



7th International Conference & Exposition
on Petroleum Geophysics



“HYDERABAD 2008”

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Detection of sub-trappean sediments by Deep Resistivity Sounding studies in India

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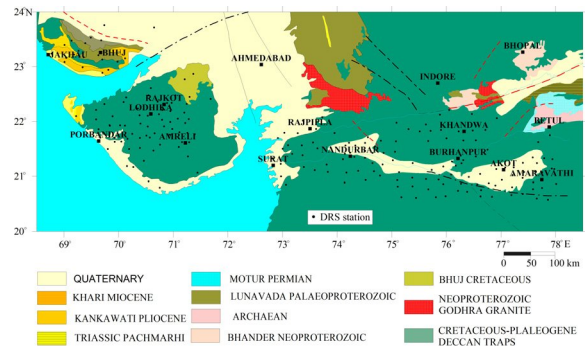
Summary

Two hundred twenty Deep Resistivity Soundings (DRS) were conducted to detect the thickness of trap, sediments and basement topography in trap covered areas of Saurashtra, Kutch and Deccan Syneclise areas by using high power deep resistivity equipment. Mostly, Schlumberger, electrode configuration was deployed up to current electrode spacing of 10 km at each station and in case of necessity it was extended with equatorial dipole array up to 15 km spread. Applicability of DRS technique for exploration of subtrappean sediments is enhanced because sharp resistivity contrast exists between trap sediments and bedrock. In this paper, some of the major results obtained from deep resistivity sounding (DRS) studies in Saurashtra, Kutch and Deccan Syneclise regions are discussed

Introduction

The Detection and mapping of the sediments in the Deccan trap covered area has been a long-standing complex geophysical problem faced by the oil industry. In this direction, some of the geophysical methods like gravity, magnetic, electrical, seismic etc play an important and indispensable role in comprehending the various intricacies of the subsurface of the earth. Despite the fact that the geophysical industry witnessed an amazing all round development, spatial location of subsurface targets and geological translation of geophysical measurements/interpretation still poses a formidable challenge to the practicing geophysicists and at times continues to be cumbersome particularly when the targets of interest concealed under massive resistive basalt. The sediments underlying the basaltic layers are of varying thickness and cause considerable uncertainty in the interpretation of geophysical data. In recent times, geophysical prospecting has moved towards the use of integration of electrical methods with other geophysical methods for regional and prospect evaluation prior to drilling. Electrical methods in general and resistivity in particular have proven cost effective for exploration in basalt-covered area. Recently, non-seismic geophysical methods got wide attention in hydrocarbon exploration, especially in mapping the trapped sedimentary basins

beneath the basaltic flows, which limits the seismic studies to a greater extent. The integrated explorative approach taken by NGRI in the basaltic covered regions of India, namely, Kutch, Saurashtra and Central Indian Deccan Syneclise (figure 1), evidenced significant Mesozoic sediments beneath the basaltic layers, prospective of future hydrocarbon explorations. The simultaneous use of Deep Resistivity Sounding (DRS), Magnetotellurics, gravity and seismics provide better resolution in the layer parameter estimations. The electrical resistivity contrast between the basaltic layers (Traps) and sedimentary layers provide a better opportunity to delineate the subsurface layers in these sub-volcanic provinces.





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Figure 1. Geology (after GSI, 1998) and Location map of Deep resistivity sounding locations in Kutch, Saurashtra and Deccan syncline region of central India

Methodology

Generally Schlumberger configuration with maximum electrode spread of 10 km is used to make measurements at each DRS station. If necessary, further depth extent is realized by deploying equatorial dipole-dipole configuration, to ensure probing the entire section of Tertiary sediments, Deccan Traps and Mesozoic sediments that overlie the basement. The calculated apparent resistivities (ρ_a) plotted on a double-log sheet against the half current electrode separation ($AB/2$) forms the resistivity sounding curve. The field-sounding curve is interpreted to get the true layer parameters such as resistivity and thickness. The conventional curve matching techniques can be applied using the available theoretically computed master curves and auxiliary curves for a large number of models. The introduction of computer algorithms for data processing and interpretation made the otherwise laborious resistivity sounding data analysis easy. The sounding data interpretation comprises two steps; the forward modelling and the inversion techniques. In the forward modelling one computes the apparent resistivity responses for a given model using different techniques (Stefanescu et al, 1930; Koefoed, 1970; Ghosh, 1971a & 1971b; Das and Ghosh, 1974; O'Neill, 1975 and Gupta Sarma, 1982). Inversion techniques make use of the iterative methods to fit the forward response of an initial (user defined) model with the original field data. Though this technique can save lot of time, one should be careful in assigning the initial model which otherwise leads to wrong interpretation due to the equivalence problem in resistivity sounding interpretation. For the present study, the individual DRS data are modelled using the inversion program based on the techniques given by Jupp and Vozoff (1975). The simplified inverse problem aims at finding layer resistivities and thicknesses that best fit the observed data. The iterative method successively improves the initial model until the error measure becomes small and the parameters are stable with respect to reasonable changes in the model. In the present modelling, attempts are made to obtain the best fit for each sounding, with an accepted error level of less than 5 percent.

We have done an extensive work on the experiment design of DRS for very deep probing the subsurface by extending the spread of electrodes up to 15 km, which required upgradation of power source and other instrumental settings. All the DRS data were collected by using high-power deep resistivity equipment (M/s Scintrex, Canada and M/s Zonge, USA), capable of injecting 20-45A current into the ground, with a maximum output power of 30 KW. Figure 1 shows the sounding locations obtained in the Saurashtra, Kutch and Deccan Syncline region. Figure 2 shows some of the selected sounding curves from the trap

covered region, providing a qualitative idea about the overlying conductive Tertiary sediments, underlain by resistive Traps followed further by conductive Mesozoics and resistive basement.

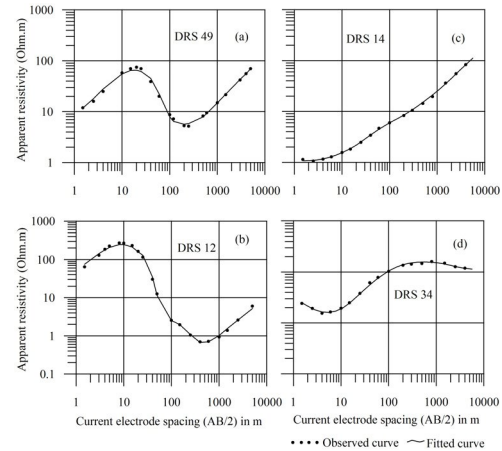


Figure 2. Some selected Deep Resistivity Sounding sounding curves (a) Saurashtra (b) Kutch (c) and (d) Deccan syncline regions of India.

Discussion and results

Saurashtra: A total of 70 DRS measurements were taken up in the Saurashtra region up to a maximum current electrode spacing of 10-15 km under a joint collaborative project sponsored by ONGC (Singh et. al., 1983 and 1998). The results evidenced a sharp electrical contrast between trap, sediment and basement. The DRS results show the resistivities of sediments, traps and basement to the order of <60, 100-600, and >1000 Ohm.m respectively for the entire Saurashtra region. Presence of a sedimentary basin is detected between Jamnagar and Mewasa having a maximum thickness of sediments aligned in NW-SE direction covering Vadali-Mulila area. This basin appears to be most promising area for future exploration. A thicker sedimentary sequence is also inferred in west and southwestern part of Lodhika well. Presence of a number of possible hidden volcanic plugs is also evidenced in the region. A geo-electrical section along E-W profile covering places Bhangor, Mulila, Lodhika and Kamalapur is shown in fig.3. The trap thickness increases from 800m (DRS-32) to 1350m (DRS-21) and then decreases to ~50m near Kamalapur (DRS-54). The resistivity of trap in general varies from 150-400 Ohm.m. The decrease of trap thickness to 50m at Kamalapur probably indicates that this region is close to a lateral contact zone between trap and sediments. The thickness of sediments increase from 900m (DRS-32) to ~1500m near Lodhika (DRS-21) and is having resistivity of 19 Ohm.m. The data suggest a basement high near Kamalapur- Jasdhan area. The basement topography is quite undulating along this section. The sharp drop in basement depth from 3700m (DRS-21) to 1800m (DRS-20) and from 3100m (DRS-18) to 1000m (DRS-1) is probably indicative of its proximity to a N-S fault zone.



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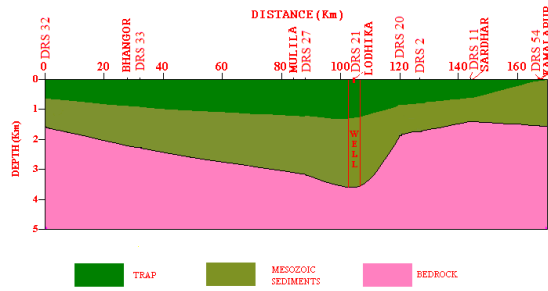


Figure 3. Geo-electrical section along Bhangor, Mulila, Lodhika and Kamalapur in Saurashtra region, India.

Kutch Basin: The Kutch basin is a marginal rift basin associated with considerable thickness of Mesozoic sediments, situated in the northwestern part of the Indian Shield (Prasad et. al., 1994). Geo-electrical sections obtained on modeling the DRS data evidenced the existence of sub-trappean sediments in the Kutch mainland (Singh et. al., 2000). The existing borehole data (Banni-2, Nirona and Suthri) were also used to constrain the resistivity modeling, especially in constraining the thickness of sedimentary layers and identifying the presence of Traps characterized by comparatively low resistivity contrast with respect to the sediments. Generally, the DRS inversion results found to be well comparable with the borehole data as shown in figure 4 for Nirona borehole.

more resistive falling in the range of 40-100 Ohm.m. In the central region, the Traps are exposed and generally absent in the northern side of the basin, covering areas adjacent to Nakhtarana, Nirona, Banni, Khavda and towards east near Anjar. In the northern region the Mesozoic sediments are exposed and seem to directly overlie the basement. The Mesozoic sediments in the central portion comprise four major formations, viz. Bhuj, Jhuran, Jumara and Jhurio. Here, the Bhuj and Jhuran formations comprise shales, claystones, marl, argillaceous sandstone, etc. with low resistivity in the range of 5-20 Ohm-m, whereas the other two formations consist mainly of limestone having resistivities 25-110 Ohm-m. The basement resistivity is found to be greater than 400 Ohm-m in most of the cases. In the southern part, the Tertiary sediments cover the Traps as well. It may thus be seen, throughout the area, the Mesozoic sediments are present, either as hidden or exposed with thicker columns in the southwestern region, reaching a maximum thickness of about 3000 m in and around Mandvi and Mundra. Similarly the results from the Jakhau - Suthri - Mandvi profile and the Anjar to Mundra profiles indicate dipping of basement towards the center from both west as well as east, suggesting presence of large thickness of Mesozoic sediments along the coast and possibly in the offshore regions.

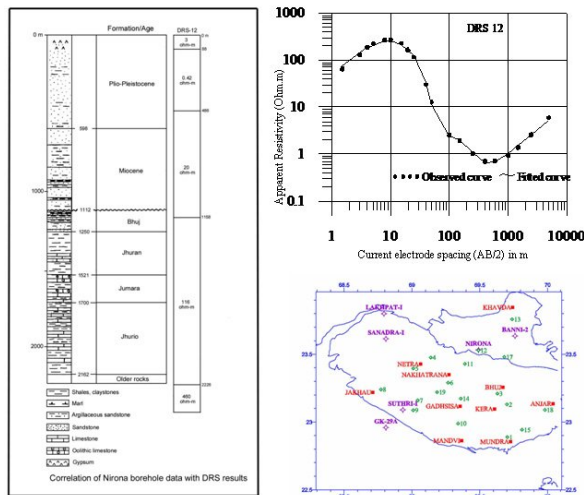


Figure 4 Correlation of borehole lithology with DRS 12 near the Nirona well in Kutch region, India.

The surficial Tertiary sediments, observed mainly towards the southern part are characterized by very low resistivities in the range of 1-40 Ohm.m, commonly exhibiting less than 10 Ohm.m in most of the profiles, comprising mainly of shales, claystones and sandstones as evidenced from the well data. The underlying Deccan Traps are comparatively

Figure 5 shows geoelectrical section along Suthri - Nakhtarana, (DRS stations 9, 7, 19 and 6) covering a distance of about 50 km trends in a NE-SW direction. The top Tertiary sediments of about 400 m thickness are observed near Suthri. They became thin towards northeast and ultimately vanish further north where the Traps are exposed. The Traps also seem to be thinning towards north and are almost absent at Nakhtarana. The thickness of Trap at Suthri agrees with the borehole information. A thick Mesozoic sedimentary column has been detected at Suthri. This thins out towards the NE direction. The DRS-19 indicates a hump in the basement with a shallow depth of about 2.6 km. Present results indicate the presence of thick sedimentary column beneath the Deccan Traps, which is of significant importance to the hydrocarbon exploration.



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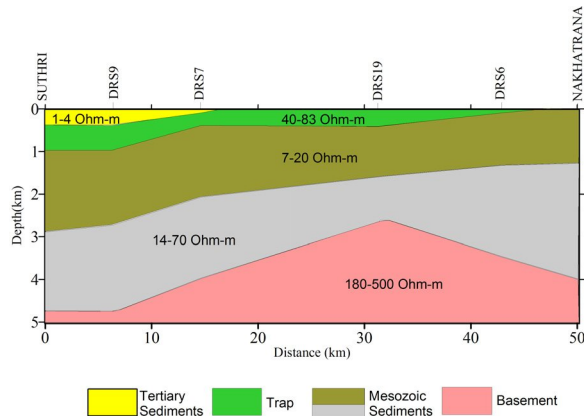


Figure 5. Geo-electrical section Suthri-Nakhatranabased on DRS studies in Kutch region, India.

Deccan Syncline, Central India: One hundred and thirty DRS stations were covered in Western and Eastern parts of the Narmada -Tapti region of Deccan Syncline between 20°30' and 22°15'N latitudes and 72°30' and 78°15'E longitudes to identify existence of thick subtrappean sediments, potential for further hydrocarbon exploration. The DRS data were modeled for the layer parameters (i.e., resistivities and thicknesses) and geo-electrical sections were prepared along different profiles to see the lateral and vertical variation of Traps, sedimentary layers and the basement configuration (Singh et. al., 2003). This provided additional insights into the extension of different formations at depth. Present DRS studies evidenced the existence of a major sedimentary basin towards the eastern part of the investigated area, with very large thickness of Mesozoic sediments of the order of 1500 to 2500 m. The Mesozoic sediments are quite thin in northern part of investigated area except near Rajpipla where its thickness is more than 1000 m. The bedrock resistivity varies from 600-9000 Ohm-m in the study area. Lower resistivity for bedrock and large thickness of Mesozoic sediments are observed near the major fault zones like Tapti fault, Shahada fault in the study area. It is quite likely that these faults are deep seated and bedrock might be saturated with water due to which low resistivity values are observed for the bedrock. The thickness of Tertiary sediments appears to be maximum (> 1500 m) in the western part.

A geo-electrical section along Vardhe tembe-Sirpur-Saver profile covering a distance of about 70 km involving Deep resistivity soundings (19, 22, 21 and 09) is shown in Figure 6. A considerable Gravity low was observed in the Shirpur area and this profile is following more or less Tapti fault and is cutting the low gravity anomaly. The entire profile is covered with thin (125 m) of alluvium having resistivity of 5-45 Ohm.m followed by trap 140-585 Ohm.m, sediment 10-90 Ohm.m and the bedrock 900-9000 Ohm.m. The eastern part of the sediments is characterized with low resistivity 10-55 Ohm.m compared to Western part of sediments 70 to 90 Ohm.m along this profile.

The thickness of sediments appears to be largest (2600 m) near DRS-22 and it is thinning in the Vardha tembe region. Large thickness of sediments also continues to exist in the Shirpur-Saver area. The thickness of trap is minimum (300m) in Saver area and its thickness increases up to 1100 m in Shirpur area, then it decreases to 800m in Vardhe tembe area. The basement topography looks to be quite undulating and a sharp resistivity contrast exists in bedrock between Shirpur (900 Ohm.m) and Saver area (9000 Ohm.m) which might be due to circulation of meteoric water upto large depth in Shirpur area causing presence of low resistivity for bedrock in central part of the section. It appears that the resistivity distribution of sediments along this profile has been controlled by Tapti fault.

With the above success of our research towards unraveling potential oil bearing formations, a new project was formulated under CSIR network program for delineation of thick sediments in the Eastern part of the Deccan Syncline area. Eighty-one deep resistivity soundings were conducted to delineate thickness of sediments, trap and basement configuration covering Jamer, Burhanpur, Jalgaon, Achalpur and Amaravati region under this project. The results from this study indicate large thickness of sediments near Burhanpur and Amaravati regions.

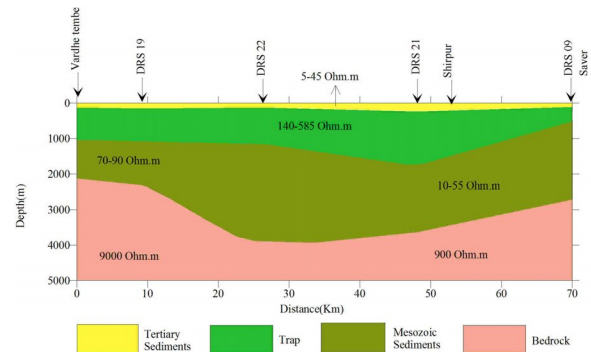


Figure 6. Geo electrical section along the Vardhe tembe-Shirpur-Saver based on DRS studies in western part of Deccan syncline, central India

Conclusion

Our studies suggest the successful implementation of Deep Resistivity Sounding method as one of the possible non-seismic methods in mapping the sub-trappean sedimentary basins, which is one of the major concerns in India with very vast flood basalt regions. We found that the applicability of DRS is enhanced towards delineation of Mesozoic sediments due to the presence of significant electrical contrast between Trap, sediments and basement. Deep Resistivity Sounding has played a definitive role in understanding the subsurface structure below the Deccan trap in India and possibly delineating sub-trappean sediments wherever sharp resistivity contrast exists.



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Various novel applications of this methodology have resulted in delineation and detection of sub-trappean sediments underneath basaltic cover in Saurashtra (Jamnagar) and Kutch (Mandvi) and the areas covering Shirpur, Sendhwa, Nandurbar, Narayanpur, Sakri, Burhanpur and Amaravati of Deccan Syneclise.

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Acknowledgements

The authors are grateful to the ONGC Ltd., and OIDB for their financial support and constant encouragement in implementing new approaches in oil exploration programs in trap covered regions of India. We thank Director, NGRI for his guidance and permission to publish this work.