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UTEM5
Multifold STEP LOOP
Surveying

Introduction:

In EM exploration for deep targets one of the most critical factors to be considered is resolution and discrimination. In sounding horizontally layered structures, it is the vertical resolution of layer boundaries that is of interest. In exploring areas of steep dip or where lateral changes occur, horizontal resolution is of equal importance. In the late 1980's a UTEM3 Multifold Step Loop survey using a 3 loop configuration was carried out over the Cigar Lake Uranium Deposit (depth of ~450m, pre-development). The approach used to process this data set - correlation processing - is described in the paper:
"**Polzer,B., J.Macnae, Y.Lamontagne, and R. Koch, 1989, Lateral resolution enhancement of TEM data by correlation processing: 59th Annual International Meeting, SEG, Expanded Abstracts, 182–184, doi:10.1190/1.1889600**".

The development of the UTEM5 system - with many technical improvements over the UTEM3 - coupled with the level of computing power now available brought us to the point where we felt it was time to revisit both the survey configuration - now called UTEM5 Multifold Step Loop - and the task of processing the resultant data.

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UTEM5 Multifold STEP LOOP Surveying

An example of a grid for Multifold STEP LOOP Surveying is shown in Figure 1a/b below and Figure 1c/d/e on the following page. The Figure shows 4-fold coverage on 3 west-east survey lines with 200m line spacing and 50m stations spacing. Overall line length to be covered with 2 Txs is shown as 1750m. This setup would be ideal for a three UTEM5 Receiver crew - UTEM5 can collect data from up to 3 Tx Loops simultaneously.

Note that the survey line can be extended by adding Loop sets to either end of the line. Coverage can be extended to either side with additional lines. The fold of the coverage can be changed by adjusting the move-up of the Loop set (200m in the example) and the number of stations surveyed from each Loop set.

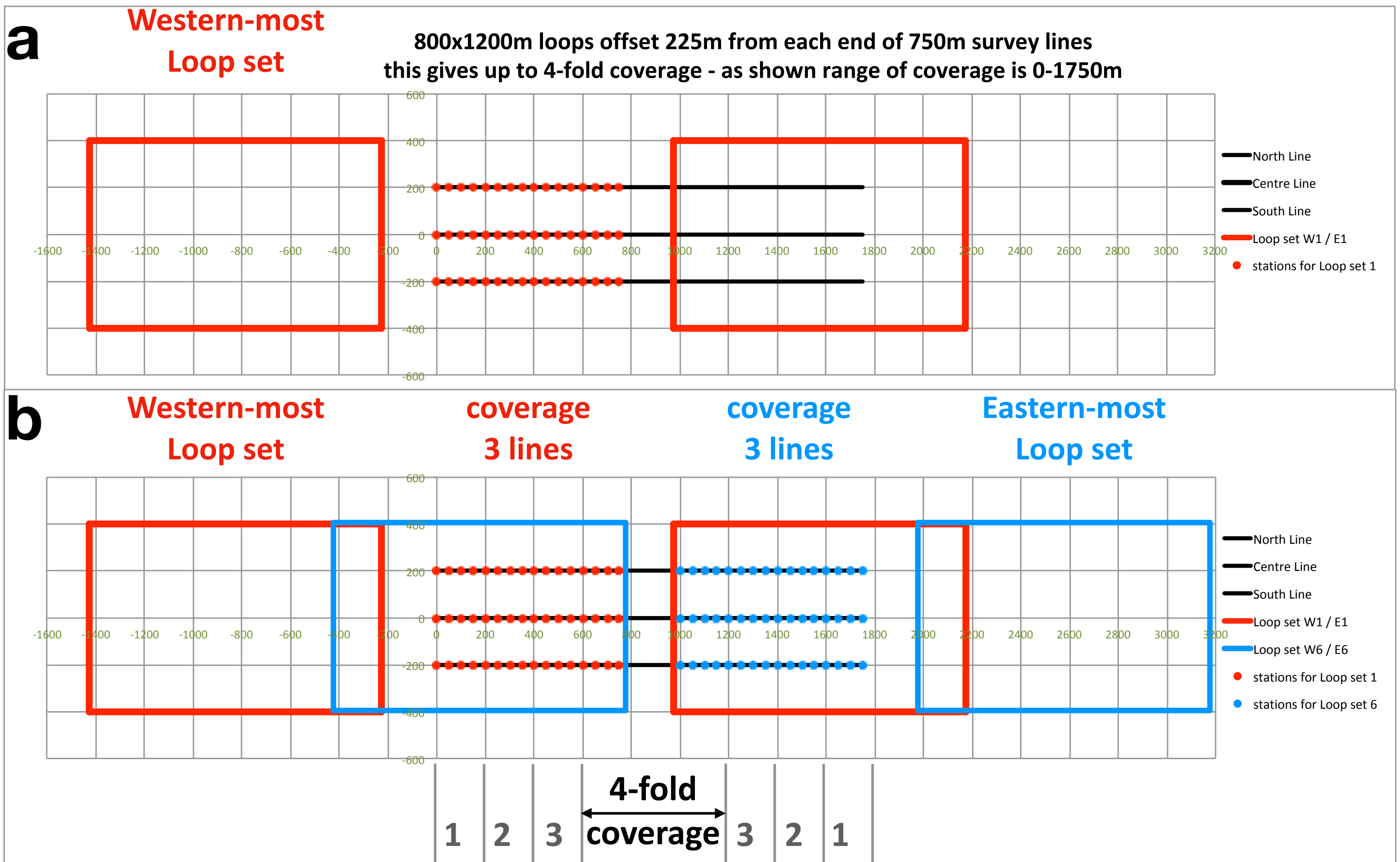

Figure 1a/b: UTEM5 Multifold STEP LOOP Surveying

Figure 1a: shows the first **Loop set/16 stations (750m)** along with the overall line length.

1b: shows the **first** and **last** **Loop set** and **stations** and the overall line length.

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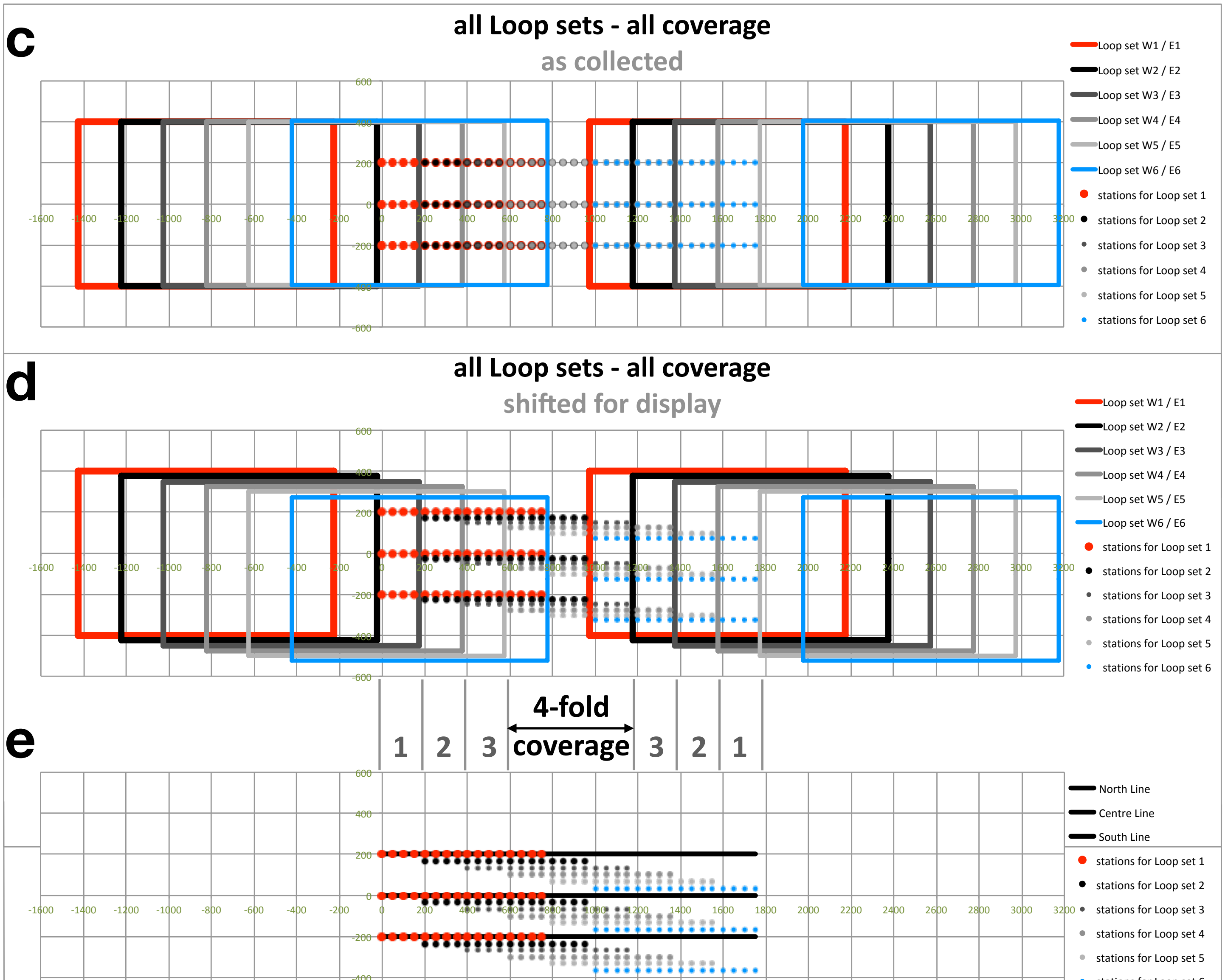

Figure 1c/d/e: UTEM5 Multifold STEP LOOP Surveying

Figure 1c: shows all **Loop sets** and **stations** as collected.

Loop set move-up is 200m. **Each Loop set** surveys 750m of line as shown.

1d: offsets the **Loop sets** and **stations** and shows the fold of coverage acheived.

1e: final product: 3 lines x 6 loops x 750m profiles (16 stations) for each of 2 Tx loops for 36 x 750m profiles and 576 individual readings

Notes: - as this is an example all of the parameters are subject to adjustment.
- work to date indicates that a line length of 15 **Loop sets** or more is optimal

- line length is increased by adding additional **Loop sets** as required at either end of the line.
- all line length added is full-fold coverage - in this case full 4-fold coverage.
- the fold of the coverage at the ends of the lines can be adjusted - from 1-2-3-4fold-3-2-1 as shown to say 2-3-4fold-3-2 - by adding a **Loop set** at either end and limiting the surveying to 550m from those **Loop sets** - effectivly stopping at the ends of the lines.
- completing a line with full-fold coverage is not recommended - unless extensions are planned.

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UTEM5 Multifold STEP LOOP Processing - SLP

The aim of a UTEM5 Multifold STEP LOOP survey is to acquire a data set suitable for interpretation by visual means in the immediate and by imaging methods as these become available. The next step was to develop the imaging methods/tools required. And then to think about extending towards the development of a realistic full scale-synthetic data example to be used as test data set for further refinements of imaging and inversion methods.

Discussion:

An EM system such as UTEM5 provides measurements over a wide range of frequencies. This wide bandwidth is in itself necessary for conductivity imaging or inversion but it is not sufficient to produce stable inversion results. This is particularly so in cases where background responses have comparable decay time characteristics to those of possible target conductors. Since the decay time of the response of a conductor for a particular shape is proportional to the product of its conductivity and the square of its size there can be an overlap of decay times between highly conductive massive sulphide targets of moderate size and very large structural conductors of lower conductivity. Decay time alone is thus not sufficient to clearly detect discrete massive sulphide targets in an environment with complex large-scale background conductors.

And it becomes more difficult - the response of large formational conductors has a much greater amplitude than that of finite target bodies even at moderate depths. It is tricky distinguishing the short-to-moderate wavelength small-amplitude anomalies of discrete conductors superimposed on top of large-amplitude response of a formational conductor. It is not enough to rely on the finite wavelength of the anomalies of discrete conductors to detect these responses among those of large scale conductors. For the detection of highly-conductive discrete targets there remains the advantage that the inductive interaction between the discrete targets and the background conductors is limited. So their response may simply be ~additive to that of the background response - particularly at late sampling times. It can, however, still be hard to visually distinguish the discrete response on top of the larger background response.

Together with the wide bandwidth of the UTEM5 measurements, it is hoped that the use of a STEP LOOP survey configuration can help in discriminating discrete massive sulphide bodies in the presence of large background conductors. The rationale of the multifold coverage is that a finite conductor will produce discrete variations in response when subjected to a variety of primary fields directions and intensities - discrete variations that will be both greater and distinct from those of background conductors. Our goal was to develop a processing method that can use this effect to emphasize the response of particular discrete conductors and present the results as images in which conductors of desired characteristics are highlighted.

From our development of ISR (Inductive Source Resistivity) imaging we learned that any direct method for estimating, even approximately, the inverse solution can save a majority of the calculations of the whole imaging process. What we call here the inverse method (as opposed to inversion method) is the way to extract from the data the model modifications that explain the main features in the data or in the un-rendered residuals after an iteration. Instead of using linearized inverse methods it is hoped that correlation methods can achieve something similar or better with much less computational effort than “regular” linearized inversion. Instead of applying constraints such as model smoothness, compactness, etc. we consider particular model shapes, orientations, depths, size-to-depth ratios to have a “signature”. The results can be constrained by not including bodies too small-relative-to-depth to be resolved or with dips/shapes which are not geologically plausible.

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UTEM5 Multifold STEP LOOP Processing - SLP

Step Loop Processing (SLP) tools have been envisaged for a number of years. An attempt, decades ago, to use the methodology described below was suspended when it was realized at the time that available computational speed was not up to the task. In recent years it was felt that SLP processing was feasible. What was required was a realistic set of data in order to develop the SLP method. Once a data set was available, development was underway.

Matched filter approach:

An approach that is particularly suitable for discrete conductor detection is the correlation method Matched Filter Processing (MFP). A matched filter is an optimum detector for a particular template in a data stream. The method assumes that the template is additive to "noise + background responses" subject only to translation. If a template is not present in a data stream (profile), the matched filter output will be a near-zero output time series whereas a linear inversion can fit the data with a wild superposition of the template.

In our application the "**event**" to detect and locate is a conductive body of a particular shape, dip, depth, lateral location across lines, etc. An **event** will produce a different anomaly shape (template) in each profile (data stream) of the multifold/multiline coverage . The anomaly shape is different for a given body depending on the respective component, traverse line location, transmitter location and separation. We apply the term "**signature**" to designate the set of anomaly shapes (templates) on all profiles processed. By extension, we use "**signature model**" to designate the particular body shape, size, orientation, etc. that generates a **signature**.

So the method used in the SLP tools is basically one of pattern recognition - looking for the anomaly signature of complete target signature models. The rationale for this approach is that, in contrast to potential field methods, an EM response generally cannot be approximated as the sum of the responses of elementary blocks forming a model. A target body must therefore be generally defined as a whole. For this reason we want to define and utilize a process that uses data with multiple primary field excitations to detect the presence of a conductor of particular shape, size, orientation, lateral position. We do not expect the method to resolve the anomalies of conductors that strongly interact with background (nuisance) conductors. We hope the method will be applicable to the late time response of very conductive targets which are uncoupled from the background conductors and therefore a ~purely additive response .

The data needs to be re-arranged as multiple moving loop profiles, one profile per loop-station separation (16 from the example), per loop series (2), and per component (3). The availability of this large number of streams generally increases the resolution of the correlation process by a factor that can be as much as the square root of the number of independent streams, so potentially by up to a factor of 9-10 in the example. This means that the method has the potential for detecting anomalies of particular conductors that are literally buried in the larger responses of background conductors.

Multifold STEP LOOP Processing - SLP Development:

The SLP method considered requires the calculation of a great variety - tens/hundreds of thousands - of representative test responses over the same geometry and bandwidth as the measured data - to build the signatures. So in addition to the greater computing power needed, an efficient formulation was required to generate synthetic data quickly. SLP development started with preliminary steps to create tools for this purpose and then proceeded through the development steps of the SLP proper.

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Preliminary developments

The first part of the project involved the development of a very fast numerical solutions for finite conductors and for extensive formational conductors. Ellipsoid shapes were adopted to represent finite discrete conductors. For development purposes - to keep the number of **signature models** under 100k - prolate and oblate spheroids of revolution were the first chosen. A wider variety of **signature model** will be added as computational power expands - additional lateral locations and tri-axial ellipsoids. The obvious shape for formational conductors is a half-plane of finite conductance.

It was decided to use only ellipsoids for first version of the processing algorithm - more realistic target shapes. Inclusion of half-plane signature bodies awaits new hardware and software improvements. The purpose envisaged for half-plane **signature models** is to render and attempt to strip any background response - an extension to the initial SLP.

Ellipsoid conductors

The ellipsoid solution developed uses a digital volume integration over dipole responses affected by a depolarization tensor (as proposed in Grant and West,1966) to evaluate the inductive limit response of an ellipsoid with uniform primary field excitation. This basic algorithm was expanded by trial and error experimentation to approximate fairly well both the anomaly amplitudes and time decay characteristics of the analytical response of a sphere and of the numerical 3D response of ellipsoids obtained by MGEM (a multi-grid finite difference solution). Using these comparative data the solution was extended further to be valid for a gradually varying primary field so it approximates reasonably well the early and late decay behaviour of the true response even for bodies in a very non-uniform primary field.

The range of parameters used for ellipsoidal conductor shapes results in a number of **signature model**s that easily numbers in the tens of thousands. Considering the need for redundancy to counter end of line effects it was estimated early on that a useful run would involve a minimum of 30,000 **signatures**. To date runs include a maximum of >100,000 **signatures** - runs of a million+ **signatures** are weeks away (PDAC 2021).

Multi-channel data application

The measurements over multiple time channels are not treated as separate data streams in the processing. The measurements sampled in logarithmic time are considered as located over a different axis in a two-dimensional matched filter stream so the object of the Matched Filter Processing (MFP) is to locate the signature target along the logarithmic time axis as well as along the profile coordinates.

Multifold STEP LOOP Processing - SLP Overview and Summary:

There are two main software processing steps involved in the STEP LOOP Processing. The first step is the Matched Filter Processing itself (MFP). The second step is the Image Synthesis (IS) which creates images synthesized from the results of the MFP.

The results are a volume confidence density for conductivity classes distributed logarithmically. Sections of this distribution are presented as colour plots. These can be viewed on a web application - confidenceplot - available on the website: https://www.lamontagnegeophysics.com/

After several decades of anticipation Lamontagne Geophysics has available Multifold STEP LOOP Processing software. At present (PDAC 2021) it is being upgraded on both the hardware and software fronts. We look forward to a formal presentation at a later date in 2021. But we are happy at this time to discuss both Multifold STEP LOOP surveys and processing. ***…new developments are always underway…***

For more information, please contact us: https://www.lamontagnegeophysics.com/
…and be sure to visit us @ PDAC 2022 booth 1103