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Time-Domain Electromagnetics for High-Conductivity Mineral Exploration: On-Time Step Response and Low-Frequency, B-Field, Late Off-Time - A Discussion

10th December 2020, 4:30 PST (00:30 UT, 11th December, 2020)

Panelists: Daryl Ball, Geophysicist, Raglan Mine, Glencore Canada
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After development of the UTEM time-domain EM system at the University of Toronto by Gordon West and Yves Lamontagne in the early 70's, there has been a debate among geophysicists who use TDEM to explore for high-conductivity ore bodies (e.g. magmatic Ni-Cu-PGE deposits), concerning the utility of off-time TDEM versus on-time readings. In principle, there will be no off-time TDEM response from a perfect conductive body (i.e. infinite conductivity), because the time-varying primary EM field cannot penetrate infinite conductivity, regardless of frequency. The EM skin depth of a conductor is inversely proportional to square-root of conductivity times frequency, and if conductivity is infinite, then skin depth must be zero. Hence, zero penetration by the primary EM field, and zero induced eddy currents penetrating into the conductor, and zero response after the primary field has been turned off.

There will be eddy currents induced on the surface of the infinite conductor, but they are entirely in-phase with the primary field and do not decay significantly within realistic time frames as they would in a moderate conductor. But the surface eddy currents do produced a secondary EM field, in-phase with the primary field. In close proximity to the conductor, the primary and secondary in-phase fields are equivalent and opposite, resulting in a near zero field. Time-domain measurement of the signal in-phase with a step waveform primary field is termed the 'step response'. The primary and secondary fields can be separated if the primary field can be calculated theoretically, and this is the basis of the UTEM system's approach to the problem of detecting a perfect conductor.

The early commercial application of TDEM for mineral exploration was based on the pioneering research in 1948-51 by James Wait and others at Newmont's geophysical research facility in Jerome, Arizona (and contemporaneous research in the former Soviet Union), and by Tony Barringer with the development of his airborne INPUT TDEM system in the late 50's. These systems all had in common the idea that the response from the ground can be measured more accurately and more sensitively in the absence of primary field. This is still a prevalent idea today. However, before about 2000, it was only practical to measure an EM field with an induction coil-based system, and the base frequency had to be high enough (i.e. above 5-10 Hz and routinely 25 or 30 Hz) to generate a high-fidelity reading above the noise level of the coil and electronics.

No conductors in nature have infinite conductivity. But some conductors (e.g. massive pyrrhotite in a nickel ore body) can be extremely conductive. So conductive at these relatively high frequencies, it was pointed out by the proponents of on-time step response TDEM, that there will be little to no measureable (i.e. above the noise level) off-time secondary response. One had to use step response to detect such extremely strong conductors. However, with the advent of small, sensitive fluxgate magnetometers and subsequently SQUID magnetometers for use in TDEM, in the late 90's and into 2000, geophysicists were able to measure the B-field TDEM response (with ground and borehole systems at least) down to 1 Hz base frequency and lower.

Hence, the question of whether it is better to measure the on-time step response, or conversely a very low-frequency, late off-time secondary response, really comes down to a signal to noise discussion. In the first case, it is the noise inherent in calculating the free-space primary field to be subtracted from the measured primary field, versus the amplitude of the in-phase secondary field from the strong conductor, which depends on the conductivity and size of the conductor. In the second case, it is the B-field sensor noise, versus the amplitude of the off-time secondary field, which is dependent on the amplitude of the induced eddy currents, which is dependent on the conductivity of the conductor and the primary field generated by the transmitter.

And the final complication is the fact that almost all massive sulphide ore bodies have varying conductivity throughout the body. Hence, there is likely to be zones of lower conductivity, even with a massive pyrrhotite ore body, that will give rise to strong off-time secondary response, at a low enough frequency.

All of these factors will be discussed by leading TDEM geophysicists at this webinar. Each will have an opportunity to make a short (10 minute) presentation, followed by 20+ minutes of open discussion between presenters, with questions from the audience.