Uses of Lotem for Indonesian hydrocarbon applications

R. Aftartu[1], S. Davydycheva[2], and K. Strack[2]

[1] *Sucofindo, Jakarta*
[2] *KMS Technologies , USA*

*corresponding author's email : Kurt@kmstechnologies.com

Abstract. While magnetotellurics has been used extensively in Indonesia, the percentage of good quality data is limited due to the high population density and often the geologic condition. We investigate application of controlled source electromagnetics (CSEM) in the time domain, sometimes also known as long-offset transient electromagnetics (Lotem) because it overcomes the noise issue by using a high-power transmitter. Among many applications for Indonesia we have selected sub-basalt and porosity mapping in carbonates where we can demonstrate the benefit of the technology with successful Lotem case histories of the past and illustrate its new use with 3D modeling.
Sub-basalt exploration is hindered by either diffuse reflection of the seismic wave or high seismic velocities. EM sees transparently through them. Targets are resistive (hydrocarbon) and conductive (sediments). We are illustrating the success of Lotem with results from Europe and India for similar situations including joint inversion with magnetotellurics.
Carbonate porosity mapping is also difficult for seismic due to the high velocities and the low acoustic velocity contrast between oil and brine. The latter shows an excellent resistivity contrast and since the section is resistive it is also an ideal Lotem target. Over the past few decades there have been similar applications in Australia and Europe which at that time appeared challenging but in today world with more successes in EM make complete sense. We also illustrate the use of improved focusing for a case history in Papua New Guinea where we avoid the influence of near surface karsting.

INTRODUCTION

Indonesia has used electromagnetics historically for its mining and geothermal industries. For geothermal mostly magnetotellurics is being used. For hydrocarbon, only offshore CSEM is used. After the commercial success of marine electromagnetics [1, 2], the interest in land electromagnetics was revived. Over the past 15 years, we have developed a complete new generation of electromagnetic hardware that can be used for land, marine and borehole applications. Key in making surface measurements successful is the integration and calibration with borehole data.

Since Indonesia's geology has many application opportunities for CSEM, we have selected two of the bigger ones: sub-basalt mapping and carbonate porosity mapping. The first sub-basalt problem we illustrate with a case history from India and the second with a 3D feasibility modeling study using a model derived from a Papua New Guinea (PNG) case [3, 4] which is like the one from Indonesian oil fields.

While magnetotellurics is a passive EM method using signal coming from currents in the ionosphere and atmosphere, CSEM uses man made signals generated by a grounded dipole transmitter on the Earth's surface. The responses this signals generate in the subsurface are recorded. Details of the CSEM technique used, namely the Lotem method are described by Strack [5]. Lotem today, unlike described by Strack (1992), is defined as TEM method with grounded dipole when the offset is equal to or larger than the target depth [6].

SUB-BASALT CASE HISTORY

The sub-basalt case history from India developed over a period of over 25 years. First a project was proposed and a feasibility carried out in 1986. After funding the field work was done in 1989 with subsequent interpretation over the next 2 years. In 1999, a well was drilled and another 3 years the loops were closed and the material was reconciled and finally partially published as synopsis in 2007 (Strack, and Pandey, 2007). Figure 1. Show the survey map with the survey being done around the deep electrical sounding profile shown at the top left of the figure. The deep electrical sounding results were not very reliable due to the long spacing and the low power equipment plus interpretation used pre-1985. However, it did show that there are conductors, most likely sediments under the basalts. This was used as input to the Lotem forward modeling shown in Figure 2. The curves in the figure are early and late time apparent resistivities. Two parameters, the thickness of the Deccan trap basalts and the thickness of the Mesozoic sediments are of interest and varied. The variations show clear responses in the curves and based on them the survey was designed.

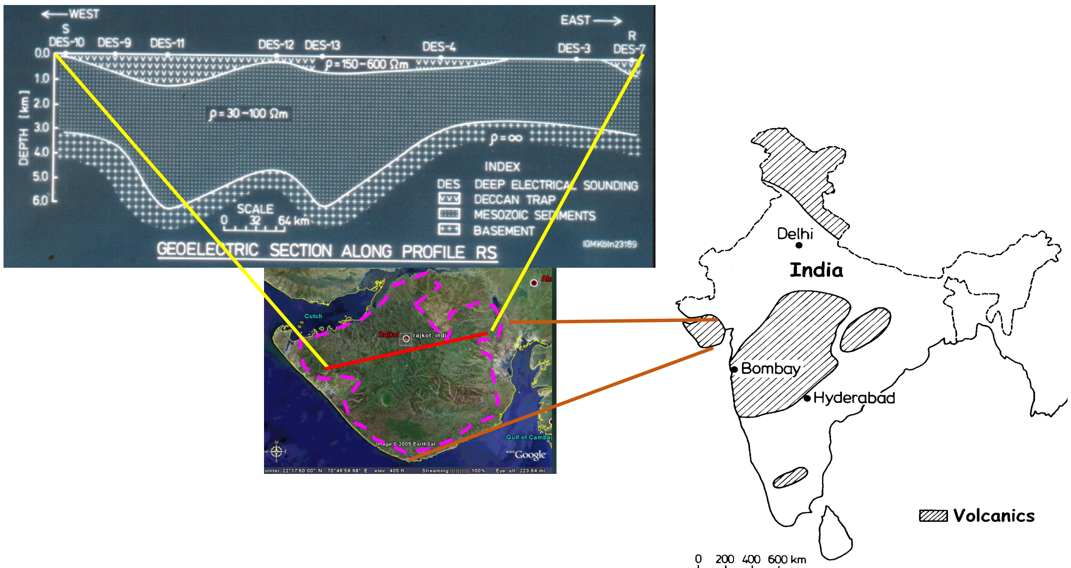


FIGURE 1. Location map of the sub-basalt survey in India. The work was carried out on the Saurashtra Peninsula shown in the center. The red profile indicates the location of the deep electrical sounding carried out by ONGC of India before.

The system layout is shown in Figure 3. Most of the receiver sites were broadside. The source was about 1 km long with 400 A current being injected into the ground. Figure 3. also, shows the current waveform and the magnetic field receiver waveform plus pictures of the transmitter and the receiver. The contour lines in the figure indicate the induction current move out. The survey was then carried out in 1989 and for 2 months about 360 surface locations were recorded.

Normally, vertical magnetic field and two horizontal electrical field components were recorded and inverted without specific bias and sections as shown in Figure 4 resulted. The figure shows on the left side the data displayed as apparent resistivity curves with 95% confidence interval (shading). On its right we see the section compilations. Most of them were relatively stable and clearly one-dimensional. Profile R1 (2nd profile on the right) shows a dyke in the profile, which we verified with extensive 3D modeling. All the various models confirmed that the dyke was underneath the receiver. Given that Lotem has two primes areas of sensitivity (namely under the transmitter and under the receiver) this questions needs to be answered in every individual case. The final test was to take the 3D synthetic data and invert it with one-dimensional inversion to see where the information content is spatially derived from. The results of this exercise are shown in Figure 5.

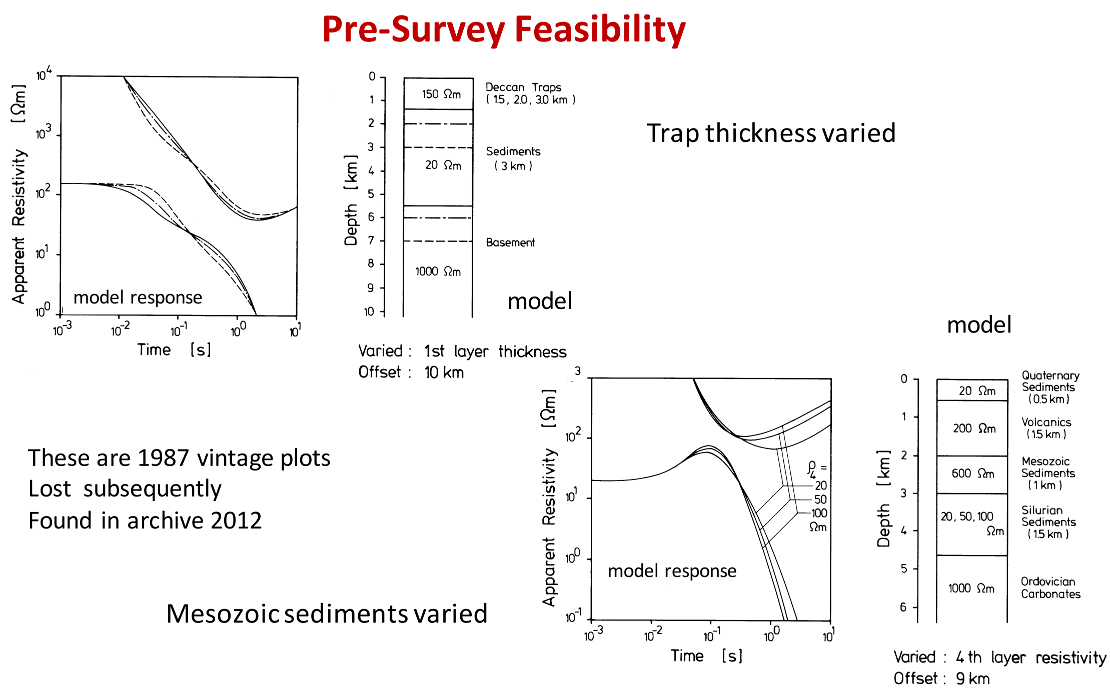


FIGURE 2. Pre-survey feasibility results. The curves are early and late time apparent resistivities for model variations due to variation of basalt thickness (top left) and sediment thickness (bottom right).

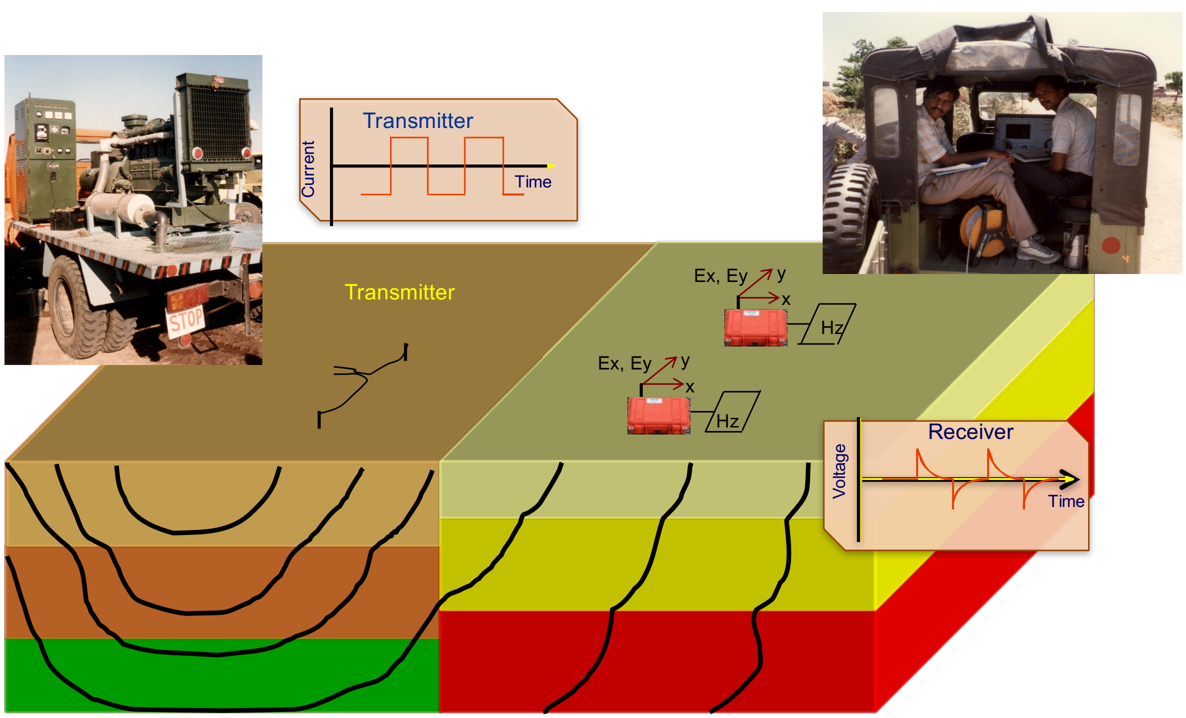


FIGURE 3. Typical survey layout of transmitter and receiver. Equipment sample pictures for the India survey; current wave form and receiver data are also shown.

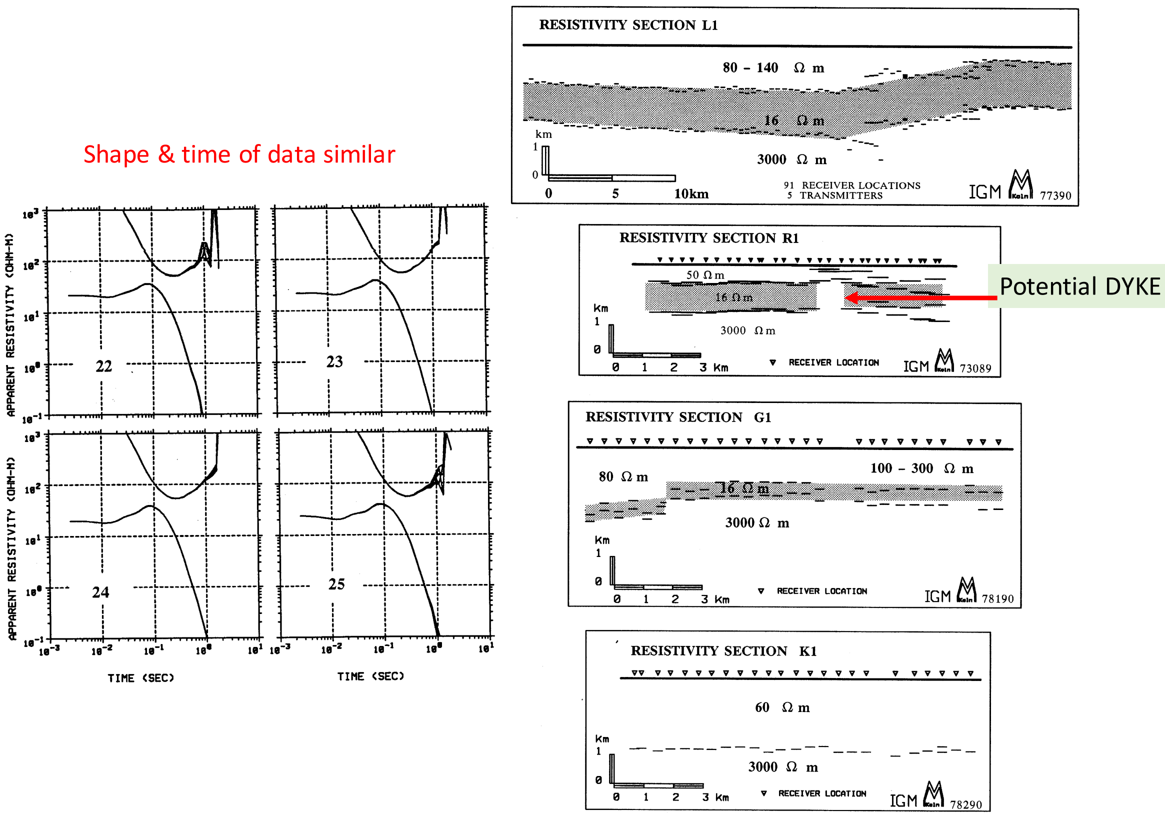
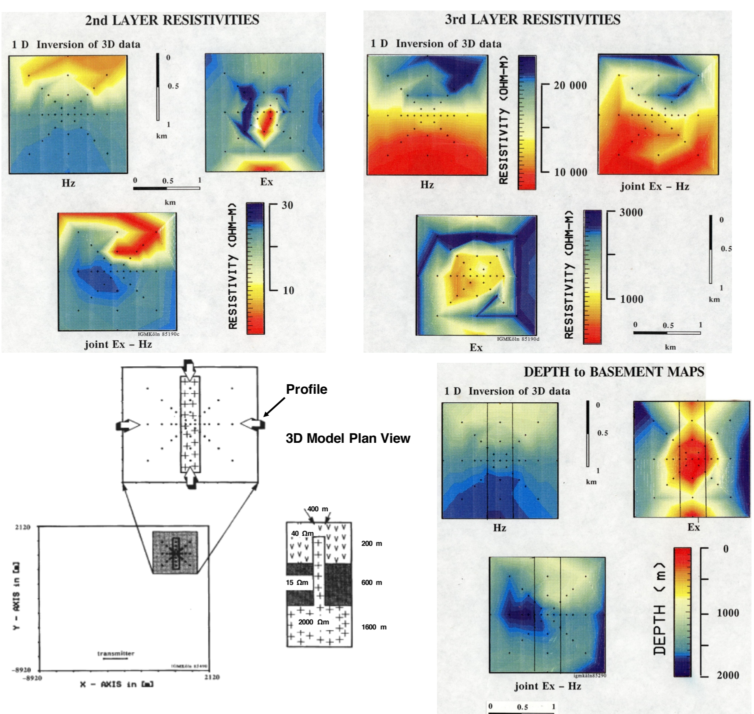


FIGURE 4. Sample processed data for the India survey (right side) and inversion results for several sample sections.



- Anomaly is located underneath receiver
- Electric field less sensitive than magnetic field
- Total conductance is BEST

FIGURE 5. Compiled inversion results for 1D inversion of 3D model synthetic data simulating the dyke structure in Figure. 4.

Figure 5. shows the individual and joint inversions of the electric and magnetic fields for the model resistivities of the 3 layers and total thickness. In the bottom center of the figure we also have the model and survey plan for the synthetic data. The individual inversions do not show the dyke structure but the joint one allow a hint. The Total thickness inversion clearly outlines the dyke in the electric field as does the total conductance [7]. Based on these results the well location was picked around thickest sediment package below the basalt and a well was drilled (Rajkot 1). The log interpretation is shown in Fig. 6. The sediments as predicted from the Lotem measurements were confirmed within 90-95% accuracy.

After these results more wells were drilled in the area penetrating the Deccan traps and more recently significant oil reservoirs were found in the Kutch. Electromagnetics is now part of every exploration program in India.

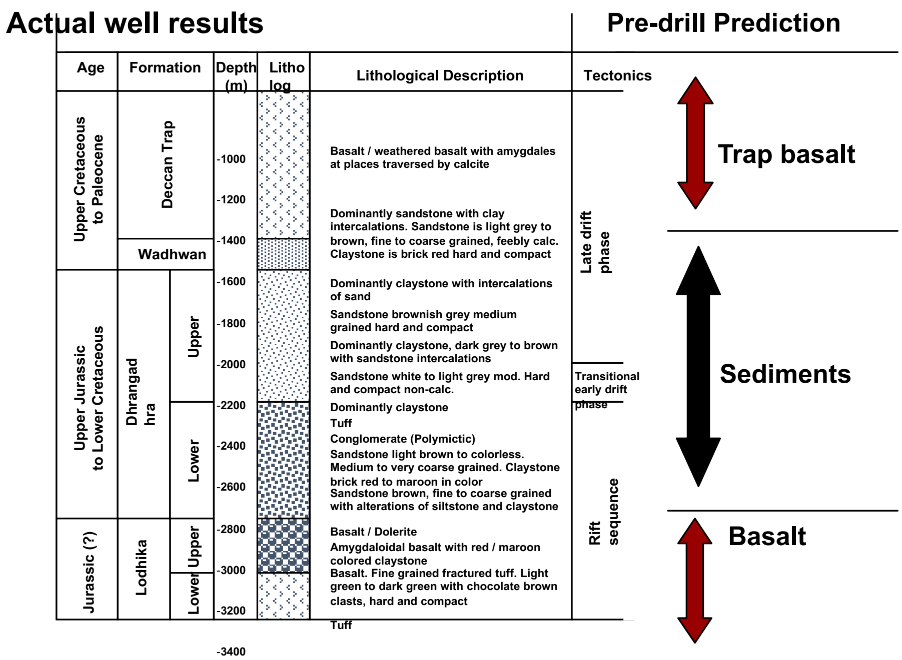


FIGURE 6. Compiled well log response for the Rajkot well drilled on the Lotem results. (after Strack and Pandey, 2007)

CARBONATE MAPPING FEASIBILITY

In Indonesia, several oil fields have carbonate reservoirs. Mapping the sweet spots inside the carbonates is important as seismic is not very accurate due to the high velocities in carbonates. Since the geologic details of these oil fields are proprietary, we selected an oil field from Papua New Guinea which has similar well known problem.

As shown in the previous case history, the focus of the information is always of concerns. We thus calculated 2D sensitivities for frequency and time domain CSEM and show the results in Figure 7 (left). For the frequency domain sensitivities, the depth of investigation (and information volume) increases with offset. For the time domain, we have the above mentioned dual focus underneath the receiver and the transmitter. On the right side, we display the current patternafter focusing it by taking differential measurements for either time or frequency domain Focused Source EM (FSEM) [8, 9, 10, 11]. We can clearly see that the information now comes from below the receiver. The focusing is obtained by taking the differences of adjacent measurements, like laterolog focusing [12], or even using a circular array. In the following figures, we will investigate this further for the PNG feasibility. The target in this case is at the depth of approximately 1600 mand its model is shown in Figure 8.

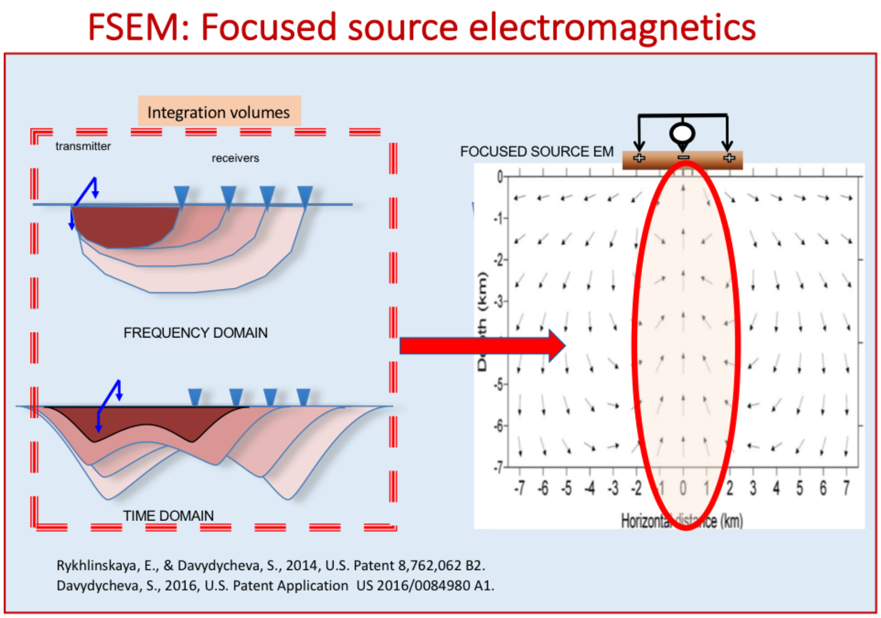


FIGURE 7. 2D sensitivities for frequency and time domain CSEM (left) and focused source EM (right).

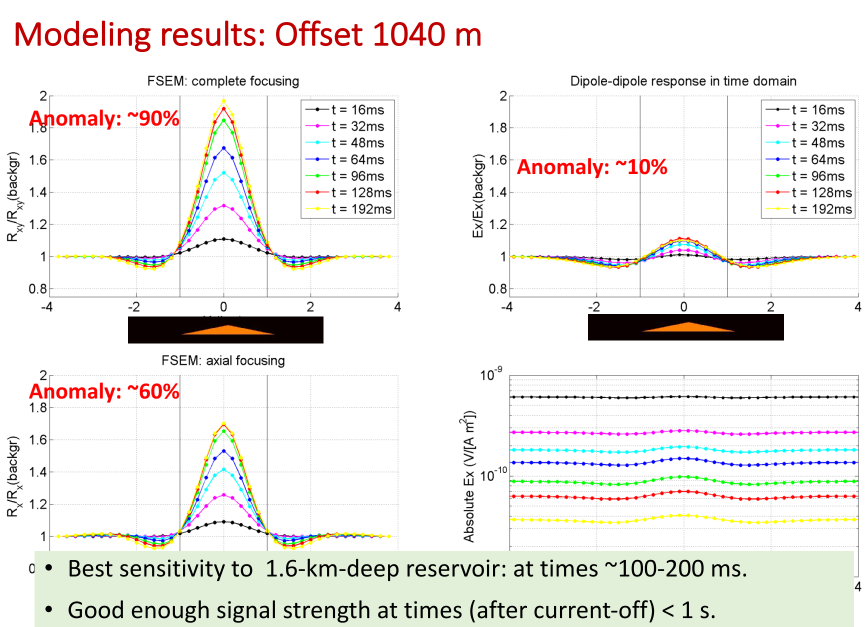


FIGURE 8. Modeling results for a carbonate model at 1600 m depth. On the left are the FSEM and on the right the lotem time domain results.

Figure 8. shows the anomaly due to a resistive reservoir for both linear (axial) and circular (complete) focusing on the left and for standard Lotem on the right. The modeling was performed using 3D EM modeling software [13]. Displayed are different decay times after switching-off the current. The anomaly is significantly enhanced by at least a factor of 6. Next we add near-surface inhomogeneities to the model, wherethe carbonate karsting is a serious issue. We included a resistive and a conductive anomaly in Figure 9.

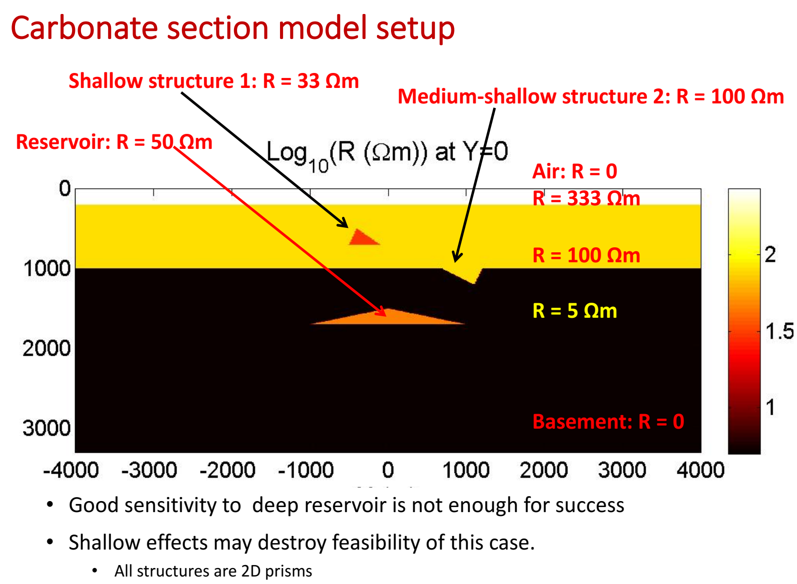


FIGURE 9. Model setup of the carbonate model with near surface inhomogeneities.

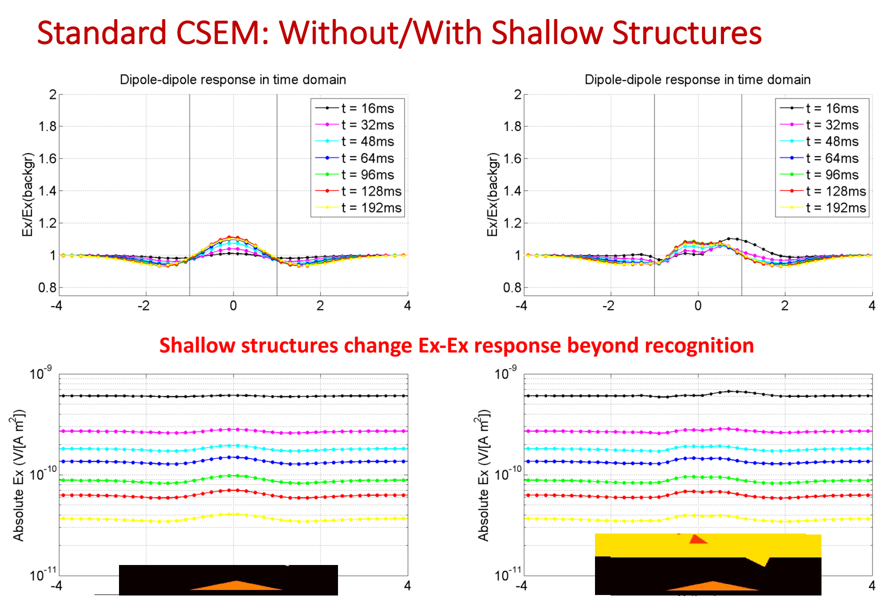


FIGURE 10. Modeling results for a carbonate model at 1600 m depth. On the left: the CSEM without shallow karsting; on the right: the response when the karsting is included.

Figure 10. shows the modeling response of the standard Lotem with and without the near-surface inhomogeneities (right). Clearly, the near-surface effects are signifcant and disturb the shape of the curves beyond the recognition. Displayed are different decay times after switching-of the current. Figure 11. shows the same models but for the FSEM configurations. The anomaly is much larger and we can clearly see that the shallow structures are time separated from the deep ones. Subtracting these responses at early times removes this effect as shown in Figure 12.

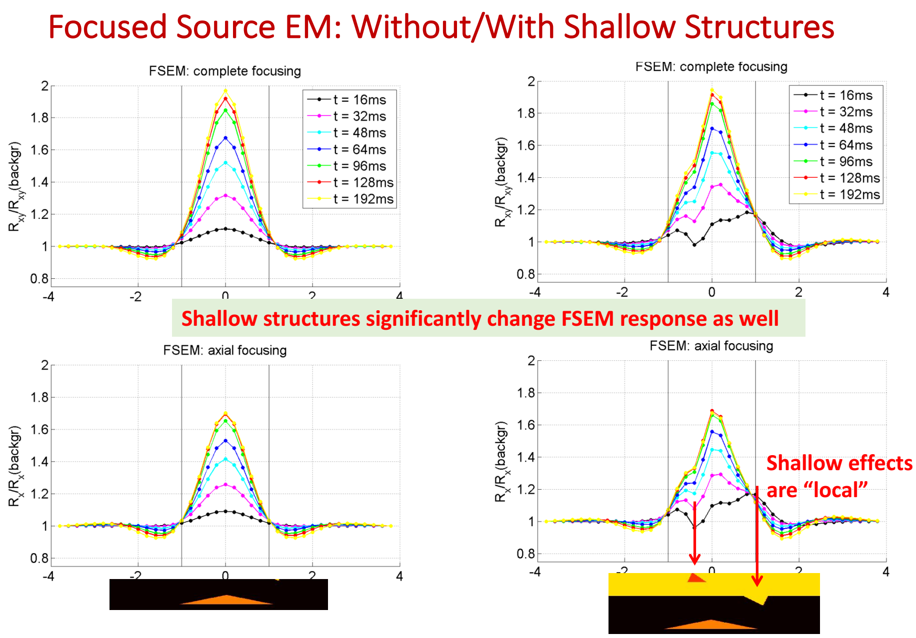


FIGURE 11. Modeling results for a carbonate model at 1600 m depth. On the left are the FSEM without shallow karsting and on the right the response when the karsting is included.

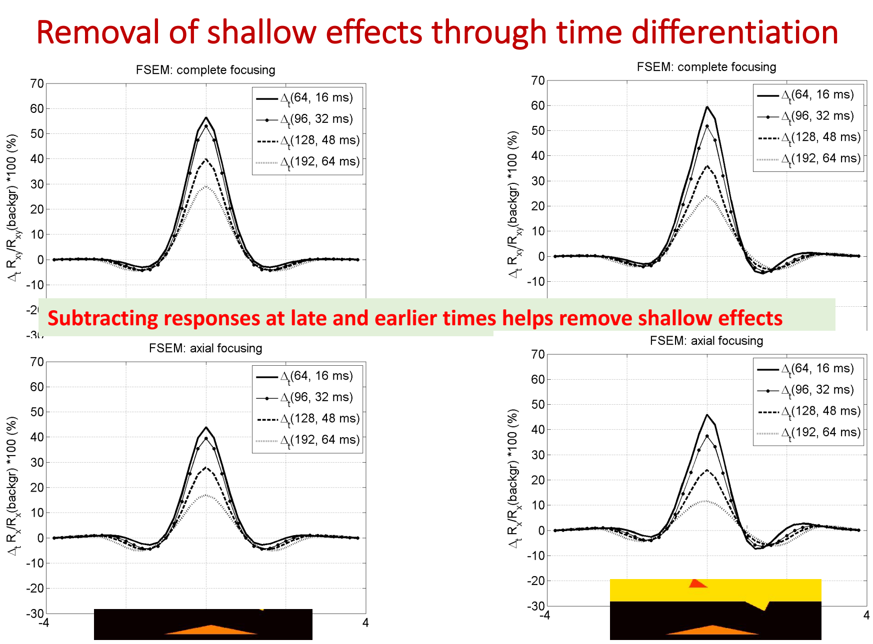


FIGURE 11. Modeling results for a carbonate model at 1600 m depth. On the left are the FSEM without shallow karsting and on the right the response when the karsting is included, and now the shallow effects have been removed.

CONCLUSIONS

Controlled Source Electromagnetic methods are routinely applied for geothermal exploration and only to a more limited extend for land hydrocarbon exploration. In Indonesia, they are important as MT has often problems with noise. Indonesia also has many EM specific challenges such as sub-basalt imaging or mapping within carbonates.

A case history from India shows what we can expect for Indonesian conditions. In the Indian case the results were successfully confirmed bydrilling and the methodology is now part of the routine exploration workflow. A feasibility using 3D modeling and focused source EM shows that we can get information from below the receiver and even remove near-surface effects and artifacts in the data.

This makes this method a prime methodology for Indonesia.

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