

Delineation of Basaltic Covered Sediments in the Saurashtra Region using Deep Resistivity Sounding Studies

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ABSTRACT : The Deep resistivity sounding (DRS) studies in Saurashtra have brought out very important results with regard to broad general distribution of thickness of trap, sediment and basement topography. The sediments are characterized by resistivity of less than 60 ohm-m, traps of 100-600 ohm-m and basement of high resistivity above 1000 ohm-m. Presence of 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. The thickness of Mesozoic sediments is estimated to be about 1400 m between Dhrangadhra-Kamalapur region in the northern part of Saurashtra. It is observed that the trap thickness is more than 1000 m between Jamnagar and Mewasa and less than 600 m in the Dhrangadhra-Kamalapur area and ~2000 m in Lathi-Ansador region. Presence of a number of hidden volcanic plugs in the area of Porbandar-Navibandar, Kutiyana, Junagadh and Rajula region are observed. Some of these plugs are not exposed at the surface and could be an extension of famous Girnar, Barda and Alech hills at depth.

INTRODUCTION

The problem of delineation of thickness of sediments underneath basaltic cover has been a long-standing complex geophysical problem for the oil exploration in Saurashtra region. These sediments underlying the Deccan traps of varying thickness are either exposed at the surface at some places or lie beneath a top thin cover and causing considerable uncertainty in the interpretation of the geophysical data. In order to have better understanding and resolving the above problem seventy Deep Resistivity Sounding (DRS) were carried out in Saurashtra area upto a maximum current electrode spacing of 10-15 km by Singh et al (1983, 1998). The Schlumberger and equatorial dipole arrays have been deployed jointly in Saurashtra Peninsula for delineating Mesozoic Sediments as they provide exactly the same results for laterally homogeneous and horizontally stratified earth. Schlumberger array is least influenced by lateral inhomogeneities which are generally confined to shallow depth, therefore it is taken upto profile length of 10 km and thereafter the equatorial dipole is used till the maximum profile length of 10 – 15 km. The applicability of DRS is enhanced towards delineation of Mesozoic Sediments due to the presence of sharp electrical contrast between trap, sediments and basement.

EQUIPMENT AND DATA ACQUISITION

The deep resistivity equipment used in the present studies is the latest model manufactured by M/s Scintrex, Canada. It consists of three major units viz i) the generator ii) the transmitter and iii) the receiver. The 10 KW generator

provides a three phase regulated voltage of 210 V (600 Hz). The transmitter has maximum output power of 10kW with voltage outputs up to 3300V and current outputs up to 20 Amp. The total transmitting cycle consists of an initial period during the current is on, followed by three consecutive periods of similar duration during which the current is off, reversed and again off. The duration can be fixed at 2, 4 or 8 seconds. In the present study a duration of 2 sec was chosen. The RDC-10 receiver was used to record the potential difference across measuring electrodes. It has a wide measuring range from 30 micro volts to 30 volts. It has stacking facility with a digital display of the average value. Master slave communication sets were used for maintaining communication between field personnel along DES line.

The field procedure for the resistivity sounding measurements involves injecting of a known amount of current into the ground through two grounded steel electrodes separated by a known distance. The resulting potential difference is measured between two points with the help of two non-polarisable electrodes (porous pot containing copper rod in copper sulphate solution).

The apparent resistivity, ρ_a is a function of the known values of

- i) current (I) injected into the ground
- ii) potential difference (ΔV) developed across the measuring electrode and
- iii) a geometrical factor (k) depending on the distances between the current and potential electrodes and is given by

$$\rho_a = k \frac{\Delta V}{I}$$

The measured apparent resistivity values obtained either by the Schlumberger-array or by the Equatorial Dipole – array are plotted against AB/2 or R on double log graph sheet covering the entire profile length which forms a deep resistivity sounding curve.

DATA PROCESSING AND RESULTS

The measured apparent resistivity values are plotted against AB/2 on double log paper covering the entire profile length which form a sounding curve. Computerised forward or inversion technique is adopted for quantitative interpretation of the data in terms of resistivities and thicknesses of various layers of the assumed horizontally stratified, homogeneous and isotropic strata. The computer program of Jupp and Vozoff (1975) of inverse modeling is used in the present investigation. The scheme uses the approach of iterative refinement. Firstly, using the forward expression, apparent resistivity data is computed for the given initial model obtained earlier through either curve matching or even by an initial guess. The computed data is compared with the measured apparent resistivity data to get the residuals or the error vector between the two. The model is progressively refined to minimize the error vector. The iterative procedure is thus repeated several times till a minimum possible error between the observed and computed data is accomplished.

Modelling of electrical structure at Lodhika (Fig. 1a) by interpreting DRS-21 data indicated a thickness of 1350 m for Traps (100-150 ohm-m) and 1500 m of Mesozoic sediments (10-25 ohm-m) and the presence of a volcanic layer (50-75 ohm-m) of 750 m thickness below sediments, thus showing a close matches with borehole lithology. Though the bore hole was not drilled up to the basement, the DRS data indicates presence of basement at a depth of ~3600 m. The resistivity of volcanic material below sediments is reduced to half the resistivity of trap. This indicates a change in composition between two traps. The shape of the sounding curve alone does not indicate presence of another trap layer at a depth of 2850 m below the sediments.

The sharp resistivity contrast between trap and sediment, is very useful in identifying the presence or absence of sediments at first glance from observed sounding curve itself at a particular location. On the other hand such a large contrast will certainly affect an accurate estimation of layer parameters. This vital information is used while modelling of

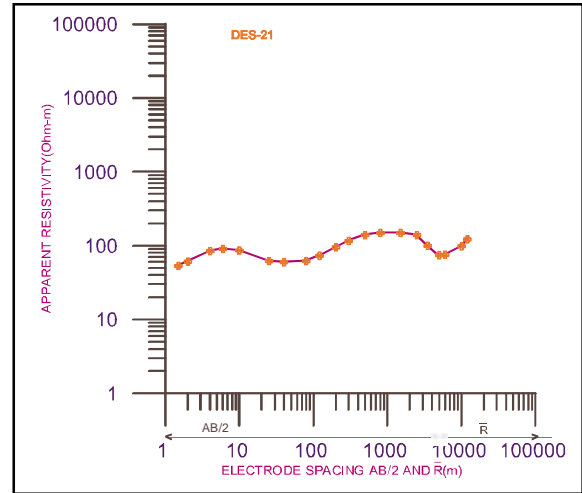


Figure 1(a) : DRS curve at Lodhika.

DRS data at other locations in the Saurashtra area. Mainly three types of deep electrical sounding (DRS) curves were observed in the present investigated area. These are:

- i) KH – type curve where Trap and sediments are overlying the basement (Fig. 1b). These type of curves are quite commonly observed in major part of the study area. The initial rise in DRS curve obtained over trap indicate the presence of thick trap and the subsequent downward trend corresponds to sediments and finally the curve again ascends indicating the basement.
- ii) A- type curve where sediments are directly overlying the basement (Fig. 1c). The sounding curve over sediments without the trap cover indicates almost a uniform value of 30 ohm-m upto a large electrode spacing

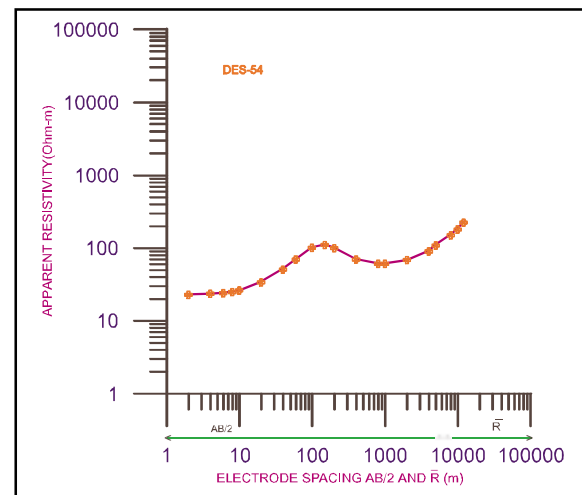


Figure 1(b): DRS curve over trap.

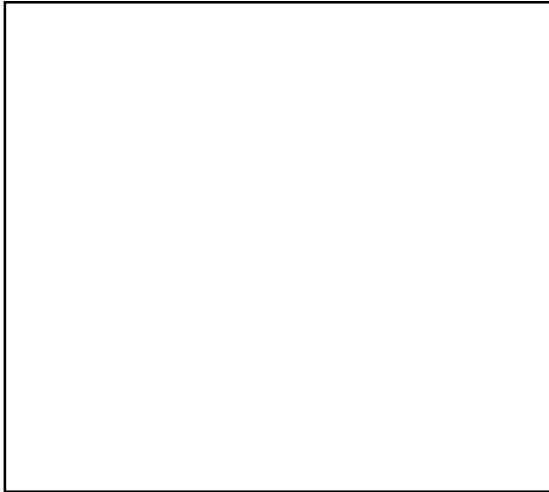


Figure 1(c) : DRS curve over Mesozoic Sediments

representing the thick sediments. The right hand ascending part indicates basement. Such observations are found to be very common in northern part of the area where Mesozoic sediments are exposed.

- iii) HA-type curve is indicative of the presence of volcanic plug buried at depth (Fig. 1d). The initial drop in sounding curve reflects the presence of clay and weathered trap saturated with groundwater. A sharp rise in the curve suggests the presence of a volcanic plug buried in Saurashtra area for trap and basement. Such type of curves are viz. Porbandar, Navibandar, Rajula region of investigated

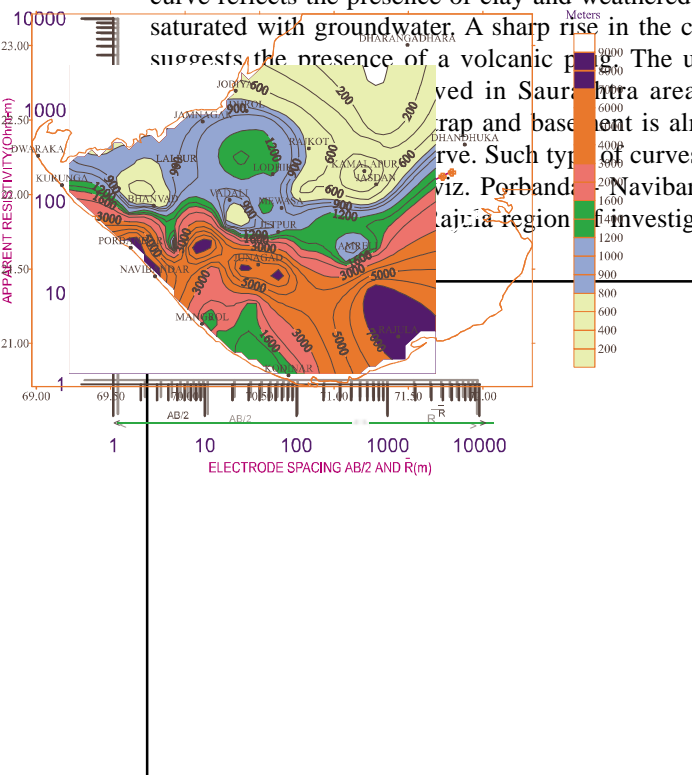


Figure 1(d) : DRS curve over Volcanic Plug.

Based on 1D modelling of DRS data, contour maps indicating thickness of trap, sediments and depth to the basement are prepared for the entire investigated area (Figs. 2 to 4). The results relating to the three maps: the trap thickness map, sediment thickness map and basement configuration map are discussed below.

TRAP THICKNESS MAP

A contour map for trap thickness was prepared based on 1D inversion results from all the available seventy deep electrical soundings of Saurashtra area. It is observed from Fig. 2 that the thickness of trap is less than 600 m in the northern part of Saurashtra, particularly around Dhrangadhara (where mesozoic sediments are exposed) and its thickness gradually increases to 600 m towards Jasdand and more than 1000 m towards Jamnagar and Mewasa region. The resistivity of trap generally varies from 50 to 600 ohm-m. In addition to this, in the southern part of the Saurashtra, the DRS results indicate



Figure 2 : Contour map of thickness of trap (m) by DRS in Saurashtra

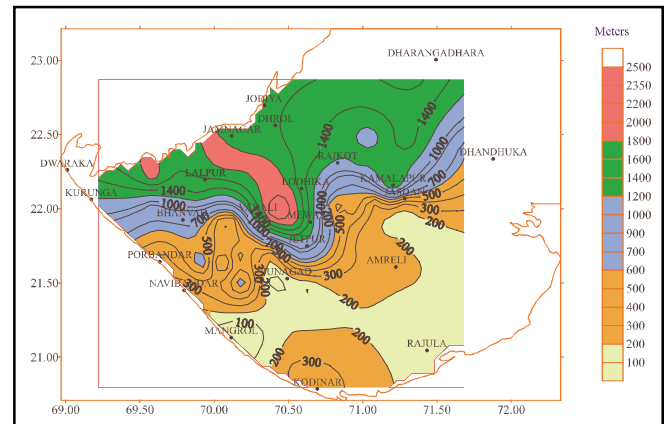


Figure 3: Contour map of thickness of sediments (m) by DRS in Saurashtra

the presence of a number of volcanic plugs which are not exposed at the surface. They could be an extension of famous Girnar, Barda and Alech hills at depth in the regions of Junagadh, Porbandar and Alech hills at depth in the regions of Junagadh, Porbandar-Navibandar and Kutiyana respectively. Another volcanic plug is noticed in Rajula region, which is also marked by a number of lineaments and majority of which are trending E-W. Further, surface manifestation of numerous dyke clusters can also be commonly seen in this region that are trending almost ENE-WSW. Besides the above there could be some hidden volcanic plugs that have not been picked up by deep resistivity due to very large station interval. The trap thickness in general is quite large in the south and southwestern parts of Saurashtra near Junagadh, Jetpur, Porbandar and Rajula which is also characterized by gravity high.

SEDIMENT THICKNESS MAP

The contour map showing thickness of sediments (Fig.3) clearly indicates large thickness of sediments having resistivity of 10-60 ohm-m in northwest and northern part of investigated area of Saurashtra region. The results of deep resistivity sounding studies indicate the presence of i) NW-SE trending sedimentary basin between Jamnagar and Mewasa with largest thickness of sediments ~2200 m ii) a sedimentary basin between Dhrangadhra and Kamalapur having thickness of sediments ~1400 m. There is an indentation in the sediment thickness contours towards Mewasa indicating large thickness of sediments. The basin located between Jamnagar and Mewasa is almost parallel to Cambay graben trend and needs attention. The thickness of sediments appears to be less than 600 m in south and southwestern parts of Saurashtra. Extensive volcanic activity in this region appears to be one of the causes for very small thickness of sediments. Most of the existing sediments must have been altered or displaced during the process of eruption, in the southern region which seems to have been the center of volcanic eruption.

BASEMENT CONFIGURATION MAP

An upwarping of basement near Jasdan-Sardhar area is evident from the basement contour map (Fig. 4), where the depth to basement is less than 1000 m. Shallowing of basement to less than 1400 m can also be seen in the Bhanvad and Dhrangadhra region. The depth to the basement sharply increases to ~3000 m in the region between Jamnagar and Mewasa. A basement fault is also inferred in this zone. Large depth to the basement in Jamnagar-Mewasa region also means to large thickness of trap and sediments. In the western part

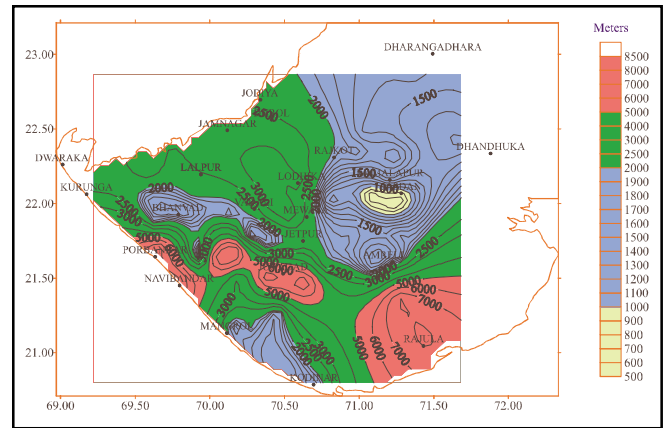


Figure 4: Contour map of depth to basement (m) by DRS in Saurashtra

of Saurashtra the depth to the basement is quite deep around Porbandar. Khar et al (1988) have also prepared a tectonic map of the area and identified a depression in this region. The basement configuration conceptualized by Zutshi et al (1989) also suggests in general a westward slope and the presence of a depression. The basement appears to be quite deep in southern part of Saurashtra, where thickness of trap is also found to be very large.

Geoelectrical section describing details of general distribution and thickness of resistive trap, conductive sediments and the configuration of basement along profile Navibandar – Dhrangadhra is discussed below :

GEOELECTRICAL SECTION ALONG NAVIBANDAR-KUTIYANA-UPLETA-LODHKA-RAJKOT-DHRANGADHRA

Deep electrical soundings (43, 25, 24, 23, 65, 66, 21, 30, 9, 10, 55 and 61) were carried out along a NE-SW traverse Navibandar – Kutiyana – Upleta – Lodhika – Rajkot - Dhrangadhra profile covering a distance of about 250 km (Fig.5). The results of DRS-43 indicate the presence of Tertiary sediments of 2 ohm-m, probably saturated with saline water having a thickness of about 250 m. The deep resistivity results of DRS-43, 25 and 24 indicate the presence of volcanic plug in the area of Navibandar - Kutiyana. The depth to the top of volcanic plug having resistivity of 225 ohm-m in Kutiyana region is about 10 m from surface. In Navibandar area DRS-43 also indicates the presence of the volcanic plug at a depth of about 250 m having resistivity of 600 ohm-m. It appears that the volcanics along western flank are probably quartz bearing. The large difference in resistivities and the depth of occurrence

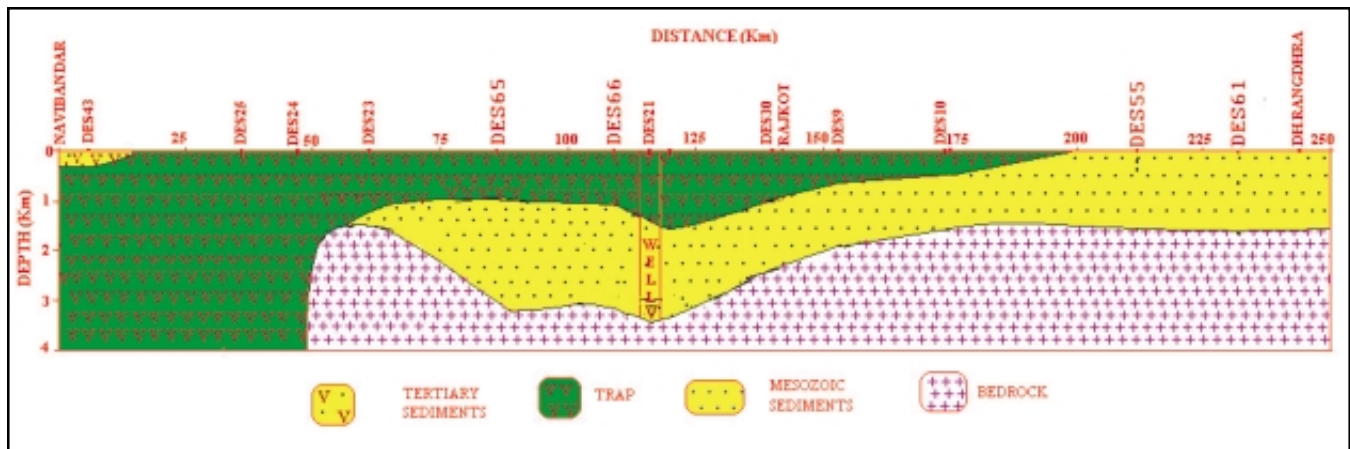


Figure 5: Geoelectrical section along Navibandar-Rajkot-Dharangdhara based on DRS

of volcanic plugs at Navibandar and Kutiyana areas probably indicate that they are from two different types of sources. The thickness of trap decreases from 1350 m at DRS-21 (Lodhika) to 500 m at DRS-10 having resistivities of 200 ohm-m and probably there is no trap after DRS-10 up to Dhrangadhra. The DRS data further indicate maximum thickness of sediments of about 2000 m in the area of DRS 65, 66 and 21 having a resistivity range of 20–40 ohm-m. The thickness of sediments gradually decreases from Lodhika to Dhrangadhra where resistivity of sediments is about 26 ohm-m. The basement topography is quite undulating along this profile also.

CONCLUSION

The DRS studies have brought out very important results with regard to broad general distribution of thickness of trap sediment and basement topography in the investigated area though the seventy deep resistivity soundings are distributed in a large area of Saurashtra with station interval of about 40-50 km. The sediments are characterized by resistivity of less than 60 ohm-m, traps of 100-600 ohm-m and basement of high resistivity above 1000 ohm-m. Some of the results of utmost significance obtained as an outcome of DRS studies are listed below:

- Three types of resistivity sounding curves were mainly observed in the present investigated area viz. i) KH-type curve where a high resistive trap followed by conductive sediments are overlying the very high resistive basement. ii) A-type curve where sediments are directly overlying

the basement and iii) HA-type curve indicative of presence of volcanic plug buried at depth.

- 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 south western part of Lodhika well.
- The thickness of Mesozoic sediments is estimated to be about 1400 m between Dhrangadhra –Kamalapur region in the northern part of Saurashtra.
- It is observed that the trap thickness is more than 1000 m between Jamnagar and Mewasa and less than 600 m in the Dhrangadhra-Kamalapur area and ~ 2000 m in Lathi-Ansador region.
- Presence of a number of hidden volcanic plugs in the area of Porbandar-Navibandar, Kutiyana, Junagadh and Rajula region are observed. These plugs are not exposed at the surface and could be an extension of famous Girnar, Barda and Alech hills at depth.
- An upwarping of basement in Jasdan, Kamalapur, Sardhar area and a depth of ~3500 m to the basement in Jamnagar-Mewasa region have also been inferred. In general the basement topography is quite undulating in the entire investigated area of Saurashtra.

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