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Wide azimuth 3D-CSEM is an additional geophysical tool to tie with seismic in reservoir evaluation

ABSTRACT

First wide azimuth 3D-CSEM (Controlled Source Electro-Magnetic) API project was conducted by ONGC in KG offshore to demarcate the established plays and find new reservoirs. The current paper is a case study, focused on all through the API stages, starting from survey design, acquisition & processing work flows with QC standards and interpretation after integration the result with the other G & G data. The equipment, survey parameters & operational details were discussed broadly and key processing steps and results like Fourier Transform, data rotation, masking and NMvO attribute for QC were discussed later. At the end, the CSEM results were discussed in brief with an example for the existing prospect and drilling targets.

INTRODUCTION

Seismic is the best tool for oil industries to investigate the subsurface information, but it is not enough. Therefore the focus is gradually shifting from elastic to resistivity property of the rocks and integrates both to reduce the risk of dry hole. During last one decade, Controlled Source Electromagnetic (CSEM) technology gone through a numerous development and today it stands on its own feet. CSEM is a tool, based on the electromagnetic principle, which allows remote sensing of subsurface resistivity variations and this variation is subjected to the fluid content in pores space of rocks. A detailed description of the method is given in Eidesmo et al. (2002) and Ellingsrud et al. (2002). The acquisition technique is analytical with normal Ocean Bottom Node seismic technology (Farrelly et al., 2004 and Summerfield et al., 2005) but processing is far different than seismic, so far inverted result correlates with seismic for better interpretation.

The study area, KG-DWN-98/2 is the part of offshore Krishna Godavari Basin and a developing oil field, targeting to produce first gas in June 2019 followed by oil production in March 2020. The main challenge in seismic here is to distinguish between the low & high saturated hydrocarbon bearing sediments, because both of them produces Similar type of AVO signature. To resolve the issues from seismic, 3D-CSEM survey was carried in 2016 to precisely demarcate resistivity anomaly extent of existing discoveries to improve in volume estimation and identify any other new prospective areas in this block.

EQUIPMENT:

Unlike the discrete sources used in seismic acquisition, the CSEM source transmits a continuous predefine waveform through a horizontal electric dipole (HED), attached behind the towfish (main controlling & navigation unit) which is feed by high voltage current and mounted by a umbilical cable from the survey vessel.

The CSEM receivers are autonomous sea floor units deployed at pre-determined locations such as OBN sensors. Each receiver unit has been assembled by a buoyancy system, recording unit / data logger, battery, transponder, acquisition unit, magnetic and electric sensors and removable sensor and the whole assembly mounted on gravity based anchor (constructed by compacted sand with life approximately six month). Each unit have two sets (Orthogonal) of electric field (silver/silver chloride electrode) sensors which is capable to measure potential difference in the pico Volt (pV) range and two induction coil magnetometers (parallel to the electric sensors) in a non-metal housing, measuring induced current due to a time-varying magnetic field.

The data logger (DAU) is the main electronic hardware in the receiver assembly. Both the electric and magnetic signals are registered and amplified before they get digitized and stored on internal storage device (8GB compact flash card) in a 24 bit format. A GPS synchronized internal clock time stamps the signals.
Both the source & receiver underwater positions were monitored by two acoustic USBL (Acoustic ultra-short baseline) transponders.

SURVEY DESIGN

The total survey area 500 Km^2 area (Figure 1) was covered by 520 receiver nodes and 44 source towlines (22 lines overlap), heading towards north-south. But, due to limitation of the receiver nodes the whole area was divided into 6 SLS (Survey Layout Sheet, like swath in seismic) which was endorsed to record minimum 4 km azimuthal data. The receivers were preferred to deploy in staggered mode to allow more azimuthal data point at different location than the regular configuration. In staggered mode operation receivers will acquire data in 1 Km X 1.1118 Km grid, but processed in 1Km X 1 Km resolution.

To generate an ununiformed square waveform (Figure 2) with 8 second time period having base frequency 0.125 Hz and its required harmonics, HED source was feed by 1200 Ampere current through towfish mounted transmitter.

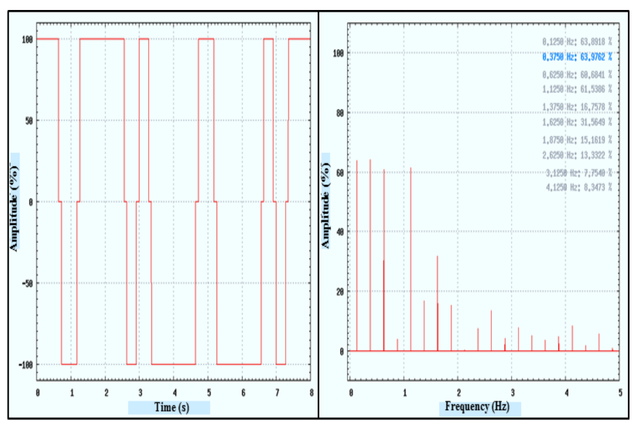


Figure 1: Survey Layout Sheet (SLS). White line- area boundary, Rx – receiver locations, Tx – Source Tow Lines. Colour codes indicate the SLS relation.

Figure 2: A. Source waveform in time domain (Left) & frequency domain (Right)

3D-CSEM OPERATION

1. CESM acquisition started with analyzing of environmental noise, caused by MT signals, sea swelling etc. One or two receivers were deployed initially in shallowest location of the area, allowed to capture background noise for 2/3 days. Noise profile is required to validate the pre-designed source waveform.

2. Towlines bathymetry (Figure 3) is essential to prepare suitable “flight path” for smooth source towing and detail receiver deployment planning. It was carried out by close spaced (10.5 m) single beam ecosounding.

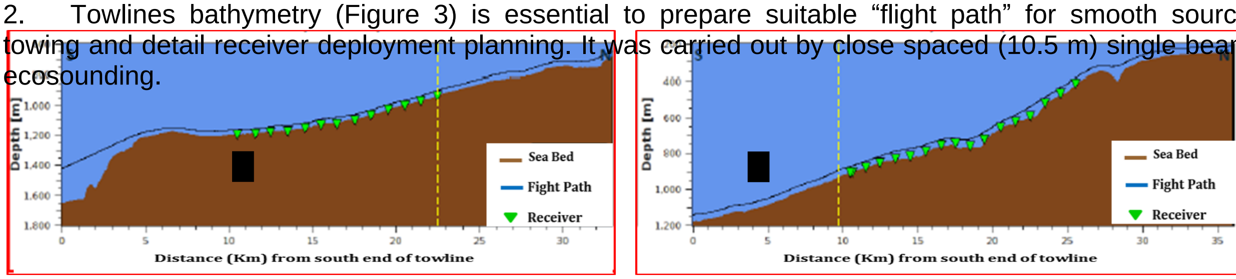


Figure 3: Seafloor topography along same towlines; A. SLS 02 from south & B. SLS 04 from north. Yellow dotted line indicates overlap region.

3. Performance of each receiver tested before deployment, and then assembled with a heavy weight anchor. Receivers were dropped from the survey vessel at their respective pre-plot location and allowed to sink freely down to the seabed. Acoustic USBL communication was used to measure the exact receiver position.

4. HED Source towed over the seabed receivers by maintaining on an average 30 m altitude along the designed flightpath by generating continuous waveform. Source covered a length of 10 km outside the each end receiver lines. The peak-to-peak current (1200 Amp) kept constant during the operation and the altitude of towfish from seabed was controlled by changing the length of umbilical cable. Towfish was allowed to move in higher altitude at steep deep (slop >4^0) areas.

5. An acoustic signal sends from the vessel to trigger the realise mechanism at the end of SLS operation and it releases the receivers from their anchors to float back to the surface. The completeness of record was checked after recovery of receivers and data harvested from the flash drive to the onboard storage device.

6. Quality of acquired data was checked by on-board QC processer to examine the requirement of redeploy or retow. Later on data delivered to the processing center for further processing.

CSEM DATA & FIELD QC

Both the orthogonal components of electric (E) and magnetic (H) field were recorded in time domain but it transformed into frequency domain for processing and merged with navigation data. The receiver registrations were then presented as Magnitude Versus Offset (source receiver distance) – also termed MVO plots for QC check.

Raw time series (Figure 4) can represent the signals and background noise pattern. Background MT noise was always less than 0.1 HZ throughout the survey but little bit dominating in magnetic field, therefore it didn’t affect the required frequencies.

Collectively all the receivers (except one) were kept within the range of 150 m away from its pre-plot position (Figure 5). No loss of data coverage was accounted as 7 failure receivers (caused by out of offsets specification i.e. 150 m or noisy H data) were redeployed and re-towed. Therefore all receiver stations have 100% usable electric and magnetic data. The recorded data is of good quality on all the dominated frequencies; the usable offset is up to 7 – 15 km depending on frequency (1.6725 HZ to 0.125 Hz), and the data quality is very consistent between receivers. The final quality assessment statistics shows that the recoverable data is 100% for both E and H.

PROCESSING

The processing started with Fourier Transformation (FT) of raw time domain data into frequency domain to extract noise from signal, and then rotated it into the inline-crossline frame to bifurcate to the two components E & H (Figure 6). The noise or unwanted data was masked depending on signal to noise ratio (S/N). The threshold mask value was applied as S/N of 10dB & 15dB for inline & azimuth data respectively, anything below the threshold will be masked (Figure 7).

Figure 6: Example; Result of frequency domain rotation of raw data along a single receiver inline. (MVO plot, A. before & B. after rotation)

Figure 7: Example illustrating the effect of data masking with 10 dB mask for all inline receivers over a towline; (MVO plot, A. before & B. after masking). Red circles highlight the changes before and after masking.

Normalized magnitude versus offset (NMvO- normalising each recorded receiver response by a reference receiver response) is a typical CSEM attributes, not meant for interpretation of the subsurface was used as QC tools to highlight noisy data points,. NMvO is represented by multi-offset line response prepared by plotting normalized response with all offset presented for each receiver on a towline for base frequency. It provides a qualitative overview of the response along the line and helps to find any outlier (Figure 8) or improper noise masking. The attribute analysis of this KG data has shown not only consistent data quality regional and along towlines but also dynamic in terms of the response strength. No outlier or unusual trend is observed in the data.

Figure 8: NMvO Plot; Comparisons of multi-offset line response for a single towline, with a rejected receiver (upper) and redeployed receiver (Lower). Outlier receivers (pink circle) can be identifiable in attribute analysis.

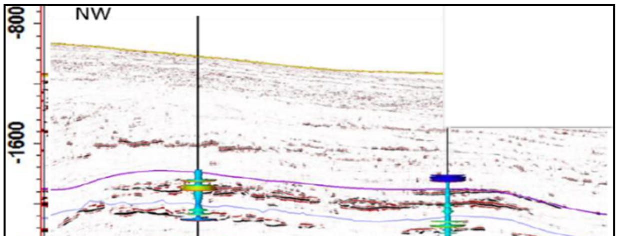
RESULT AFTER INTEGRATION WITH EXISTING G & G DATA

Gradient-based algorithm was used for unconstrained anisotropic 3D inversion, started with only geological inputs. Then the inverted model integrates with seismic as well as well data.

A set of evaluations (priors and CSEM integrated) has been produced for the already drilled targets and it simulates the possible evaluation performed before drilling any wells in the area. A similar process has been followed with the existing prospects and the upsides identified in CSEM. The result is a greater polarization of the evaluations of the existing targets and the addition of some high chance of success prospects to the block's portfolio. The results also can be compared with the drilling outcomes to understand if CSEM could have improved the exploration evaluation of the area decision making.

Also this data set is useful to re-evaluation of the volume estimation of existing prospect, because all the reservoir estimation parameters derived from seismic & well data is unable to estimate the area extension of the prospect which can be clearly demarcated by CSEM resistivity anomaly.

As an example, the seismic section in figure 9 provides only the reservoir thickness from high amplitude AVO anomaly in between the 1900-2100ms. But CSEM data integrated with seismic provides the extension (Figure 10) of the pore fluid saturation. Another interpretation regarding drill location, the well 2 drilled at the marginal location of the reservoir, it should be optimized towards right.



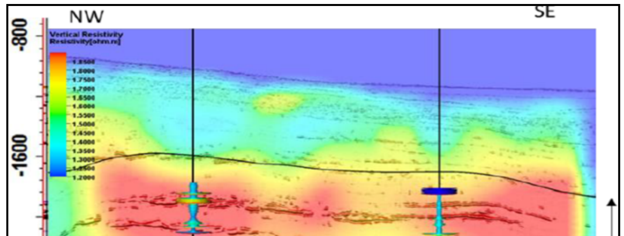


Figure 9: Seismic section, Bright spot AVO anomaly in between 1900-2100 ms.

Figure 10: The result after integration of same seismic section of figure 11 with CSEM. Red colour indicates the highly resistive zone and the colour code highlights the hydrocarbon saturation extent.

CONCLUSION

The chances of data gap can be shorted out in field itself by redeploying bad receivers and data quality was preserved by masking the unwanted noises in processing. It was assured after all QC check that all the receivers acquired 100% useable electric & magnetic data throughout project. The attribute, 'normalized magnitude versus offset' (NMvO) is the final QC tool to measure the consistency of data quality both regional and along towlines but varies in terms of the response strength and it also demonstrations that there is no outlier or unusual trend in the data.
3D-CSEM is an additional geophysical tool to demarcate the existing discoveries and improve the exploration evaluations. Therefore, it can be very much useful to prevent or delay the drilling of lower value wells, and optimized the drilling location for some of the targets.
As 3D-CSEM is a commercially viable supporting tool for reservoir potential evaluation, it can be helpful for feature prospect evaluation.

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