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Technical Note TN-29

ADDITIONAL NOTES ON OPTIMAL DETECTION OF TDEM ANOMALIES UNDER CONDUCTIVE OVERBURDEN

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Introduction

This technical note is divided into two parts. In the first, we shall show how by slightly altering the normal TDEM moving loop survey configuration used in Australia, we can obtain a factor of approximately 40 improvement in signal-to-noise ratio (SNR). In the second part we shall show how these alterations greatly improve the detectability of deep conductive targets under thick conductive overburden.

Survey Configuration

It is the objective of TDEM surveys to detect conductive orebodies. The response from such targets, when using the moving loop TDEM configuration, is essentially exponential at late times. The magnitude of the time constant is, for the case of a spherical orebody of radius a, proportional to the conductivity multiplied by the square of the radius ($\tau = \mu\sigma a^2/\pi^2$), and for a lenticular orebody of width a, length b, and conductivity-thickness S, proportional to the product of the conductivity-thickness and width ($\tau = \mu S a/10$).

It is, of course, not always true that the orebodies with largest time constants are the most economically valuable (barren sulphides can also be very conductive) however, in view of the fact that both large conductivity and large size produce a large time constant, it generally makes sense to search for targets with large time constants.

However a problem arises in detecting long time constant targets, since for off-time TDEM systems such as PROTEM, Sirotem, Crone, etc., the time response at late times is described by

$$\dot{B}(t) \propto \frac{1}{\tau} e^{-\frac{t}{\tau}}$$

and although long time constant targets have a response which persists to late times, the amplitude of their responses is generally very low, making them difficult to detect against system noise. It is obviously of considerable importance to maximize the system signal-to-noise ratio (SNR).

As discussed in Geonics TN-28, the system noise has three components; instrumental noise, atmospheric noise (including all electromagnetic interference) and noise caused by thick, variable overburden. Geonics TN-28 describes in detail the correct procedures to reduce these noise sources. They are as follows:

(1) use of sufficient receiver coil dipole-moment to overcome instrumental noise. The large dipole moment must be achieved using actual turns-area, not with electronic amplification (which usually simply increases instrumental noise). Virtually all physically small receiver coils

(including the Sirotem roving-vector receiver coil) have insufficient turns-area, which must be at least 1,000 m^2. Use of a 1,000 m^2 coil (which can still be made in rigid form, with diameter of only 1m) will often provide an increase in SNR of 3-4 over conventional small coils. The use of large flexible receiver coils is not recommended since, in heavily bushed areas, they are difficult to lay flat on the ground, and are therefore noisy as a result of wind-induced motion in the earth's magnetic field.

(2) use of large dynamic range to minimize response to atmospheric noise. Almost invariably some out-of-band noise (usually man-generated) is converted because of inadequate dynamic range, into in-band noise, which increases the overall noise level. Even with large dynamic range receivers, it is recommended that measurements be made simultaneously at two gain settings (high and low), using a multi-channel receiver, to obtain maximum information about the entire transient decay waveform, and thus about the subsurface geology.

(3) use of physically small receiver coil to minimize IP and SPM effects. Measurements may be made inside and outside the transmitter coil to identify these responses. When in-loop and out-of-loop measurements are made simultaneously, using a multi-channel receiver, identification of atmospheric noise is often facilitated.

(4) use of a transmitter loop optimized to reject overburden response. Deployment of a transmitter loop that is too large selectively energizes overburden response with respect to target response.

(5) use of maximum possible transmitter dipole moment with the optimum loop size. It will be shown below that it is highly desirable to make measurements to very long times, but that this is only profitable if the SNR is high. The large transmitter dipole must be achieved with loop size that has been optimized to reject overburden response, so the transmitter loop current must be large, which requires a powerful transmitter.

In any deep exploration TDEM system, selection of the transmitter and transmitter loop is always a compromise. Large transmitter loops with high currents are generally equated with larger depths of exploration. However, as shown in Geonics TN-28, physically large loops are not necessarily advantageous, but large dipole moments always are. To obtain large dipole moment with a moderate sized loop (preferably of dimensions 100x100m, as shown in Geonics TN-28) requires high current, which requires either heavy wire or a heavy transmitter. Fortunately heavy transmitters do not present a problem in Australia, since such transmitters can generally be carried on vehicles.

An optimum configuration for many Australian TDEM surveys would consist of a two-turn 100x100m transmitter loop (of #12 wire) powered by a 3kW transmitter. Such a transmitter (which is still relatively small and inexpensive) delivers 25 amps into the two turns to produce a dipole moment of $2 \times 25 \times 100^2 = 5 \times 10^5$ amp-m^2, with a loop which still weighs only 44 kg. This dipole moment is about 10-12 times larger than that from a normal Sirotem 100x100m transmitter loop.

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approximated as

$$\text{depth}^{-5.4}$$

(the power would be -6.0 if both transmitter and receiver were dipoles). The suggested changes in system configuration described above, that yielded an improvement in SNR of 40, will thus yield a factor of

$$40^{(1/5.4)}$$

or a factor of 2 improvement in exploration depth, even under conductive overburden. This is certainly a significant improvement, at a relatively small price.

There is a second important but less obvious improvement in our ability to detect long time constant targets. Figure 1 shows the transient responses from three similar targets, all assumed to be at the same arbitrary depth, with time constants of 10, 50 and 250msec respectively; also shown are the responses from four horizontal thin sheets (HTS) of conductances 3, 10, 30 and 100 siemens respectively. We note that, at the late time under discussion here, the target responses can be approximated as $1/\tau \exp(-t/\tau)$ and the responses from the horizontal thin sheets as t^{-4}.

Additionally shown on the figure are two noise levels, the first (labelled "high noise") at 1 nV/m^2 and the second (labelled "low noise") reduced by a factor of 40, or at 0.025 nV/m^2. Thus the figure illustrates the differences in response (relative to the noise) that would take place between

(1) a low powered system with receiver coil of insufficient turns-area: examine the various responses relative to the high noise level, and (2) the high powered system proposed here, with a 1,000 m^2 receiver coil, giving an improvement of 40 in SNR: re-examine the various responses, now relative to the low noise level.

We first discuss the responses in the absence of conductive overburden. We note that, for the high noise system, the 10msec target is readily detectable above the system noise, the 50msec target is just detectable and the 250msec target is undetectable. On the other hand, as a result of the lower noise, the low noise system is readily able to detect all targets. Reducing the system noise by a factor of 40 means that we can detect targets with a factor of 40 greater time constant.

Now consider the relative responses in the presence of conductive overburden, first for the high noise system. We note that the addition of a 3 siemens HTS makes no significant change in detectability of any of the targets, but that the addition of a 10 siemens HTS would significantly reduce the detectability of the 10 and 50 msec targets, and that the 250msec target would, of course, still be undetectable. Finally, we note that if we increase the conductance of the HTS to 30 siemens, all targets become undetectable.

For the low noise system, increasing the SNR by 40 makes, predictably, a significant difference in the target detectability under the various overburden conditions. The 10msec target is now easily detectable in the presence of the 10 siemens HTS, although still undetectable for larger sheet conductances. The 50 msec target is readily detectable under a 30 siemens HTS, but marginally detectable under a 100 siemens HTS. The 250 msec target, which was always undetectable for the high noise system, is now completely detectable, even under a 100 siemens HTS. It is clear that reducing the system noise level has greatly improved the chances of detecting long time constant targets under conductive overburden.

In the above discussion all targets were at the same arbitrary depth. To see the effects on the response of altering the depth to the targets, the exponential curves are, of course, simply raised or lowered appropriately (as mentioned above, doubling the depth causes a factor of about 40 reduction in all the signal levels).

Conclusions

In view of the doubling of the exploration depth, and the considerable improvement in the detectability of larger time constant targets under conditions of conductive overburden, the expense of a somewhat heavier transmitter loop and a heavier transmitter (easily truck mounted) is rather small. It is recommended that, in the search for long time constant targets, the configuration described in this technical note be employed, and furthermore that all measurements be made to time of at least 200-300 msec unless the operator is willing, after each measurement, to examine the data carefully to ensure that no signal exists in the later gates. Under average field conditions this decision may be quite difficult to make, even with a receiver which gives a good plot of the survey data on the output screen.

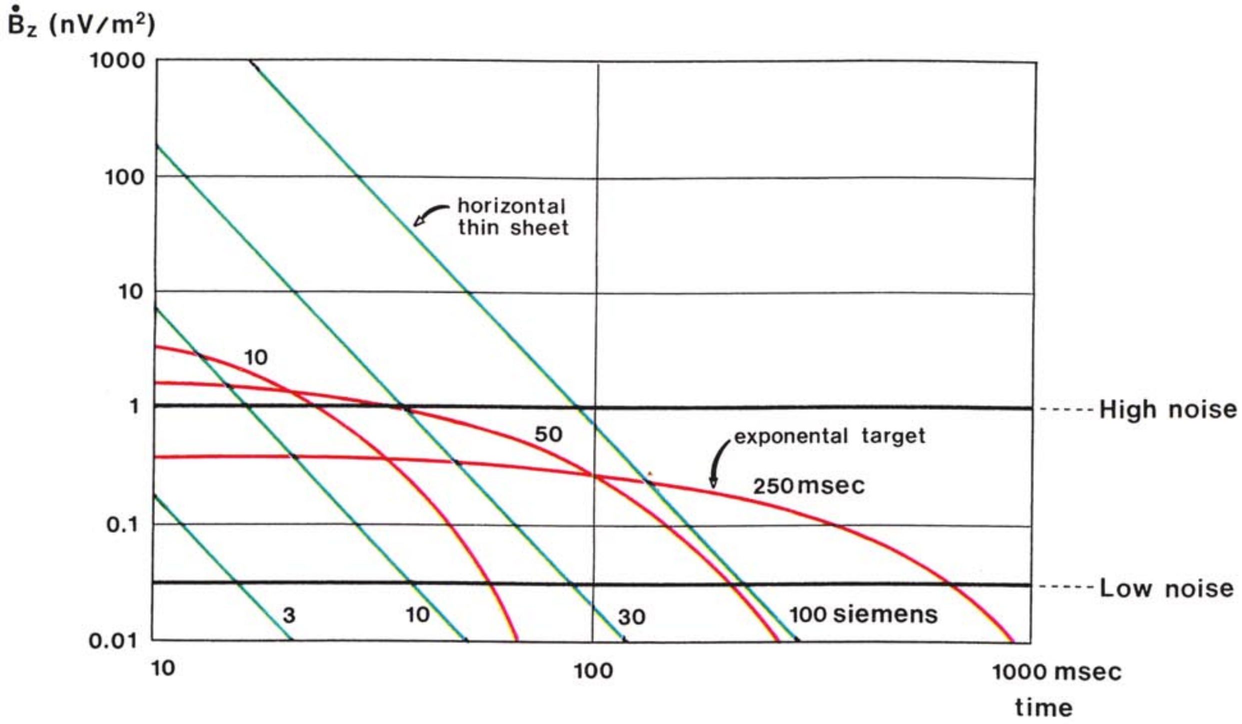

Fig. 1 Relative response of exponential targets and horizontal thin sheets at two different noise levels.