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Re-processing gegacy CSEM Data Unlocks New Potential Offshore Brazil

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Controlled Source Electromagnetic (CSEM) technology has emerged over the last two decades as a vital geophysical tool in offshore hydrocarbon exploration, playing a critical role alongside traditional seismic methods, *Menez et al* . Based on the principle of electromagnetic induction, CSEM involves the injection of low-frequency electromagnetic energy into the subsurface using a horizontal electric dipole (HED) source. The returning signal, modified by the resistivity distribution of the underlying formations, is recorded by an array of seabed receivers (Figure 1).

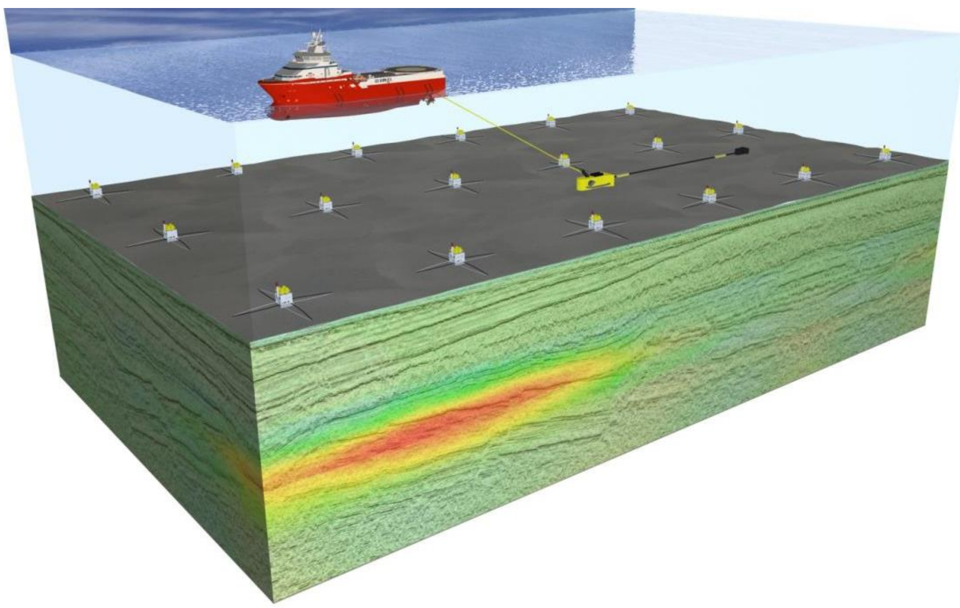

Figure 1. CSEM acquisition schematic showing receivers on the seabed in a grid format. Horizontal electric dipole source being towed using vessel.

CSEM emerged in the early 2000s as a geophysical technique designed to measure subsurface resistivity. In hydrocarbon exploration, the resistivity contrast between hydrocarbon-saturated reservoirs and surrounding water-bearing sediments allow CSEM to offer direct indications of hydrocarbon presence. While seismic excels at structural imaging and reservoir mapping, it lacks the ability to resolve fluid content unequivocally. CSEM bridges this gap by directly detecting resistivity values typically associated with hydrocarbons, thus complementing seismic data and reducing exploration risk, providing unprecedented hydrocarbon presence, volume information and a qualitative measure of reservoir quality

The method showed promising results during initial trials and was subsequently adopted across a range of geological basins, including those in Africa, Norway, Malaysia, and Brazil. In cases with simple geology, CSEM delivered the expected outcomes. However, several limitations began to quickly surface particularly in areas characterized by complex geology. These shortcomings gradually impacted on the broader adoption; despite its great promise, value delivery turned out to be harder than initially thought.

The early surveys were executed using first-generation technology: HED sources capable of emitting up to 1,000 Amps of current, and approximately 60 seabed receivers equipped to capture the returning EM signal. These efforts were primarily exploratory, attempting to assess the value of CSEM in the Brazilian geological setting. Data was acquired mostly by early adopters Shell and Devon in 2005, followed by Petrobras in 2D line configurations with a few small 3D grids, and later larger 3D surveys by Petrobras from 2011 and onwards

In these early years, the tools available for data processing were immature and the inversion algorithms failed to provide any meaningful or robust resistivity images. These left interpreters having to look at electromagnetic field measurements, which made CSEM data interpretation an almost impossible task, except for simplest geological cases. As a result, while technology showed promise, and there were few discoveries based on rudimentary interpretation the technology failed to provide consistent and clear results. Several of the data sets from this era were archived, awaiting advances in processing and imaging tools that could unlock their potential.

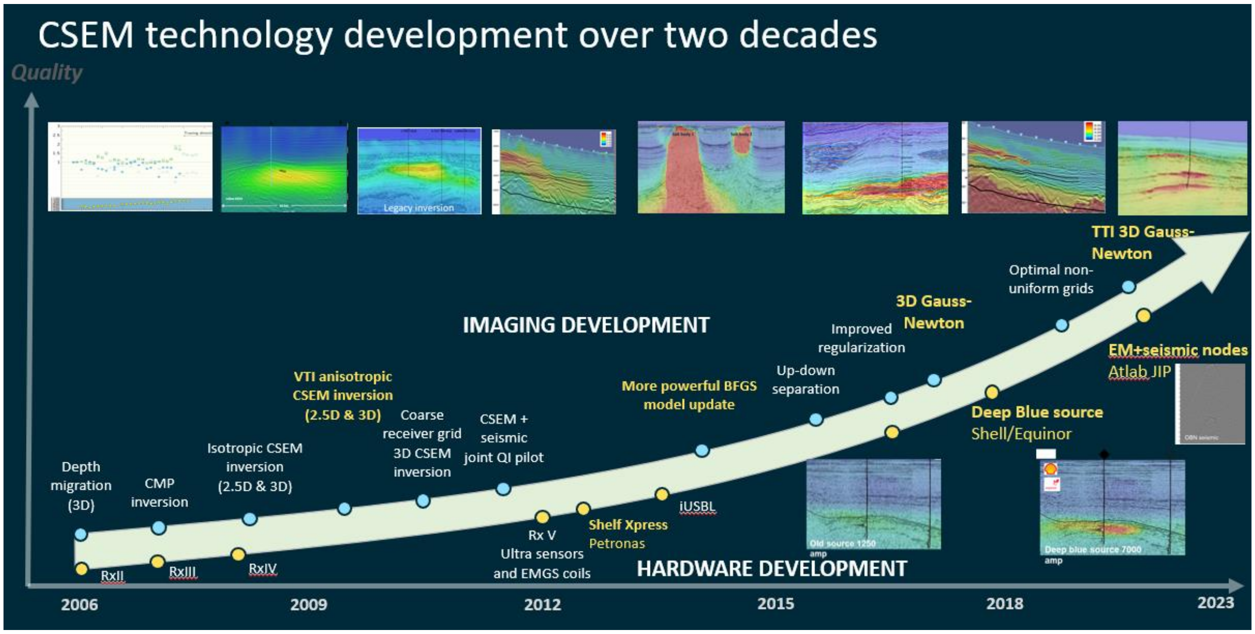

Figure 2. CSEM technology development from its early stages when the technology was first deployed in Brazil and through to 2023 technology which was used in the 2024 survey for Petrobras in Brazil

Now almost 20 years, figure 2 later the hardware and software has matured with a more powerful source enabling deeper imaging with higher frequency and on the software side, In the data processing and inversion software side, modern Gauss-Newton-based Full wave form inversion algorithms, combined with TTI wave propagation, allow accurate resistivity imaging even in geologically complex settings such as inverted fault blocks. This imaging can be done relying only on CSEM information, providing an independent source of geological information. Interpretation workflows and techniques have been developed to integrate seamlessly with seismic and geological models, providing a coherent framework

While the main value is expected to be derived from new 3D surveys in the frontier Southern Santos and Pelotas basins, re-processing result of legacy data do show multiple undrilled high resistivity anomalies have been identified in these re-processed legacy data set (Figure 9) that could indicate presence of saturated hydrocarbon accumulation still to be explored both in more mature areas, Campos and further apart such as Espirito Santos and Foz de Amazona

A few data examples can be studied as these in the Campos basin, figure 3,4 and 5. Over the Xerelete field a 3D survey was re-processed and allowed for well calibration to understand the CSEM response from these reservoirs, the downdip well is in the oil transition zone and hence have saturation levels below detectability for CSEM while the upper crestal well is well within the CSEM resistivity expression. Similarly, in the Basilisco discovery one can infer from seimic and CSEM that the reservoir quality and saturation levels will increase away from the well This is important for any development work and for understanding the response of yet to find resources as possible those in figure 5. This is a case example in the Campos basin, but similar observations are made in several other basins and will be demonstrated further in the presentation.

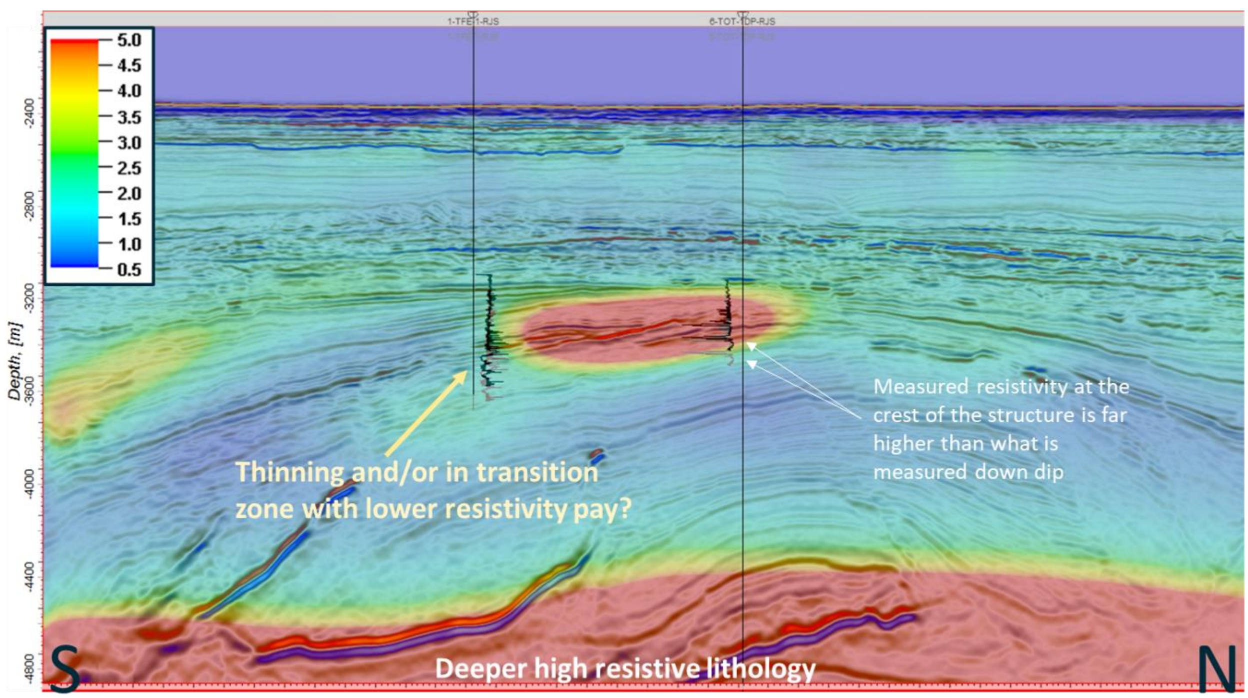

Figure 3 shows a random line through two wells in the Xerelete Field, where the downdip well is in the oil transition zone and hence have saturation levels below detectability for CSEM while the upper crestal well is well within the CSEM resisity expression

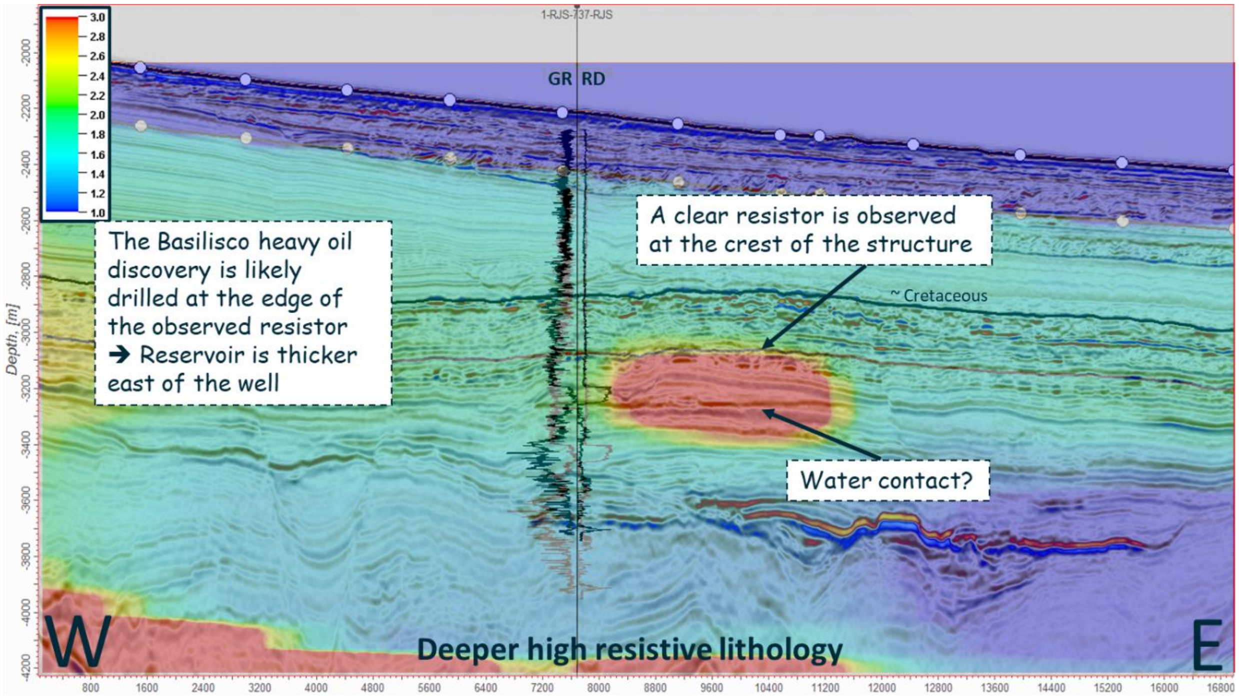

Figure 4. A CSEM and seismic line through the heavy oil Basilisco discovery. In the well location it appears to be below detection threshold and both the CSEM resisitivity and the seismic appearance indicate a thickening of the reservoir towards the East.

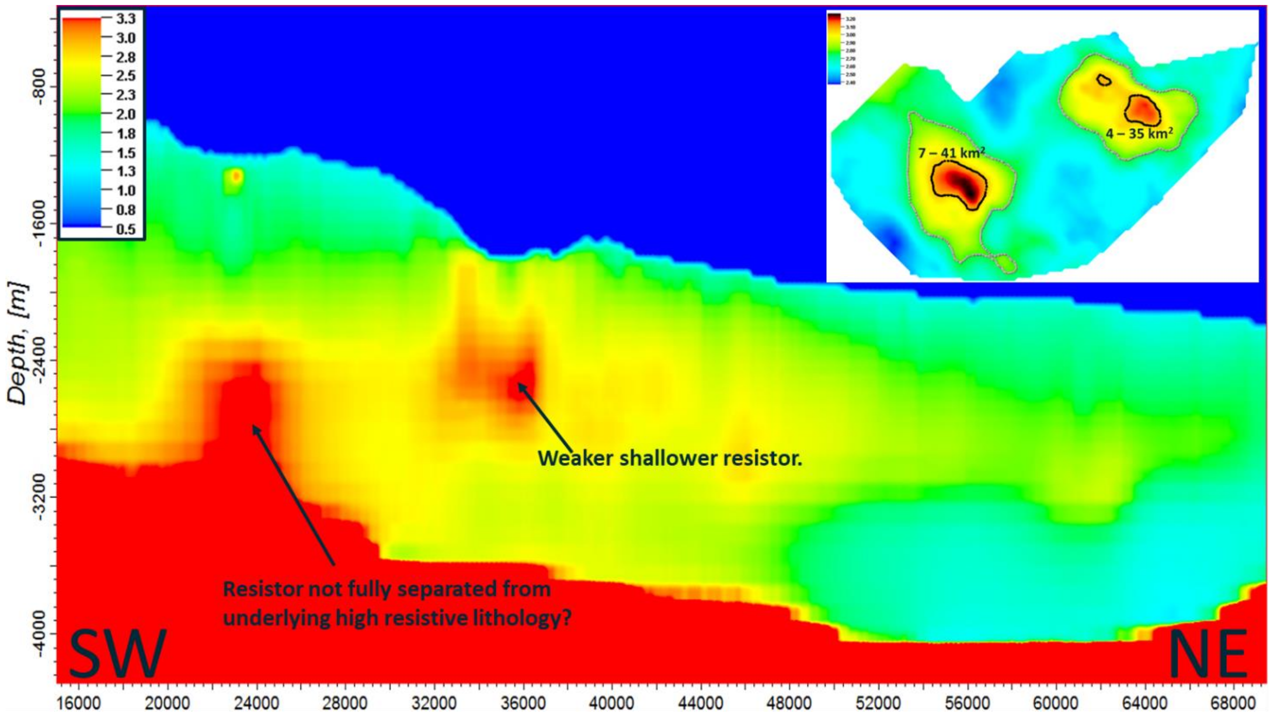

Figure 5. Example of other resistors found in a nearby legacy 3D survey and the areal size of the resistive anomaly

Conclusion

CSEM can be a catalyst for smarter exploration in the years following in Brazil in two ways.

Going back and re-processing and interpreting legacy data data was earlier overlooked due to in-capability to image the data at the time of acquisition. There are jewels to be found. Furthermore, with learnings from legacy data to better explore many of the frontier Brazilian basins through acquiring more 2D and 3D modern CSEM data.

References:

Menezes et al. 2023, Twenty Years of CSEM Exploration in the Brazilian Continental Margin, Minerals