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Reservoir Characterization and Monitoring Using Multi-Transient ElectroMagnetic (MTEM)

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The MTEM method

The Multi-Transient Electro-Magnetic (MTEM) method implements a current bi-pole source with a sequence of receiver stations that measure the resulting voltage. Source and receiver stations are located in a straight line similar to 2-D seismic. Onshore and offshore acquisition systems have been developed providing continuous coverage of the subsurface including the transition zone.

The earth's impulse response is obtained for each source receiver pair by deconvolving the received voltage for the input current. The source signal is a Pseudo Random Binary Series (PRBS) that combined with vertical stacking allows us to maximize S/N. The subsurface resistivity is evaluated from the very shallow sediments down to the target depth by continuously optimizing the acquisition parameters. This involves adjusting the length of the source bi-pole, the bandwidth of the source PRBS, and the sampling rate of the recorded signal to be optimal for each offset range.

The method allows for real time monitoring of the signal and real time assessment of the subsurface resistivity. The final deliverables are 2-D depth sections inverted to resistivity along 2-D profiles.

Reservoir characterization

The MTEM data can be interpreted as a standalone product but the full value is realized when the inversion results are overlain on seismic 2-D depth sections showing the structure and stratigraphy. The reservoir(s) can then be evaluated easily for N/G, thickness and saturation. In well constrained cases where the storage capacity of the reservoir is well known, the STOOIP can be estimated.

Time-lapse monitoring

Seismic has proven the value of time-lapse or 4-D monitoring and is now uniformly recognized as an accepted technique. However, only half of all the reservoirs are suitable for seismic 4-D evaluation, whereas a large part of the remaining half should be well suited for MTEM 4-D. Resistivity monitoring has some significant strengths compared with seismic impedance monitoring. For example, many reservoirs require significant withdrawal of hydrocarbons before a detectable seismic 4-D signal is achieved as seen in Figure 1 below.

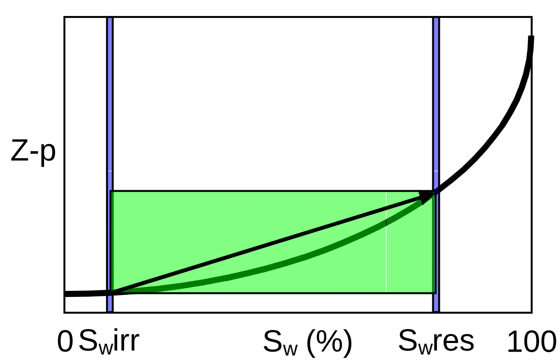

Figure 1: The water saturation (S_w) involved in seismic 4D monitoring ranges from irreducible water ($S_w$irr) at full hydrocarbon charge and $S_w$res at residual hydrocarbon saturation. The trajectory is close to linear and a detectable 4D signal may only be achieved at the later stages of production. The maximum acoustic impedance (Z-p) change is typically less than 20 %.

On the other hand, the resistivity changes most dramatically at maximum in situ hydrocarbon saturation facilitating 4D evaluation of possible by-passed volumes early in the production cycle, as seen in Figure 2 below.

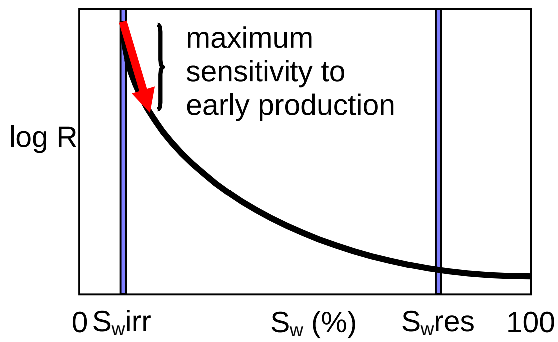

Figure 2: The range of possible water saturations from $S_w$irr to $S_w$res is the same as in the seismic case, but the resistivity is represented logarithmically. The 4D change in resistivity can cover three orders of magnitude.

Resistivity will then provide a much larger time-lapse change for a given saturation change, but EM suffers a loss of signal when the lateral extent of the by-passed volume is small in relation to depth of burial. Each case has to be evaluated individually by means of modelling, but the signal strength as a function of target size will appear as in Figure 3 below.

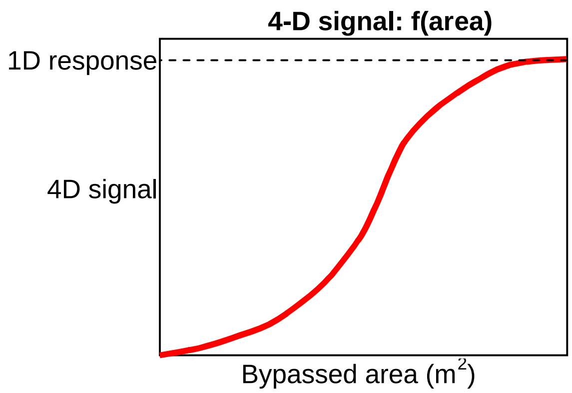

Figure 3: The time-lapse signal from a by-passed area describes an S-shaped curve as a function of area. The exact shape of the curve has to be determined in each individual case, since it is dependent on the entire resistivity depth profile.

Seismic is also sensitive to increased effective stress that results from reservoir pressure draw-down, and the stress effects tend to radiate up into the overburden affecting the velocity field. This makes it harder to equalize time-lapse volumes. Resistivity is not sensitive to stress, only to porosity loss that may affect the reservoir but not the overburden. This combined with excellent repeatability makes constrained MTEM inversion a very sensitive monitoring tool.

In Table 1 below the strengths of MTEM are compared to the strengths of seismic in terms of in situ characterization and 4-D monitoring.

Fluid characterization & 4D	**MTEM strengths**	**Seismic strengths**
In situ characterization of economic oil & gas reservoirs	All reservoirs except low resistivity pay	High porosity reservoirs & light fluids
In situ characterization of non-economic HC saturations	Yes	Cannot characterize gas saturation
4-D of high porosity reservoirs	With any hydrocarbon or CO2	Light oil with high GOR & possibly gas
4-D of low porosity reservoirs	With any hydrocarbon or CO2	No
Early 4-D changes	Most sensitive at early times	Linear with weak sensitivity at early times
Stress effects	Not sensitive	Sensitive
Porosity loss	Sensitive	Sensitive
Repeatability	Very good	Poor to fair
Cost of acquisition & processing	Wide range	Wide range
Environmental footprint	Smaller	Larger

Table 1: Comparison between MTEM and seismic of in situ characterization of hydrocarbon saturation and 4-D saturation changes.

Conclusions

MTEM offers a strong alternative to seismic in many situations where seismic cannot reveal in situ characterization of fluid type and saturation, nor any 4-D changes in saturation. The two technologies complement each other and provide a very strong solution when combined. Seismic can provide the structural and stratigraphic information and MTEM reveal the hydrocarbon saturation, hence de-risking proposed drilling targets.