IP Workshop abstracts

Electrical conduction in 3D - common misunderstandings - transmitter setup considerations
- Steve Collins

The electric potentials in a typical survey due to IP transmitter (Tx) electrodes are not well understood by many of those actually operating the survey. There is a strong tendency to make Tx electrodes in the same fashion as last time and the time before that without any question as to whether the survey operation could be improved and made safer by modifying the design of the electrodes. The total resistance of the Tx circuit is said to be the wire resistance plus the earth resistance plus the contact resistance but in reality the last two terms have no meaning. Old wife's tales abound in practical IP surveying.

Over many years a systematic plan of measuring the resistance of real field electrodes has been undertaken. This has confirmed many of the standard rules for making Tx electrodes but has also created some surprises. There are lessons to be learnt for both the manufacturers of IP transmitters and the operators of real IP surveys.

Receiver design and receiver electrode noise considerations
- Terry Richie

Recording high quality IP data for deep exploration is an exercise in maximizing the data signal to noise ratio (S/N). The obvious option of increasing signal has often been discussed. This presentation will focus on how that increase can be achieved by concentrating on lowering the noise levels at the electrodes and at other specific stages in the data processing.

Examples of the S/N levels required for exploration under cover will be given using both model and actual data.

Data collection and initial processing
- John Paine

There has been a growing shift towards using IP receivers which record full time-series data. While such receivers can be more difficult to operate, they provide a much better understanding of the data being collected in the field and allow much more flexibility in the processing used to generate the IP decay. This has improved the data collection process itself and also resulted in improved data quality when compared to traditional receivers which use fixed in-built noise reduction algorithms to generate windowed IP decays. An added bonus is that the retention of the full time-series recording allows for the data to be reprocessed to fix problems missed in the field and also test new processing techniques as they are developed.

When collecting data in the field, the operator sees the time series data and can immediately identify problems such as misconnected wires, poor connections at pots and difficulties due to various noise sources. Some of these can be fixed immediately by the operator while others can be addressed by post-processing the time series data to either eliminate or reduce the effect of noise due to things like bad cycles, tellurics and negative EM coupling.

This talk will present examples of real times series showing a variety of problems and noise encountered in the field and display the benefits available from being able to control how the data is processed.

EM coupling - is it a problem?

- Peter Fullagar

Electromagnetic (EM) coupling refers to inductive responses in IP data sets, i.e. signals unrelated to electrical polarisation.

EM coupling is well understood insofar as it is aggravated by

1. increasing conductivity
2. higher frequency (or earlier times)
3. increasing dipole size
4. increasing dipole separation
5. parallel wires, and
6. any layout of wires which inadvertently couples well with conductors.

EM coupling can either be regarded as noise, to be avoided or corrected, or regarded as signal, to be interpreted.

Standard practice is to regard EM coupling as noise. Frequency domain data are usually “de-coupled” and time domain data are usually discarded before a certain delay time. These procedures are well-established, but not failsafe.

Treating EM coupling as a component in the measured response is arguably more desirable in principle, but interpreting “EM” and “IP” simultaneously, i.e. generating 3D spectral conductivity models, remains challenging in practice.

Introduction to survey geometries

- Steve Collins

There is a tendency to for geophysicists to have a "preferred" IP survey geometry and to mindlessly use that survey type in all situations. However, there are many criteria that determine the optimal survey type for a particular prospect. The following are some of the criteria that will be considered in this session.

1. Signal strength at the receiver can large Rx to Tx separations be attained without dragging around a small power station in the field and evaporating tons of groundwater. Here pole-pole excels.

2. Direction of current flow beneath the receiver locations. Is this always constant or are there a variety of transmitter current directions to assist the inversions in 3D. Here gradient array gets the wooden spoon.

3. Logistics

a. Is the system setup so complex that feral animals have destroyed the first part of the setup before the last part is complete? What are the implications for continuing the survey should one remote part of the setup be compromised due to external interference (animals or curious locals) - does a small problem at a remote site result in the whole survey crew sitting on their backsides for a couple of hours while the problem is located? How easy is it to determine where a problem lies? Here generalised 3D surveys may be inappropriate.

b. How much manpower is required to run the survey?

c. How difficult is it to setup? Dipole-dipole and gradient arrays may be best per square km.

d. How difficult is it to train local helpers to assist in the running of the survey? Gradient array wins.

e. Is there a safety issue with high voltages on long wires. Pole transmitters are a problem here.

f. Is the use of dipole receivers or transmitters applying a high pass spatial filter to the data preventing detection of deeper sources? Pole-pole wins again.

g. How easy is the setup in difficult terrain with no vehicle access? Cut lines in jungle or rocky steep ground.

h. Can the survey spread be quickly put in a state where it can be safely left overnight in areas with curious nocturnal, sharp teethed wildlife.

4. How susceptible is the geometry to EM coupling? Dipole-dipole is best here except that for this geometry the coupling is always of the same sign (positive) as the IP response and may be indistinguishable from it.
5. How likely is it that receiver dipoles lie near a transmitter equipotential and thus have errors associated with low primary voltage. Offset dipole-dipole may have a problem here. This problem does not occur with inline surveys.
6. How susceptible is the receiver dipole to telluric noise and sferics? Long receiver dipoles may lose out because the telluric noise increases almost linearly with dipole length but the IP signal increases more slowly. Pole-pole has this problem.
7. What is the cost per square kilometre?

When the Offset Pole-dipole array was first devised the criteria were:- It should use as many receiver (Rx) channels as was practical for survey efficiency, it should have large Tx-Rx separations for deep penetration, it should have as many Tx current directions as possible below each Rx station to improve 3D modelling and it should be efficient in layout so that it could be packed up at night to avoid damage by animals.

The survey geometry achieves the first three of these but the fourth criterion is difficult to achieve in practice. Never the less it remains a very efficient means for collecting large quantities of IP data with reasonable effort and cost.

Dipole Dipole

- Simon Mann

The collinear Dipole-Dipole Induced Polarisation (DDIP) survey method has been a very widely (and successfully) used tool for mineral explorers for decades. The use of more flexible multi-channel receivers and greater transmitter power in more recent years has led to DDIP being applied in more and more challenging conditions in a variety of ways.

DDIP surveying presents numerous technical advantages over other array types including reduced EM coupling, symmetry of response, high lateral resolution and ease of manual and operator interpretation. This latter aspect has always been important for quality data collection whether due to lack of accessible inverse modelling in early days or through the addition of many channels and complicated collection methods in modern times. Due to the limited transmitter dipole size, in many instances DDIP provides simpler logistics, faster setup times and considerable safety benefits.

Those planning, conducting and interpreting DDIP data do however need to be aware of the limitations and issues that may arise from use of this configuration. Of particular note is the reduced signal strength and sensitivity at higher Tx-Rx separations when compared to other geometries.

Offset Dipole Dipole

- Kim Frankcombe

The Offset Dipole-dipole (ODD) array evolved from the Offset Pole-dipole (OPD) array described by Collins and White to better handle Western Australian conditions. In particular is suffers less from EM coupling problems and has few issues with potential electrodes falling on equipotentials. In some environments it can lead to greater signal at the receiver compared to OPD, although this is not generally the case. In locations such as PNG and Indonesia where running a 3km long live wire out to a remote pole requires a considerable logistical effort to guard against the accidental electrocution of locals or in other places where animals are likely to attack the wire the dipole transmitter offers enhancements in safety and productivity.

As with OPD it can be laid read and pulled in a day although this is rarely achieved in practice.

Combined inline/offset bipole-dipole
- Alex Copeland

If you are recording on offset Rx lines, why not record on the Tx line as well to receive data when recording 3D offset surveys!
What is true 3D?
When does trying to take a reading on an equipotential become a real problem.
A few examples will be presented of noise recorded in full waveform data over the last decade.

Full 3D surveying
- Roger Sharpe

We will examine some benefits of measuring 300 receiver channels for every transmit. Ostensible deployment of an equal number of dipoles in each of the two Cartesian directions can reduce directional bias and distortion , permit greenfield forays into the truly unknown and provide a more robust basis for 3D tomography and 3D target definition. For every transmit, certain dipoles will have obvious issues with low signal both due to receiver and transmitter separation and the inevitable equipotential coupling. But who's to actually know where the equipotentials lie unless you measure them? The most interesting and economic earth is 3D. Similarly there are issues with EM coupling. We do our best to use all of the data, but QC and evaluation tools are critical - at least until full-waveform DC and IP inversion become available! In many circumstances, the cost of a fully bidirectional 3D dataset can be reasonably compared to many 2D systems - and the result is an enduring data asset that will stand through many future tests and evaluations. We will address questions of logistics and cost and show some data examples.

Large scale gradient array.
- Barry De Wet

We will discuss how the HPX Typhoon has enabled IP to become a “greenfields” exploration tool by using large scale gradient array surveys to quickly focus exploration on the most attractive target areas. With expert inversion technology provided by our Computational Geosciences Inc. in Canada, a subsidiary of HPX, we are able to produce large-scale, reliable 3D inversions using minimal constraints for the gradient array data. We have verified inverted chargeability models at depths of up to 1600 m with drilling. We will discuss the advantages and limitations of such gradient array surveys.
Gradient Array surveys offer the opportunity to add important DC-IP electrical information to a “greenfields” exploration project, where magnetics and gravity are not the primary exploration tools, with the important outcome of lowering exploration risk.

Reconnaissance IP surveys in Mongolia (RIP).

- Mike Haederle

The Reconnaissance IP (RIP) method was developed by Kennecott Exploration in the 1970s to quickly and cheaply screen large areas for porphyry copper systems, which are characterised by large disseminated sulphide footprints. The method is a detector of anomalies only - determining the depth, geometry etc of sources requires follow-up work using other configurations.

Survey Configuration:

Each set up comprises a very large transmitter bipole (typically A-B > 1km) and widely spaced receiver sites (generally >500m), employing dipoles with M-N of 50m, 100m, or 200m.

There are many variations on the theme. Typically orthogonal Rx dipoles are read - allowing the scalar resultant chargeability and apparent resistivity to be determined. Orthogonal Tx bipoles can also be employed, and full tensor values determined. The increase in information using orthogonal Tx and Rx dipoles comes at the expense of production.

The derived chargeability and apparent resistivity values are conventionally plotted at the Rx station site.

In 2014 CRTX ran RIP surveys in Inner Mongolia using 4 Rx crews, successfully testing an area of just under 1400squ.km - one of the largest ever single IP surveys in terms of area covered.

Inversion of borehole data

- Loke Meng Heng

The inversion of borehole data adds new requirements above that required by normal surface 3D IP surveys. A finer mesh is required in the vertical direction to accurately calculate the subsurface potentials, sometimes resulting in finite-element grids with more than ten million nodes. Another problem is artefacts near the subsurface electrodes due to the higher model sensitivity values near them. A reasonable number of borehole and surface electrodes should be used to get sufficient data coverage. Inversion of misse-a-la-masse type of data have generally been disappointing as the inversion algorithm frequently produce models with anomalously large anomalies near the subsurface electrode. Despite the many challenges, IP surveys with borehole electrodes have been successfully used to map conductive ore bodies. Conductive wells can be used as long electrodes to improve the survey depth penetration. An example of mapping reagent flow through a rock pile in leaching of residual gold using surface and subsurface electrodes is shown. The computer firepower needed frequently requires the use of workstation-type PCs with multiple CPUs and at least 128GB RAM.

Case history - North Parkes
- Mike Haederle

A deep drilling programme at North Parkes had discovered low grade copper mineralisation below the Altona Thrust, including some potentially ore grade intercepts. Almost all sulphides in the system are copper bearing (Bornite+Chalcopyrite, and almost no pyrite). Consequently the 3D distribution of chargeability might be a proxy for copper grade.

IP surveys at North Parkes historically have been challenged by conductive and variably thick Goonumbla clays that conceal bedrock, and which limit and modulate the signal from the bedrock. In this instance the target is deep, and consequently surface IP surveys were considered unlikely to provide the desired vector to ore.

With the advent of recently available software tools to model true 3D data acquisition, a trial IP survey was designed in Pole-Pole mode utilising an array of electrodes both within boreholes and at surface. The process included some forward modelling to provide proof of concept, careful design and build of downhole electrodes, actual surveying, and finally quite exhaustive data processing and various attempts at generating 3D models by a number of leading IP experts. Ultimately the approach failed to provide a sufficiently convincing result to indicate it was working. The main conclusion to be drawn from the trial is that this type of survey design is only likely to succeed under specific conditions (which are unlikely to be met in many cases).

Case history
- Kim Frankcombe

In mesothermal and epithermal deposits gold is often associated with quartz veins with a disseminated pyrite halo into the country rock. Where that pyrite halo has dimensions of metres away from the vein it may be able to be seen by IP.

Using a combination of surface current electrodes and down hole potential electrodes and down hole dipole sizes of up to 50m off hole chargeable bodies have been detected a similar distance away from the hole. By changing the direction of current flow at the surface a guide can be obtained as to the direction of the target from the hole.

Down hole IP does not always provide interpretable data but when it does it is spectacular.

Borehole property measurement case history
- Andrew Sloot.

Through the early 90's while working for Scintrex we were asked to undertake numerous downhole IP surveys around the Mt Isa region. Some of the data looked erroneous though that was thought to be typical of downhole IP surveys where electrodes were sitting within sulphide zones. In 2013 we had a number of requests to undertake downhole surveys in NSW. Our array was set up in a similar fashion to that used previously, though with an improved electrode set up. The majority of the data was very clean but one hole in particular had us questioning its validity. I contacted a company who specialise in the installation of submersible pumps in boreholes who made up for us a double insulated 4 core cable with specially designed electrodes. The electrodes are marine grade stainless steel with a protective sheath.

We saw a huge improvement in data quality and also some interesting results when compared with the geology and geochemistry. As it turned out, the previous noise issue had not come the electrodes themselves but from a minuscule nick in the wire. This example illustrates the need for using high quality cabling and electrodes when surveying downhole for intrinsic electrical properties.

Tweaking 3D inversion settings
- Loke Meng Heng

New developments in the 3D IP surveying method over the last 15 years have required parallel developments in data modelling, inversion strategies and microcomputer technology. The surveys are often carried out in rugged terrains where keeping the survey lines parallel is impossible. To model such complex survey geometries, a huge 3-D finite element mesh consisting of millions of nodes with the surface molded to match the topography is used. Some of the popular offset pole-dipole and dipole-dipole arrays have very low potentials. The complex resistivity method is required to calculate the IP anomalies accurately for such arrays. The L-curve method is used to estimate the optimum damping factor to balance the minimization of the data misfit and model roughness. To avoid artefacts in the inversion model aligned along the direction of the survey lines, diagonal roughness filters are used. The use of the L1 and L2 norm inversion methods should match the expected data noise characteristics and geology. Methods such as the VOI and model resolution can be used to assess the reliability of anomalies seen in the final resistivity and I.P. models. The geometric factor and its relative error should be used in the planning stage to filter out potentially unstable arrays.

Depth of penetration of IP systems
- Kim Frankcombe

The depth of penetration of IP systems is a function of signal to noise ratio, the resolution of the system at depth is a function of the array used. Although there is significant room to improve signal to noise by enhanced signal processing at the receiver and through smarter design of electrodes, a solution immediately available to all geophysicists and in all environments is to simply use more power and in some cases, higher voltages.
All electrode arrays have their own sensitivity pattern and some perform very poorly at resolving discrete targets at depth. An investigation into the resolving powers of the planned array should form part of any survey design.

Opportunities for reducing transmitter power through advanced signal processing.
- Various

An improvement in signal to noise ratio of an order of magnitude is equivalent to a reduction of transmitter power by 100. Rather than going for ever increasing Tx power, with its associated logistic and safety issues, modern IP surveyors should be striving to improve the processing techniques to achieve better data more safely.

There is a tendency for IP receiver manufacturers to be secretive about exactly how they get from the raw signal entering the instrument to the final Vp and IP readings. Kim Frankcombe suggests an open discussion of the processing involved in this as a means toward obtaining the best possible method to improve data quality.

Modern IP receivers can measure thousands of time slices over the IP half-cycle period. However, there are only a very few relevant parameters that determine each reading. Mostly we only require two, apparent resistivity and chargeability. Two parameters from the thousands of samples measured. In recent years dimension reduction algorithms have caused a dramatic improvement in data from radiometric surveys. Are the same or similar algorithms applicable to highly sampled IP data to produce cleaner data from lower powered equipment?

Using resistivity non-linearity (with respect to current density) for exploration
- Bob White

A search for an exploration technique that was unique to sulphides, i.e. did not respond to graphite, clays and other polarisable materials lead to the investigation of non-linear conduction in sulphides.

When currents of two different frequencies are passed through a non-linear network the resultant output contains the original two frequencies, harmonics of the two frequencies, and inter-modulation products of the two frequencies. Narrow bandpass filters can be designed to distinguish the intermodulation frequencies from within the much stronger primary and noise signals in order to measure non-linearity.

If non-linearity arises at semiconductor interfaces within sulphide accumulations then adding a direct current bias may increase the non-linearity to the extent it could be used in the field under normal practical current densities.

In laboratory tests a DC bias was found to increase the non-linear effects three to four fold.

The detection of non-linear effects could be integrated into existing IP surveys, using the on/off times of the IP transmitter as DC bias. This would help the signal processing with the off-time signal being subtracted from the on-time signal to isolate those signals resulting from the DC bias. This may increase the signal to noise enough for the non-linear effects to be detectable in real survey conditions. Alternately, should the effect be measurable in practical situations it may be possible to modulate the DC bias to obtain more information and further enhance signal to noise.

Further study and understanding of these non-linear effects may allow for the combined inversion of this data with the resistivity and IP information. If successfully established as a ground (or borehole) exploration method then it should be possible to extend the method to airborne platforms including drone receivers.