**Shallow Marine Test of MTEM Method**  
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**Summary**

We present a test of the Multi-Transient Electro-Magnetic (MTEM) method in water 10 – 20 m deep in the Firth of Forth, Scotland. Using a low-cost experimental system and currents of less than 50 A, we recovered earth impulse responses at offsets in the range 600 – 8000 m, corresponding to target depths up to 2 km.

**Marine Controlled-Source Electro-Magnetic Measurements**

Since the 1980’s controlled-source electro-magnetic measurements have been made by several research groups (Scripps, Toronto, Cambridge, Southampton) and companies (Exxon Statoil, EMGS, OHM, AGO). Key references include Cheesman et al (1987) and Sinha et al. (1990). Apart from Edwards’s group at Toronto, all these groups use the same method, employing an alternating-current (AC) bi-pole source towed near the sea floor with remote autonomous units that measure and record the response at approximately 1 km intervals on the sea floor. When the autonomous units are returned to the sea surface and picked up by the vessel, the data can be checked for quality and analysed. Essentially, the system is designed to measure the steady-state response at the frequency of the square-wave input, and at a number of odd harmonics of this frequency.

Edwards uses a different system with a bi-pole current source and autonomous receiver modules in a single cable dragged along the sea floor. The source may emit a continuous alternating current, like the others, or it may emit a transient signal; each receiver module measures the voltage response between in-line electrodes and records it.

At the frequencies used in exploration the electric field obeys the diffusion equation. Energy diffuses through the sea floor and through the water. When the cable is wound in and the receiver modules retrieved, the data can be checked for quality and analysed.

At the water surface there is a refracted wave, the ‘air wave’ that travels at about the speed of light. The receiver receives energy from below that has diffused through the earth, and energy from above that has diffused through the water and refracted at the water-air interface. In shallow water, the amplitude of the refracted air wave at the receiver may be much larger than the wave from below. For the steady-state AC systems used by most practitioners of CSEM, the air wave is always present. Its amplitude is reduced by increasing water depth and becomes negligible if the depth is great enough. CSEM with an AC source is normally restricted to water depths exceeding 300 m.

**The MTEM method**

The MTEM method is relatively new (Wright et al., 2002; Ziolkowski et al., 2005; Wright et al., 2005) The setup is shown in Figure 1. The layout is similar to 2-D seismic reflection.

The source puts in a transient current $i(t)$ between source electrodes A and B. This is the ‘source signature’, which is measured, and each receiver measures a different time-dependent voltage $v(t)$, which is recorded and displayed for real-time quality control. The response at receiver electrodes C and D is related to the input current via the convolutional equation

$$v(t) = i(t) * g(t) + n(t),$$

Figure 1 A typical MTEM source-receiver configuration, with a current bi-pole source and its two electrodes A and B, and a line of receivers in line with the source, measuring the potential between pairs of receiver electrodes, for instance C and D.
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in which \( g(t) \) is the impulse response of the earth, the asterisk \(*\) denotes convolution, and \( n(t) \) is uncorrelated noise.

This equation applies provided the input signal is constant or zero for a period exceeding the duration of the impulse response \( g(t) \). The impulse response can be recovered by signature deconvolution using methods that have long been standard in the processing of seismic data.

In the land case, the response includes an air wave that travels at about the speed of light. Since there is no water layer, there is no diffusive effect and the air wave arrives at the receivers almost instantaneously. After deconvolution, the air wave appears as a sharp impulse that precedes the earth impulse response. The air wave and response from the earth below are therefore separable in time (Ziolkowski et al., 2005, Wright et al., 2005).

In the marine case the air wave is a peak that is less sharp and is followed by a long tail. This is superimposed on the earth impulse response.

One of the beautiful aspects of a programmable electric source is that there is much freedom in the choice of the source time function, although the current output is modified to some extent by the earth load and the impedance of the circuit. For our marine test we used a pseudo-random binary sequence (PRBS), as proposed by Duncan et al. (1980), to drive the current generator.

Site

The Firth of Forth near Edinburgh, was chosen for the marine test. The location is shown in Figure 2. The target was the coal measures of the Leven Syncline (Ritchie et al., 2003), which have been mined extensively on both sides of the Firth. Marine seismic data in the Firth of Forth show that the coal measures are continuous under the Firth from Fife in the north to Lothian in the south. Numerous boreholes on both sides of the Firth plus the marine seismic data allowed a structural model of the basin to be built, with well-constrained resistivities.

Data Acquisition

Figure 3 shows the layout. The source and receiver vessels had independent recording systems that were synchronised using GPS. The following parameters were used:

- source electrode separation : 200 m
- receiver electrode separation : 200 m;
- number of receivers : 10;
- input current : 20 – 50 A.
- The PRBS was of order 14 : 16,383 samples.

The objective of the experiment was to show that broad bandwidth impulse responses could be obtained at offsets out to 8 km.
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Using the rough approximation that the depth of penetration is approximately equal to half the offset, Figure 4 shows the approximate subsurface positions (small circles) at which maximum depth of penetration is reached for different source positions.

Data Example

Figure 5 shows an example of raw recorded data at an offset of 600 m. The sampling rate was 3.75 kHz. The vertical timing lines are at 2 s intervals. The PRBS can clearly be seen up to about 4.4 s, when it stops. The large amplitude low frequency signal is the uncorrelated background noise. Superimposed on this is 50 Hz cultural noise; there are several power stations on the Firth of Forth, so it is not possible to get away from this noise, even on the sea floor.

Data Processing

Processing of the data is essentially deconvolution for the known current – the source signature – to recover the impulse response of the earth. In principle we also scale the data, using the known acquisition parameters, to the response to a 1 A m step in current. (This is then used in subsequent inversion.)

First we recover the impulse response and then integrate this to obtain the step response. Figure 6 shows typical impulse responses and their corresponding step responses.

Conclusions

The MTEM method, already demonstrated on land, has now been demonstrated in shallow water. Broadbandwidth impulse responses have been obtained at offsets from 600 m to 8 km using source currents generally less than 50 A. Adequate signal-to-noise ratio was obtained by using a broad-bandwidth pseudo-random source current, followed by deconvolution. The success of this experiment has encouraged us to build a commercial system with a much larger source, which we intend to introduce in the summer of 2006.

References

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Ritchie, J.D., Johnson, H., Browne, M.A.E., and Monaghan, A.A., 2003, Late Devonian-Carboniferous tectonic evolution within the Firth of Forth, Midland Valley; as revealed from 2D seismic reflection data. Scottish Journal of Geology, 39, 121-134.


Figure 5: Raw data at 600 m offset. The timing lines are at 2 s intervals

Figure 6: (a) Impulse responses at offsets 2 – 4 km (b) Corresponding step responses
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EDITED REFERENCES

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REFERENCES


Ritchie, J. D., H. Johnson, M. A. E. Browne, and A. A. Monaghan, 2003, Late Devonian-Carboniferous tectonic evolution within the Firth of Forth, Midland Valley; as revealed from 2D seismic reflection data: Scottish Journal of Geology, 39, 121–134.


