (e.g. UTC time). To achieve this, they both need to be equipped with a GPS module and to detect enough signal from satellites. Once the GPS time is caught and the instruments locked, GPS synchronization is achieved. Some systems will use a backup crystal clock to ensure synchronisation remains stable when the signal from the satellites is interrupted (e.g. in dense forest, hilly terrains or underground surveys).

TEM and MT acquisition systems have been equipped with GPS timing for some time due to the need for precise timing of higher frequency signal and this has been more recently adopted in IP hardware development. Note that GPS time stamped data does not imply that the DCIP survey was carried out using GPS synchronisation, but simplifies processing possibilities. As an example, the removal of telluric noise using a remote reference station, at which the Tx signal should not be detected, requires a GPS time reference.

FULL WAVE RECORDING

As opposed to “processed” data, full waveform or time-series refers to the complete raw signal measured at the receiver (i.e. every electrical potential signal digitized at a relatively high sample rate). Ten years ago, data was generally filtered, binned and averaged by the receiver before being recorded to memory for later processing. Limited QA/QC and noise analysis can be achieved from this receiver processed data. Qualifying the noise from these final binned output values does not allow evaluating and determining its frequency and amplitude. In absence of time series, the best way to define and eliminate noise is to increase the amount of stacking to cancel some of it through statistics and to repeat readings for at a given survey station and discard the noisier repetitions.

Having access to the full waveform of measured primary and secondary voltages, grants geophysicists the possibility of thoroughly visualizing entire acquisitions, editing, re-computing and enhancing final apparent resistivity and chargeability. As simple examples, one may want to re-window the secondary voltage (integrate for Mx) of a given survey to compare two historical IP datasets, improve the overall data quality by discarding noisy half-cycles, enhance final apparent resistivity calculation using real-time current measurement when using a non-current controlled transmitter (see "Current Monitoring" section). The removal of coherent noise, lightning spikes, timing errors, operator error, transmitter dropout and many other problems are reasonably easy to fix using full wave data and in some cases may mean the difference between useable and unusable data.

Access to full wave recording has become commonplace within IP receivers in the last 10 years (e.g. Instrumentation GDD, Iris Instrument, Zonge International, etc) and capability is now approaching the sophistication that has been available for EM or MT applications for some time. On the other hand, as opposed to on-time EM data, inversion and modelling of full wave IP data does not appear to be available yet. Will on-time modelling and full wave IP inversion become accessible in the coming decade?

Accurate timing and recording of full wave data allows additional information to be gleaned from IP time series and utilising all of these data will likely be a focus for future development. Additional information includes EM coupling produced by inductive processes resulting from current injection and telluric signals from atmospheric or solar sources that are almost always present in IP data but have traditionally been a nuisance. The next 10 years may see these data used routinely to improve the value and interpretability of IP survey data. Figure 2 shows a four-channel raw IP time series containing both EM coupling and telluric signal.

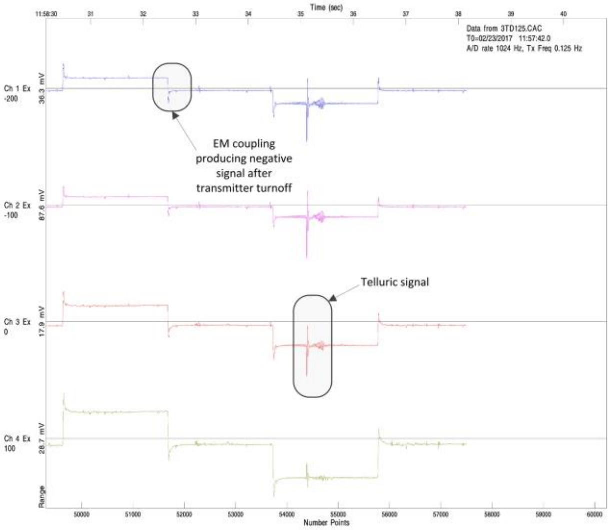

Figure 2 Raw IP time series showing clear EM coupling and telluric signal

The following is a list (not exhaustive) of some ongoing work (as yet unpublished) or developments made possible with full wave data recording:

Dipole summing: a method of collecting and processing full wave data from electrodes (with common reference) to calculate the dipole response from integer multiples of the electrode spacing: e.g. 100m, 200m and 300m dipoles from 100m spaced electrodes (Search, Dias). This can be very useful if signal strength is poor from dipoles of the desired spacing. This also provides high data redundancy and density.

Telluric correction: the method of recording remote magnetic or electric field data, free from primary transmitter signal in order to model and remove unwanted telluric signal. Figure 3 shows an example of time series treated using the method developed by SouthernRock Geophysics.

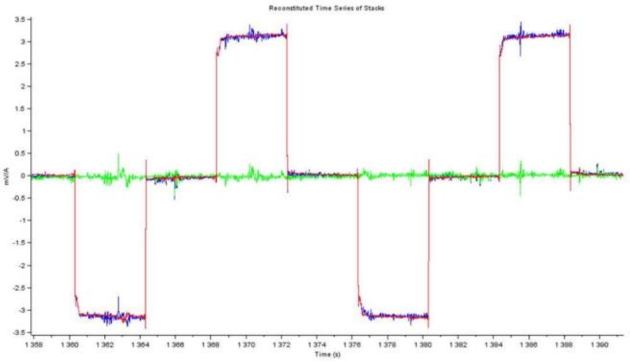

Figure 3 Example of Pole-Dipole data with raw E-field data (blue), modelled telluric component (green) and corrected E-field data (red).

Extraction of both time and frequency-domain IP measurements from one time series, 50% or 100% duty cycle: Historically, a receiver would record time-domain decay or frequency domain phase shifts, full wave data allows both to be calculated. Figure 4 presents a plot of an FFT IP spectra from a time-domain acquisition, highlighting that most of the energy mainly lies between the transmitter base frequency and approximately 10Hz.

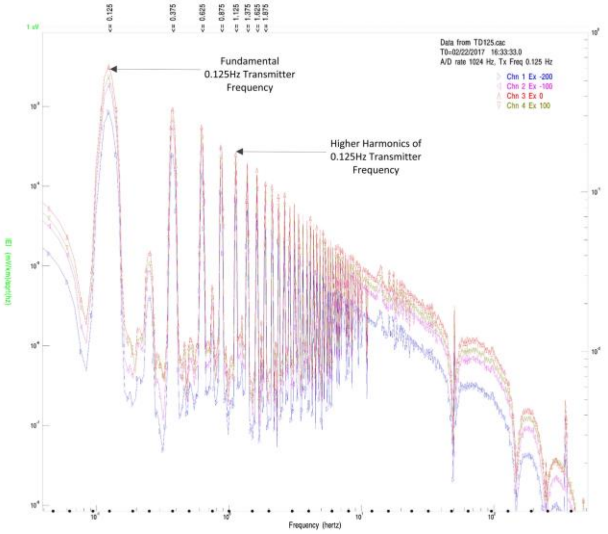

Figure 4 Example of IP spectra from Fourier Transform of a time-domain acquisition

If an IP time series is sampled at high enough sample rate, then it is likely to have also captured EM coupling and telluric signals of sufficient bandwidth for analysis. Figure 5 shows an example of raw IP time series sampled at 32 kHz and resulting telluric signal with filtering of primary transmitter signal (hardware and software developed by Zonge International, data collection and processing by Zonge Australia).

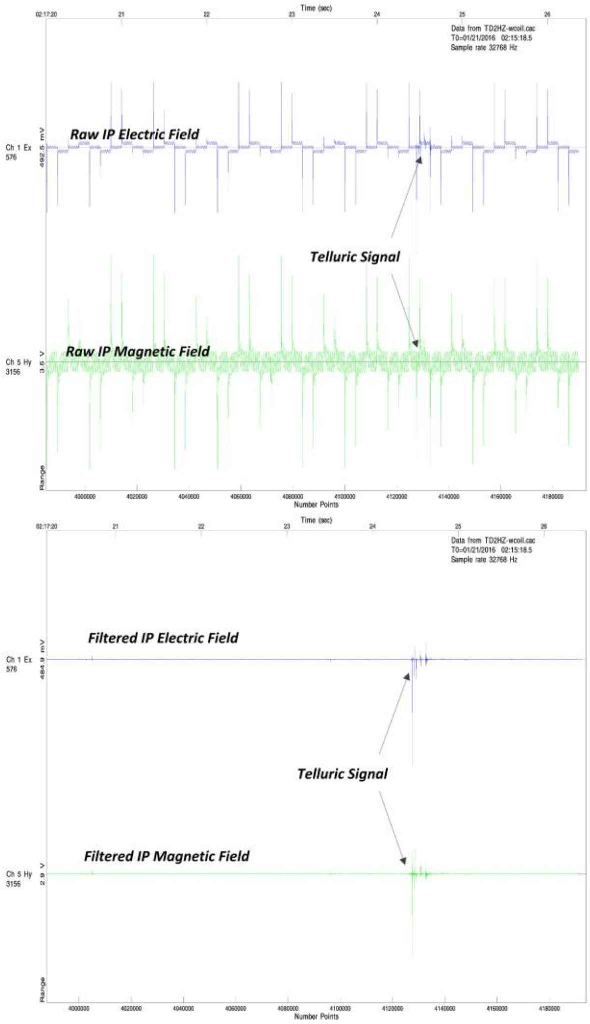

Figure 5 Raw Gradient Array electric and magnetic field IP time series (top) with primary transmitter signal filtered to extract electric and magnetic telluric signal (bottom).

There is a trend observed in the past decade with resistivity and IP surveys: geophysical contractors are developing proprietary acquisition systems to collect raw data. The logging system allows from 1 to 6 channels and is light and portable. In the field, the unprocessed data is being acquired and stored for hours and then harvested at the end of the survey day (or longer) for processing. The key to this survey method is to ensure good stable electrode contacts and steady wire connection throughout the spread of poles or dipoles over the recording period. Then, at the base of operation, using in-house processing software, the geophysicist will review the time series, clean the raw data, compute the resistivity and chargeability and ultimately, start interpreting. Therefore, efforts in the field are put on increasing productivity and survey coverage, where daily expenses are significant. Processing is then left to a single-person job and computer at the office. This way of separating data acquisition from processing is not new. Originally, acquisition systems dedicated for seismic and MT surveys have been developed as such. In the mid-90's, M.I.M. Exploration (MIMdas, now operated by GRS) and Quantec Geoscience (Titan-24) initiated the Resistivity / IP development of multichannel acquisition systems (Boivin, 2007), which operate in this manner.

Among the resistivity / IP systems recently developed following this philosophy, the DIAS32 DCIP system (Dias) consists in a single pole, common voltage reference, acquisition system developed in 2014. A spread of any number of single-channel receivers (hundreds or even thousands if available) is deployed and GPS-synchronized to the transmitter. Mesh networking technology provides real-time monitoring of system health and data quality via radio-frequency (RF). The full waveform Vp acquired is fully processed at the base of operation afterwards.

The development of the Volterra system (SJ Geophysics) started in 2004 and was finalized in 2011. It consists of a 4-channel system adapted for IP, MT and EM surveys allowing a wide variety of 2D and 3D applications. The raw data is stored in a memory stick and harvested at the end of the day. One field operator will control 5 to 8 units, synchronized by GPS.

In 2007, Quantec launched its DC/IP distributed array system: Orion. For 3D surveys, the 6-channel units are spread using 50-100-200m dipoles spacing for a total of 300 dipoles. Each unit, GPS-synchronised to the transmitter, will record the time series and be harvested at the end of the survey day.

The gDAS-24 from SouthernRock Geophysics (since 2012) for which each 4-channel receiver records time series data for MT and IP processing uses GPS timing and slaved crystal oscillators to allow post acquisition processing. Field data is recorded and periodically backed-up to a solid-state memory drive and data is later downloaded to a PC for processing.

Similarly, manufacturers of geophysical equipment have developed logging receiving instruments suitable for distributed configurations (Iris Instrument, Phoenix, Zonge International). The next 10 years is likely to see both multichannel and distributed receivers in common use and the trend toward gleaning additional data from time series data will develop further.

CURRENT MONITORING

In all active galvanic or inductive geophysical methods, a known transmitted current is key for recording and interpreting data correctly: e.g. to calculate the correct apparent resistivity. Geophysical transmitters may be non-current controlled or current controlled, with the former providing stable voltage output and the latter directly controlling output current and allowing voltage to vary. In stable transmitting conditions (i.e.

constant load) both would provide the same result: a known output current over the duration of data collection. If transmitting conditions change, a variation in output current will occur for non-current controlled transmitters. The variation may be small in which case the change in recorded data may be negligible. In some IP operating conditions however, particularly highly resistive grounds (ice, sand, gravel, etc.) or using small surface area electrodes (e.g. stakes) at high voltage, the variation can be significant and must be accounted for. When using pole transmitting configuration, the current monitoring at the transmitter and infinite electrode may also be useful to detect leakage from cable to ground causing unreliable readings and posing a safety hazard.

The incorporation of GPS and full wave recording into both receiver and transmitter hardware allows output current to be accurately combined with the recorded voltages. Figure 6 shows an example of a full wave IP acquisition with corresponding real-time GPS stamped transmitted current (hardware and software developed by Instrumentation GDD). For distributed systems, even those that utilise current controlled output, this is critical so that the correct current is applied in processing. For non-current controlled transmitters in unstable transmitting conditions, this is an important development and allows more accurate results.

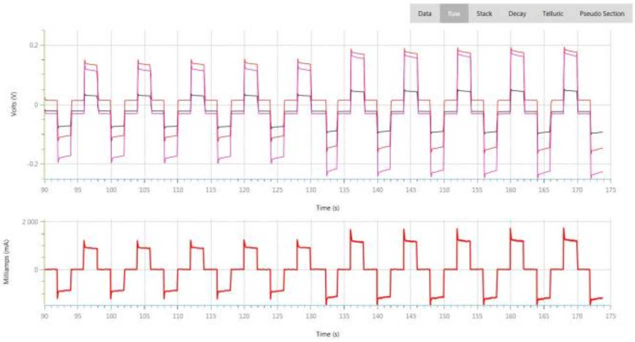

Figure 6 Example of a full wave IP acquisition (top) with corresponding real-time transmitted current (bottom) showing a shift in injected current at 135 sec.

SAFETY

The change in safety culture and standards, globally over the past 10 years has been significant and mining and exploration is no exception. This change is highly visible with the often mandatory use of high visibility workwear, signage, personal protective equipment (PPE) and procedures in many workplaces. The mineral exploration industry has to some degree enjoyed a lack of oversight and close inspection from regulatory bodies, possibly due to the generally limited danger to the general public and often specialised, low volume and remote nature of the work. This lack of oversight has led to a lack of coherent standards worldwide and on the national level with respect to training requirements, procedures and equipment safeguards for IP surveying.

Although IP surveying presents many safety challenges including extreme conditions, driving long distances, difficult manual effort and many others, the electrical energy used is the most notable IP specific hazard. In this regard, transmitting equipment is now routinely equipped with open circuit protection, emergency shutdown buttons and clear earthing instructions. Additional features include wireless operation and status updates to field staff to reduce the hazards of transmitted voltages. Resistivity / IP (and TEM) transmitter output power, voltage and current limits have all increased during the last decade. Nowadays, the capabilities of newer systems such as the HPTX (Gap Geophysics) and the Typhoon (HPX) transmitters, just like those of older transmitters such as the T-200 (Phoenix), raise legitimate safety concerns and require much higher specification cable than previously seen (see "Transmitter Developments" section). The use of very high currents at the moving injection site requires very well constructed electrodes and bare or exposed transmitter electrodes are no longer ideal.

Within the past 10 years, government scrutiny within Australia (and likely other places) has raised questions over safety with respect to IP practices (and electrical geophysics in general) and under what existing standards it should be regulated. The Ground Geophysical Survey Safety Association (GGSSA) was formed in 2011 with the aim of developing industry guidelines for ground geophysical surveys. The formation of the association was in response to concerns by the government of New South Wales around electrical ground surveys and the failure to adhere to NSW State Legislation and Australian Standards AS/NZ 3000 & AS3007, particularly with electrical protection, and isolation and insulation. Since its inception, GGSSA has grown to 36 members and expanded from Australia to include companies across the globe. The purpose of the association is to monitor risks and incidents associated with ground geophysical survey activities, and to encourage members to take a proactive approach to safety. In the last two years GGSSA has noticed the incident rate has decreased, and the most common failures involve vehicles, Standard Operating Procedures and electrical incidents.

ELECTRODES AND POTS

There have been limited changes to receiver or transmitter electrodes over the past decade. Both non-polarizable stainless steel electrodes and porous pots have remained basically the same over the past decade. The key criteria remains the same: to establish good, constant electrical contact with the ground. This notably contrasts with the major advances that have occurred with Electromagnetic (EM) sensors in the past ten years. Just to name a few, low-temperature and high-temperature Superconductive Quantum Interference Devices (SQUIDs), feedback coils and inductive magnetometers have pushed the limit of detection of a wide variety of conductive targets buried at greater depths than ever.

The main challenge with porous pots remains their maintenance. After one year, they dry out, their resistance increases, generate extra noise and are no longer usable. Phoenix Ltd has recently improved their pots' compound allowing them to absorb the ionic solution, preventing leakages. Their porous pots now last more than 2 years and can be re-hydrated to extend their duration even longer. Walcer Geophysics porous pot electrodes also include a new type of porous disk which reduces the contact resistance to the ground.

Developments and application of capacitive coupled sensors for electric field measurements may present an alternative to conventional galvanic electrodes (Zhiyu, W. et al., 2016) for some applications. GroundMetrics and Geomatrix promote their development of such sensors. These do not suffer maintenance and contact resistance issues encountered by conventional non-polarizable electrodes. However, published case studies have not been found and performance at lower frequencies often used for IP/resistivity surveying is thus uncertain. Their applicability for resistivity surveying in resistive conditions, towed applications or where it is impractical to install electrodes is promising.

DATA PRECISION

In the past 10 years, analogue to digital converter (ADC) resolution has increased from a standard 16 bits to 24 bits and in the case of the Zonge International ZEN system 32 bits is available. In addition, ADC and Control Processor Units (CPU) are now much faster and are commonly able to reach a sampling rate higher than 1 MHz. For IP surveys this is perhaps less important than it has been for EM and MT data where signal is inherently smaller. When considered with full wave recording however, the wider dynamic range offered by 24-bit resolution allows improved faithful capturing of transmitter on-time as well as significantly smaller decay magnitudes. Higher resolution also allows reduced gains to be used without affecting signal resolution and reducing the likelihood of saturation due to tellurics, SP or other unwanted drift. Ultimately, a fast ADC combined with high resolution will require a lot of power, directly impacting on the receiver battery life.

Ten years ago, most of the available IP receivers were sampling data at 100 Hz or so. Multipurpose receivers designed for TEM and MT as well as IP, offered higher sampling rates, but with IP effects known to be “slow”, there seemed to be no real need for improvements. The bandwidth required to faithfully capture IP and resistivity data is relatively small (0.1-10 Hz in most cases) compared to EM and MT methods, and the sample rates used by IP receivers over the last 10 years has generally remained below that seen offered by EM and MT instrumentation. Multipurpose receivers developed over the past 10 years such as the EMIT SMARTem24 and Zonge International GDP3224 allow variable sample rates including much higher rates. This may become important over the next decade as users attempt to extract EM and MT data from these time series. However, adverse implications of faster sampling are significant, as file size rapidly becomes impractical and fast sampling is often technically difficult on the large number of channels used for modern IP surveys.

In recent years, a lot of attention has been paid to understanding and explaining “IP effects” measured from airborne TEM surveys. Geophysicists are still working on relating these to geological units and ideally, to sulfides. One of the challenges arising is that these “IP effects” are observed in the late-time windows of TEM decays collected at 30 Hz base frequency. On the other hand, ground IP surveys are collected at a much lower repetition rate, typically 0.125 Hz. Even though some case studies presented recently have shown coincident IP responses from airborne TEM and ground IP surveys, direct correlation of these responses has to be made with care. So far, the geological explanations for these “IP effects” have been limited to large scale occurrences of small grain magnetite and clay (Kaminsky, et al., 2017 and Kwan, et al., 2015).

TRANSMITTER DEVELOPMENTS

Numerous companies have developed their own transmitters over the past 10 years. The driver behind this is often the need for regionally appropriate transmitting capability and the desire for more powerful, cleaner and faster IP systems. In many cases these transmitters have offered higher power, however total available power can only be used if the output voltages and current ranges are appropriate for the operating conditions. Thus, new transmitters often have these ranges “tuned” for specific conditions (e.g. Instrumentation GDD’s 4800V transmitters for resistive conditions). Very high power systems (up to 250kVA) with high current capability have been developed for deep exploration using very large transmitter dipoles, with low contact resistance and heavy cabling.

PHYSICAL ROCK PROPERTIES MEASUREMENTS

Another aspect related to Resistivity / IP instrumentation is the recent development of small Tx-Rx units or receiver options allowing the measurement of apparent resistivity and chargeability on rock samples and core. There is definitely a growing interest nowadays within the exploration industry to characterise the geophysical signature of geological targets and their surrounding environment. Either earlier in the process to optimise a geophysical data acquisition, or afterwards to constrain a 2D or 3D inversion, physical rock property measurements are now more commonly a key component of IP / resistivity surveys. For practical reasons, downhole in-situ logging is unfortunately still not routinely carried out and post-drilling lab measurements remain a good alternative to acquire the data. While some IP receivers can be coupled to external low power Tx device, Instrumentation GDD (SCIP Tester) and more recently, Terraplus (KT-20), have designed portable units allowing rock sample resistivity and chargeability measurements.

CONCLUSION

Resistivity and Induced Polarisation surveys, instrumentation and modelling have greatly evolved during the past decade. 2D surveying will continue to be a staple tool for target evaluation, however more exploration projects will benefit from co-parallel or “offset” configurations survey coverage and 3D modelling. With access to the full wave time series, GPS synchronization, more powerful transmitters and faster receivers, it seems the time has come to proclaim the end of the Bronze Age for IP surveys.

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