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Introduction to the 1996 Special Volume on DHEM

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This special volume of Exploration Geophysics has its genesis in a DHEM workshop held at Macquarie University in June, 1993. To attend this meeting, one had to be an author, or co-author, of a paper; ie, no observers, just participants. The presentations were to be progress reports, with a formal paper to be submitted for publication following the workshop. Abstracts for most of the papers were distributed in a folder given out at the workshop. Appendix 1 gives a list of the papers presented, the principal author and his then affiliation. This volume contains 13 papers which, mostly, are developments from the workshop presentations. The delay in publication can largely be laid at our feet -apologies to those (few) authors who submitted their papers promptly after the workshop.

The 1993 workshop had a similar format to one held in Melbourne in 1985, the results of which were published in Eadie and Staltari (1987), but there had been considerable growth in the appreciation and application of DHEM in the intervening years. At the 1985 workshop, 12 papers were presented. In 1993, there were 24.

In 1985, discussion concentrated on data quality (including determination of polarity) and interpretation, with several case histories used as examples. Only axial surveys were described. At the 1993 conference, three component case histories were presented in papers by Hughes and Ravenhurst, and advantages of the Utem system with its triangular waveform were illustrated by Lamontagne and by Macnae and Mutton. Understanding of the effect of overburden on buried conductors was advanced with scale model studies by Buselli and Lee and in case histories by Bishop and by Jackson et al. Sensor response, including 'self response', received some attention in 1993, with two papers devoted to the subject. Subsequent work has shown that at least some of the effects then attributed to self response are due to loop-hole geometry; eg, Bishop's paper on Broken Hill. One of the most important advances since the earlier workshop, has been the utilisation of the true trace of the drillhole for modelling, rather than the straight line approximation, which had been used hitherto. Things which had not changed included the use of thin plates in free space for modelling, and sign convention.

At the discussion sessions at this and the earlier workshop, some time was spent on how to determine what the correct polarity was and how to determine whether it had been recorded. In our experience, the correct polarities are mostly, though not always, recorded. However there is still no widely accepted sign convention and we have taken this opportunity to state some basic definitions.

The problem of sign convention is not simply a matter of two opposing views -there are several differences and even, in some cases, a lack of definition. The one universally(?) accepted convention is the use of a right-handed coordinate system (**X** x **Y** = **Z**, where **X**, **Y** & **Z** are vectors) and **Z** is positive upwards.

With one exception (the Utem system), the definition of sign for the signal received from an axial probe is also universal: the signal received from a probe placed in a downwardly inclined drillhole and surrounded by a transmitting loop (a so called collar loop), should be positive. We suggest that this definition be extended to include horizontal and upwardly inclined holes, by stating that the positive direction of the sensor coil is *towards* the cable head. (Lamontagne Geophysics define the positive direction of an axial sensor as positive away from the cable head and thus Utem records a negative signal when placed inside a loop.)

Although most impulse systems only measure the secondary field, the primary field is a much better way to check polarity, since it usually behaves in a much more predictable fashion (see Hughes and Ravenhurst's discussion on primary field distortion), However, at present, Crone's PEM, with its controlled ramp, is the only impulse system which measures during the on time. Buselli et al (1987) described a method for checking the polarity of a probe, which had the advantage of also calibrating its response. However, unfortunately, this has not been widely adopted by the industry. (The problem of polarity generally does not arise with systems such as Utem, which measures both the primary and secondary field.)

However, polarity is only part of the problem. One can use either a set of fixed (geographic) axes, or a local, relative, set which are defined by the azimuth of the drillhole. To date, most of the three component data collected in Australia has used the latter. However, for holes with a large change in azimuth; e.g., in 'corkscrewing' holes, interpretation using relative axes can be difficult , if not impossible.

In the local, hole axes, the axial component, '*A*' is tangential to the hole and is positive upwards. '*U*' is in the vertical plane containing the tangent, normal to it, and pointing upwards. '*V*' is normal to the plane containing *A* and *U* (and is thus

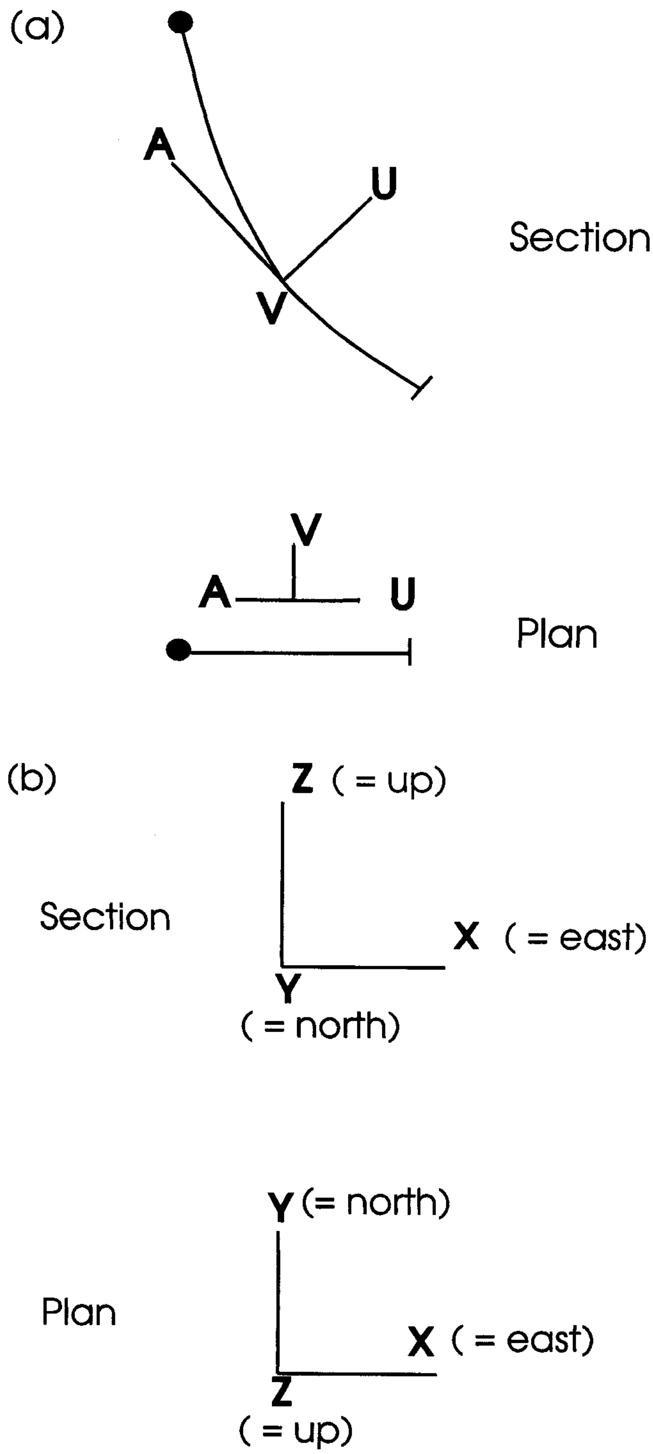

Fig. 1. Three component DHEM probes often use a ccordinate axes which use the azimuth of the hole as a reference as shown in (a). With this system, the direction of U and V will follow the declination of the drillhole. An alternative convention, is fixed geographic axes as shown in (b). The latter convention is preferred, especially in steeply dipping holes which 'corkscrew'.

horizontal) and forms a right handed coordinate system such that **U** x **V** = **A** (Figure 1a). In the Crone system, these three directions are labelled *X*, *Y* & *Z*, but we prefer to reserve these letters for the fixed coordinates. (*XYZ* has also been used by Cull to describe the relative axes, in his paper on three component DHEM.)

Data produced using the local hole axes will change sign when, for example, the azimuth changes by 180 degrees, since '*U*' will then also 'flip' direction. A system of fixed coordinates; eg, *X* (=east), *Y* (=north) and *Z* (=up) does not suffer from this problem (Figure 1b).

It is also possible, of course, to rotate the relative axes to an arbitrary, fixed value; i.e., to re-define '*U*' as having one fixed direction (e.g., the average azimuth) down the length of the hole.

Note that even when using fixed coordinates, there is still a need for a convention to determine the correct polarity of the recorded signal. Normally, this is trivial, but is not, for example, in a horizontal hole or if using a vertical, underground loop.

Another point raised in the workshop discussion session was the question of loop size: whether large loops were always preferable, or if, in some circumstance, smaller loops gave better results. At the time there was little consensus, but experience since then suggests that smaller loops (say no more than 200m x 200m, possibly with multiple turns) tend to reduce the response from conductive overburden and are more focussed on the target.

At a DHEM workshop held in 1994 in Canada, Ravenhurst (1994), speculating on the future for DHEM, predicted better instrumentation, more power, longer time bases and three component probes. Certainly these goals are being actively pursued in Australia. Poseidon has a transmitter capable of producing 100 amps with a quick cut off. Duncan at EMIT has produced a 'Smartem' with improved signal processing. Cull at Monash University has produced a three component probe. Public exploration companies are funding both public and private research.

One prediction which has not yet had a public airing(?), is measurement over the full wavelength with a user-definable waveform. Such a system would combine the superiority of step systems such as Utem to detect good conductors, with the ability of impulse systems such as Sirotem, Nanotem, Protem, etc, to better detect poor conductors. The primary field information would be an added bonus. Perhaps we shall soon see examples of this, interpreted with programs allowing several arbitrary shaped bodies embedded in a layered conductive host.

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Eadie, E.T. and Staltari, G. (editors), 1987,. Downhole electromagnetic methods special issue. Exploration Geophysics 18, no. 3.

Ravenhurst, W., 1994, The Crone Borehole Pulse EM system. Presented at Short Course 4 on the fourth annual CIM Geological Society Field. Sudbury Ontario, September, 1994.

APPENDIX 1

Papers presented at the DHEM Workshop
Macquarie University, June 1993.

Principal author & (then) affiliation	Title
Asten, M. (BHP)	Interpretation of multiple off-hole conductors at Eloise, Qld.
Bishop, J. (Mitre)	5 site, Broken Hill: a deep DHEM case history.
Boyd, G. (Poseidon)	Scuddles & DHEM.
Buselli, G. (CSIRO)	DHEM scale modelling.
Collins, S. (Arctan)	Being positive about negative EM.
Cull, J. (Monash Uni.)	Vectem.
Duncan, A. (Aerodata)	Interpretation of Vectem by inversion.
Fallon, G. (MIM)	Underground DHEM at MIM.
Flis, M. (Newcrest)	Golden Chief: DHEMP case history.
Hatherly, P. (CSIRO)	RIM case histories.
Hughes, N. (Pasminco)	Self response.
Hungerford, N. (Billiton)	Iberian Pyrite Belt case history.
Jackson, J. (MIM)	DHEM experiences at Mt Isa.
King, A. (Inco)	Deep DHEM at Sudbury.
Lamontagne, Y. (Lamontagne)	Utem case histories.
Lewis, R. (Uni. of Tas.)	Bringing 'background' to the fore.
Macnae, J. (CRCAMET)	Dugald River & DHEM (with systems comparisons).
Mudge, S. (RGC)	Multiple loops at Mt Lyell.
Pik, P. (CSIRO).	Self response.
Raiche, A. (CSIRO)	CSIRO's DHEM research project.
Ravenhurst, W. (Crone)	Multicomponent DHEM.
Silic, J. (Aberfoyle)	Testing times in Tasmania.
Trench, A. (WMC)	Application of DHEM for Nickel exploration.
Turner, G. (CSIRO)	Borehole radar.