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Geoelectrical studies for delineating seawater intrusion in parts of Konkan coast, western Maharashtra

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ABSTRACT

A total of 28 Vertical electrical sounding (VES) were carried out in the coastal area of Konkan in Kudal-Malvan region, western Maharashtra to delineate the spatial extent of seawater intrusion into the mainland. Resistivity contouring were carried out at depths of 5, 25, 50, 80 and 100 m which indicated confined aquifer in NE part of the study region comprising unconsolidated sediments. Perhaps this aquifer is recharged from the percolating rainfall and River Karli which is flowing in this region. Very high resistivity feature is observed in the northwestern part due to the presence of laterites. In the southern part, very high conductive zone is observed in SW area near coast indicating extensive influence of saline water intrusion. Two dimensional modeling of resistivity data over three profiles in the study region show the flow of saline water from the coastal side, partly controlled by the lineaments. It is also observed that the effect of saline water intrusion diminishes from southern to northern part of the region. The depth-conductance maps over the three profiles advocate high salinity at the coastal side.

Key words : Resistivity, seawater intrusion, conductance, Malvan, Sindhudurg
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INTRODUCTION

Saline water intrusion is one of the most universal problems in coastal areas of the world (Bear et al., 1999, Park et al., 2005, Song et al., 2007). Contamination of groundwater in coastal regions occurs when seawater mixes with freshwater aquifers. This process can be natural and human-induced. With growing industries and urbanization, this problem aggravates when excessive pumping of freshwater from an aquifer reduces the water pressure and thus draws seawater into the aquifers (Adeoti et al., 2010). Water resources in such coastal areas thus assume significance since any developmental activity will depend upon availability of potable and fresh water to meet industrial, farming and household requirements.

There are several factors which may elucidate the seawater intrusion into freshwater pockets. Lineaments play a major role and may act as pathway for seawater intrusion into mainland. Also seawater contamination may occur through any rivers flowing in the vicinity of coastline (Benkabbour et al., 2004).

Keeping in mind the numerous lineaments that traverse the Konkan coast, the changing land use pattern, the adverse effects of increased withdrawal of groundwater and decreased rainwater infiltration, this region has been chosen for detailed geophysical study. The purpose of this study is to demarcate the zones of seawater intrusion in the coastal areas of Konkan region in western Maharashtra using electrical resistivity technique (Fig. 1). Data were acquired at 28 VES points in a grid pattern covering Malvan, Oras, Kudal, Nerur, Dhamapur and Parule between longitude 73.52° to 73.70° and latitude 15.98° to 16.12° (Fig. 2).

GEOLOGY AND HYDROGEOLOGY OF THE STUDY AREA

The Konkan region is a rugged section of the western coastline of Maharashtra and is one of the most important geological terrains of western India. The Sahyadri mountain range, known as the Western Ghats, forms the eastern boundary of the Konkan, and the Arabian Sea marks the western boundary (Kumaran et al., 2004). The area extends 720 km in the North-South and about 44 km in East-West direction. The entire region exhibits unusual physiographic set up with undulating terrain throughout the region, except in coastal plains. The area displays a dendritic drainage pattern. The drainage density is quite high due to hilly undulating area with structural control. The steep slopes and high drainage density contribute to the major runoff and thus scanty groundwater recharge. On the contrary, in the plain and valley areas where drainage density is low, recharge is generally good (Dikshit, 2001).

The major stratigraphic units represented in the Konkan region are Archean complex, Kaladgi Supergroup, Deccan Trap, Laterite and alluvium (Radhakrishna, 1982, Sarkar and Soman, 1986, Kale, 1995). Deccan basaltic lava flows formed between 60 and 68 millions years ago occupy a large part of Konkan region. The entire pile of horizontal and multilayered lava flows show variation in their physical characteristics (Subbarao, 1988). Besides basalt, other rock types observed in the study area are Trachytes and Rhyolites. Another important geological formation here is Laterite. These deposits are very extensive in and around Malvan. In places like Kudal, the metamorphic rocks like Schist's, Gneisses, Granulites, Phylites, Granites and Granitic Gneisses are exposed. Sandstone, Shale, Quartzite, Grits and Conglomerates of Kaladgi series occupy a very small area of Vaibhavwadi, Malvan, Devgad talukas of Sindhudurg district. A narrow stretch along the coastal plains comprises of coastal alluvium or marine alluvium (Deshpande, 1998).

LANDSAT imageries study (Sarkar and Soman, 1986) in and around Katta in Sindhudurg district revealed several NNW-SSE to NE-SW trending lineaments. A number of parallel en echelon lineaments trending NNW-SSE runs from Malvan in the north to Nivti in the south near the coast. These lineaments are associated with intense fracturing, brecciation and silicifaction. Another NNW-SSE mega lineament runs from Maldi in the north to Kalsa (near Kudal) to the south. This seems to terminate at the northern part of river Karli. Using remote sensing data, Hanamgond and Mitra (2008) have also reported several NE-SW lineaments and identified a NNW-SSE mega lineament in this region that controls the physical setting of the coast. Hari Narain et al. (1968) and Sarkar and Soman (1983) further reported that rejuvenation of these faults and lineaments during different periods is evidenced from the observed brecciated Dharwarian quartzite in the Kaladgis, emplacement of silica veins in the kaladgi sandstones and a drop of a few tens of meters in the altitude of laterite along the major lineaments. These also point towards the tectonic activity related with the west coast faulting in this and surrounding areas (Powar, 1993).

Deccan basalts are hydro-geologically inhomogeneous rocks. Two types of basalt, the vesicular amygdaloidal basalt and the compact basalt, occur as alternate layers in the volcanic pile (Deshpande, 1998). Although the rocks are generally inhomogeneous, the zone of weathering and structures in the basalt, such as sheet joints and vertical joints, serve as zones of groundwater flow. In Konkan region, the groundwater occurrence is affected by factors like degree of weathering, structures and topographic setting. Weathering increases porosity and permeability of a media and structures with topographic setting controls the movement and discharge of groundwater. The basaltic hard rock has very poor primary porosity. However, the basaltic lava flows develop secondary porosity like weathering, jointing, fissuring and fracturing which make the basaltic rocks capable of holding and transmitting groundwater (Pawar et al., 2008). The vesicles and joint systems contribute considerably to yield groundwater from the basaltic flow. Thus, a highly weathered vesicular lava flows has good porosity and permeability and proves to be a good groundwater potential zone.

The average depth of the wells in the study region varies from 5 to 8 m bgl and diameter varies from 3 to 5 m. However, at places, depth of the wells ranges from 12 to 15 m bgl (CGWB, 2009). As mentioned earlier, another important formation in this region is Dharwarian rocks. In these rocks the occurrence of groundwater mainly depends on fracturing and fissuring. These rocks are very hard and compact and possess practically no primary porosity. However, on weathering, fracturing, jointing and prominent lineament structures, these develop a secondary porosity, which act as groundwater circulation channels to form groundwater-bearing horizons. Moreover, banded and fractured metamorphic rocks yield high and steady supply of groundwater. Here the thickness of such zones varies from few meters to about 40 m bgl.

Beside these, the alluvium formations occur in the western part of the study region along the coast and creeks. At some places along the creek near Malvan, the mud deposits occur. The thickness of alluvium ranges between 10 to 25 meters. These alluvial deposits are potential aquifer up to shallow depths only. At more depth, seawater intrusion contaminates the potential aquifers. However, lineaments and fractures at shallow depths facilitate intrusion of seawater into these shallow potential aquifers.

METHODOLOGY & SURVEY DESIGN

As mentioned earlier, the geophysical investigation incorporated use of electrical resistivity method. The VES electrical resistivity studies is based on measuring the potentials between one electrode pair while transmitting direct current (DC) between another electrode pair. The depth of penetration is proportional to the separation between the electrodes, in homogeneous ground, and varying the electrode separation provides information about the stratification of the ground (Dahlin, 2000). This method is carried out to decipher problems of saline water intrusion into freshwater in the hard formation such as the Deccan Trap region.

The VES was carried out in the study area with a SSR-MP-ATS resistivity meter supplied by IGIS, Hyderabad. The location of electrical soundings is shown in Fig. 2. Electrical resistivity soundings were conducted at 28 different locations in a grid manner by using the Schlumberger array for delineating vertical distribution of water bearing zones, constituting the aquifer bodies in this region and to delineate the zones of seawater intrusion. The Schlumberger soundings were carried with maximum current electrode spacing (AB) of 200 m (AB/2=100 m). The field data acquisition was generally carried out by moving two or four of the electrodes used, between each measurement. The resulting geoelectrical layer succession was used for predicting various conducting zones based on true resistivities. Employing Schlumberger configuration the apparent resistivity was calculated (Kearey and Brooks, 1988) as,

$$\rho a = \pi [(L/2)2 - (b/2)2] / b] * V/I$$

Where, L and b is the current and potential electrode spacing respectively.

The data obtained from the field was processed and modeled using IPI2WIN software, version 3.0.1.a7.01.03 (Bobachev, 2003) for interactive semi-automated interpretation.

RESULTS & DISCUSSION

In the situation where 2-D coverage of soundings spread over the area has been made, the resistivity distribution over an entire area would qualitatively correspond to variations of the resistivity at different depths. This is achieved by increasing electrode spacing; more the electrode spacing deeper is the current penetration and this could be used to establish depth-wise lithological correlation. Here, resistivity contouring has been carried out for different electrode spacing i.e. AB/2= 5 m, 25 m, 50 m, 80 m and 100 m which provides the variation of resistivity at five different horizons. The spatial distribution of the apparent resistivity of all the VES sounding points over the entire region was evaluated by the krigging method using SURFER software. Further the two dimensional longitudinal geoelectric sections have been prepared over three profiles (south, central and north profiles) in the study region. To elucidate the ingress of saline water from the coastal side, the electrical conductance has also been calculated over these three profiles to see the extent of saline water intrusion.

Resistivity contouring

Figure 3a shows the apparent resistivity distribution at shallow depths (AB/2 = 5m). A broad high resistivity (H) in the range 300-700 ohm-m is observed in the north western part of the study region. This region is at a higher elevation and comprises of laterite. The central portion has a relatively low (50 to 200 ohm-m) resistivity (L2). The river Karli is flowing in an EW direction in this region from the coast side and then takes a NE turn. It is thus possible that the low resistivity is due to the presence of alluvium in this region. It is also evident from the figure that a highly conductive feature (L1) is observed in the SW part of the study area. This feature has a resistivity in the range of 10-20 ohm-m and seems to take a north-eastward turn. It is possible that the lineaments and fractures present here aids in the ingress of saline water from the coastal side.

The apparent resistivity contours for AB/2 = 25 m is shown in Fig. 3b. It is seen that seven contours closures are clustered in the NW part with high resistivity values of more than 1000 ohm-m. As mentioned earlier, this area is flanked by hills and thus hard and compact rocks along with laterites are present in this region, giving such high values. Low resistivities of the order of 100-300 ohm-m is observed in the central-eastern (L2) part. The south western portion in the study area (L1) is characterized by low resistivity values (about 50 ohm-m), indicative of saline water intrusion from the coast.

The apparent resistivity section for AB/2 = 50 m, shown in Fig. 3c, indicates that the resistivity values in the central part (L2) have increased and ranges from 100-700 ohm-m. The high resistivity contours (H) is about 2700 ohm-m where closely spaced contours are observed in NW region. Also the low (L1) region with resistivities of 10-50 ohm-m are observed in the SE part of the study region. This feature which is evident from shallow depths seems to spread in the northern and northeastern parts.

Figure 3d shows the apparent resistivity contour map for AB/2 = 80 m. The area on NW side (H) is characterized by high resistivity values (1000-3000 ohm-m). The region L2 with resistivities of the order of 600 ohm-m is observed in the eastern part of the study region. As mentioned earlier, a broad flank of resistivity low (L1) is seen in SW part, indicative of the fact that the saline water intrusion is spreading both in north and east directions with depth.

Figure 3e (AB/2 = 100) shows a zone of very high resistivity (H) with values of over 3600 ohm-m in the western part of the study area. This represents very hard and compact rock at depths of 100 m. The region L2 with resistivities of 200 ohm-m seems to follow a northward migration. It may be mentioned here that the river Karli is also changing its course to north side after flowing in E-W direction from the coast. The SW part of the study area (L1) having very low resistivities (of the order of 1 ohm-m) may contain brackish water, due to high tides. This also reflects that a major lineament is present in this region, as suggested by Sarkar and Soman (1986);

Hanamgond and Mitra (2008), which facilitates the intrusion of sea water at such deeper levels.

2-D geoelectrical section

The 2-D geoelectrical section has been generated (Figs. 4a, b, c) over three selected profiles in the study region in order to understand the geometry of the aquifer developed and the extent of saline water intrusion in and around the study area.

The southern most profile (from west to east) covers the stations VES 21, 20, 25, 19, 7, 6, 13 and 5. It can be seen from Fig. 4a that at VES 20 a highly conductive feature having resistivities of about 10 ohm-m with a spatial extent of about 4 km is delineated from shallow depths and extends beyond 100 m. Also at lower levels, this feature is trending towards west. It is possible that saline water has migrated through the fractures and lineaments present in this region thus giving rise to such low resistivities. The resistivity values are highly influenced by the proximity of the Arabian sea. Further below VES 19, an aquifer body is developed with resistivity values of about 40 ohm-m up to depths of about 20 m. This has some effect from the River Karli which is flowing in east-west direction in the vicinity of this sounding point. Below VES 7, 6 and 14, hard and compact rocks are encountered from shallow to greater depths. This region is also characterized by hilly terrain comprising of laterites. An interesting feature is seen below VES 5 wherein a small aquifer body up to depths of 5m is developed. Further stations to the east of this sounding point would have brought out the complete aquifer body.

The second profile lies in the central part of the study region encompassing VES stations 22, 18, 28, 26, 24, 8, 15, 23 and 2. It is observed that below VES 22, there is an effect of saline water intrusion from shallow depths and beyond 100 m giving rise to resistivities of the order of 10 ohm-m (Fig. 4b). However, below VES 18 and 28, high resistivity feature is encountered, presumably due to the laterites. Below VES points 26, 24 and 8 low resistivity zone (10-50 ohm-m) is encountered from shallow depths and beyond 100 m. It seems that an aquifer body is developed here along with the consequence of the River Karli. It is also possible that a deep seated lineament exists beyond depths of 100 m which may cause the sea water to migrate from west side towards east. VES 15 and 23 is at a higher elevation which is clearly reflected in the pseudo section. Again, as observed in the southern profile, here also a small incomplete aquifer body is delineated below VES 2. The northern most profile in the study region has 8 VES points (VES 27, 17, 10, 9, 11, 16, 12 and 3). Figure 4c shows that the effect of saline water intrusion in the western part does not exist. Instead a very high resistivity block is encountered here. This region is at a higher elevation and hard and compact laterites are the main rocks controlling this region. It is thus possible that this zone is acting as a barrier to groundwater or saline water flow from the coast side. Further below VES 11, 16, 12 and 3, a large aquifer body is seen up to depths of about 20 m. This region seems to be a potential groundwater zone. Below depths of 20 m, hard and compact rocks are encountered below these sounding points.

Geoelectrical conductance

The electrical conductance is the product of the resistivity and the thickness of a unit. Hence a layer can be thinner and more conductive or it can be thicker and less conductive. This essentially produces the same results. Hence constraints on the model from borehole data or assumed unit resistivities can greatly enhance the interpretation. In the present study, the geoelectrical cross-section conductance at a depth of 50 m is calculated over the southern, central and northern profiles and plotted in Figs. 5a, b, c. It can be seen from Fig. 5a (southern profile) that towards west, a peak conductance value of 3 S/m associated with saline water intrusion is obtained. This is also reflected below VES 20 in the pseudo cross section (Fig. 4a). However the conductance limits are below 1 S/m over the eastern part of the profile.

Figure 5b shows the distance-conductance map at 50 m depth over the central profile. Here two high conductance values of the order of 4 S/m are observed. Both these high values point towards sea water intrusion. As discussed earlier, low resistivity features were observed in the pseudo cross section (Fig. 4b) below VES 22 and VES 26, 24 and 8. It is possible that a deep seated fracture or lineament exists below 100 m between VES 22 and VES 26, which is facilitating in the intrusion of salt water resulting in two prominent conductance peaks as observed in Fig. 5b. Towards east, however, the conductance values are well below 1 S/m.

The northern profile (Fig. 5c) reflects normal conductance values at depth of 50 m over the entire profile. Here the conductance values range from 0.02 to 0.3 S/m. This suggests that towards the northern side of the study area, there are no effects of saline water intrusion.

Anderson and Cummings (1999) reported that the salinity of sea water to be 5 S/m. They further suggested that if the electrical conductance ranges from 0-0.08 S/m, it is suitable for drinking purpose and also suitable for all other livestock. However, if the electrical conductance values exceed the range 0.3 to 1 S/m, it is then not suitable for human consumption or irrigation purpose. From the foregoing discussion it can be inferred that the salinity of saline water intrusion over the southern and central profiles are too high, of the order of 3-4 S/m and thus this may mix with the fresh water and make it unfit for human consumption and irrigation. Detailed chemical analysis should therefore be considered before using high salinity water for stock and other purposes, especially over the western part of the southern and central profiles.

CONCLUSIONS

Vertical electrical sounding (VES) were conducted to delineate sea water intrusion in western coastal area near Malvan, Maharashtra. A total of 28 VES points were carried out in a rectangular grid. Resistivity contouring at depths of 5, 25, 50, 80 and 100 m indicated confined aquifer in NE part of the study region which is composed of the unconsolidated sediments (mainly alluvium gravel and lateritic soil). The sediments of this area are permeable and unconsolidated near the ground surface, becoming better cemented and consolidated with depth. This aquifer is recharged from the percolating rainfall and River Karli which is flowing in this region. The northwestern part of the study region is reflected as very high resistivity feature, which is an outcome of the laterites present here. In southern part near coast, very high conductive zone is distributed in SW area, which indicated substantial influence of seawater intrusion. The quality of the groundwater in the study area varies from saline to brackish in the SW and eastern parts of the study area to fresh water in the remaining parts.

Two dimensional modeling of data over three profiles in the study region clearly indicate the flow of saline water from the coastal side. These studies also inferred that the effect of saline water intrusion diminishes as we move from southern to northern part of the region. The depth-conductance maps over the three profiles also suggest high salinity at the coastal side. It is also inferred that the saline water intrusion is due to some deep seated fault or lineament present in this region. These lineaments may act as prospective zones for the migration of sea water from western part and getting mixed with fresh water in the eastern side.

Excessive groundwater exploration may seriously affect the ground water quality through the phenomenon of saline upcoming. Therefore, it is important to maintain the balance between the fresh and saline water bodies in the coastal aquifer of Konkan region. It is also proposed to carry out detailed geochemical analysis of bore well and dug well water of this region and establish the significance of the mixing of saline water with fresh water. Also the resistivity data is proposed to be integrated with other geophysical data like magnetics, magnetotellurics and heat flow to get the exact geometry of the sub-surface crustal configuration.

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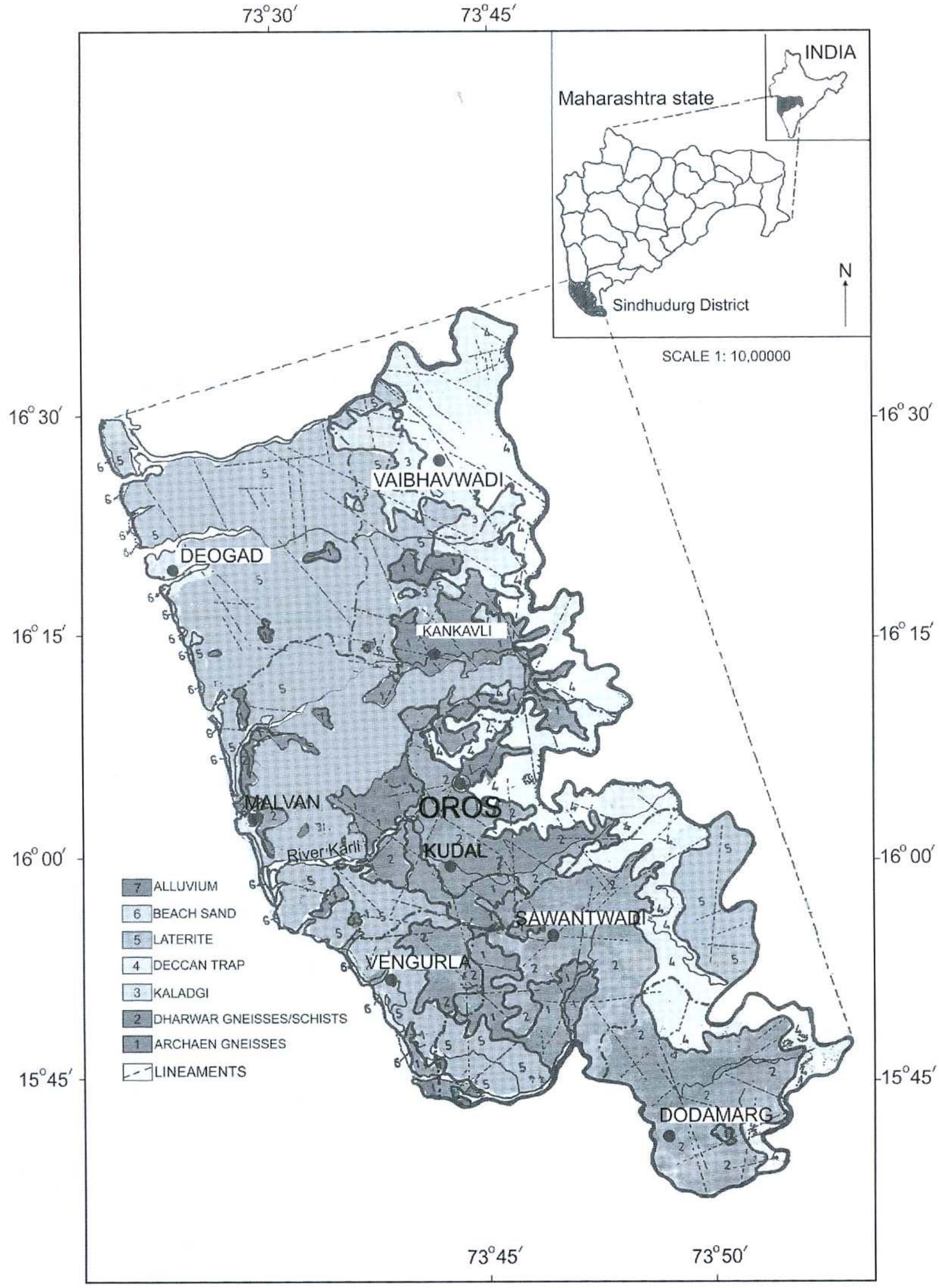


Fig. 1. Geological map of Sindhudurg indicating the study area.

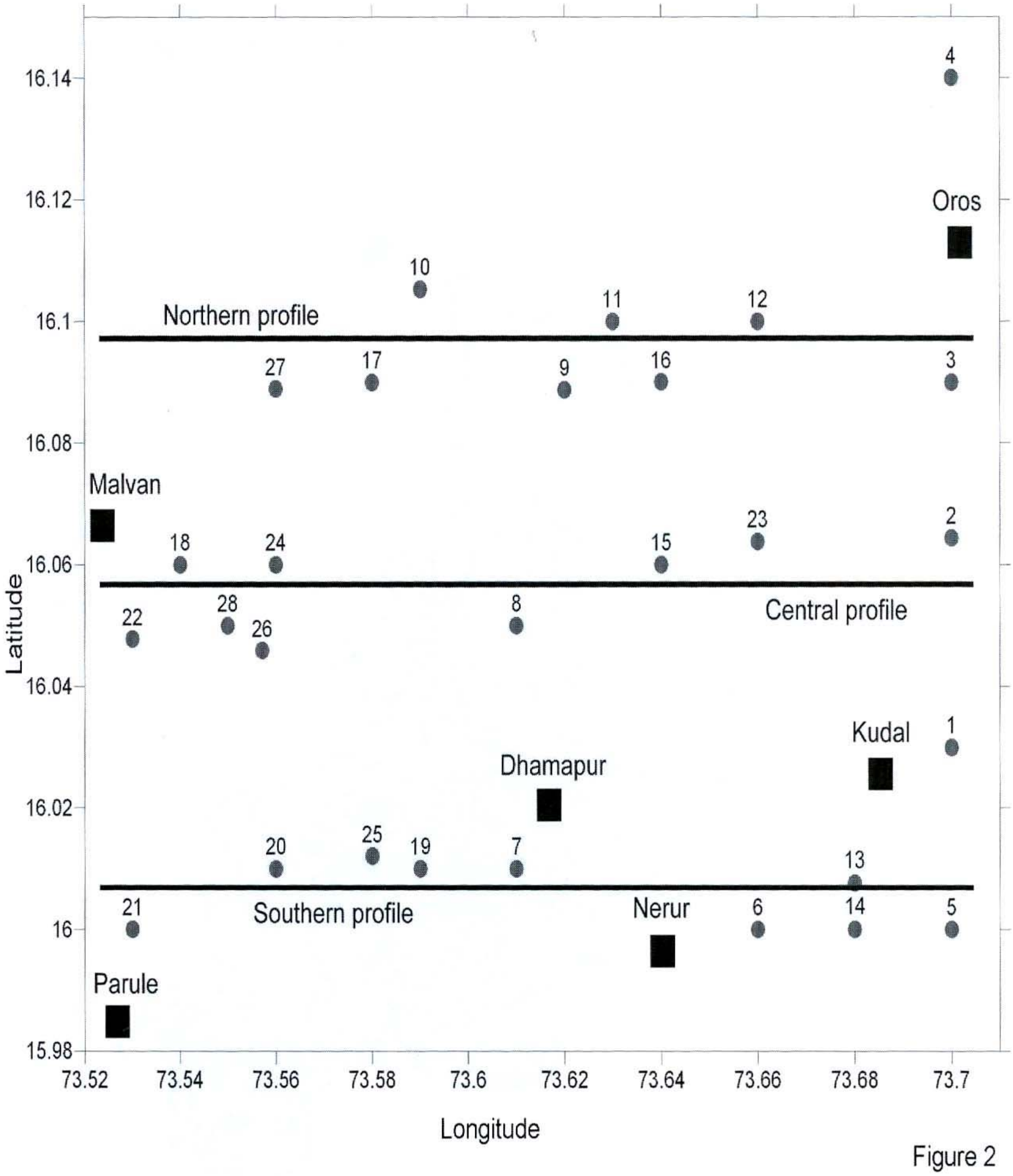
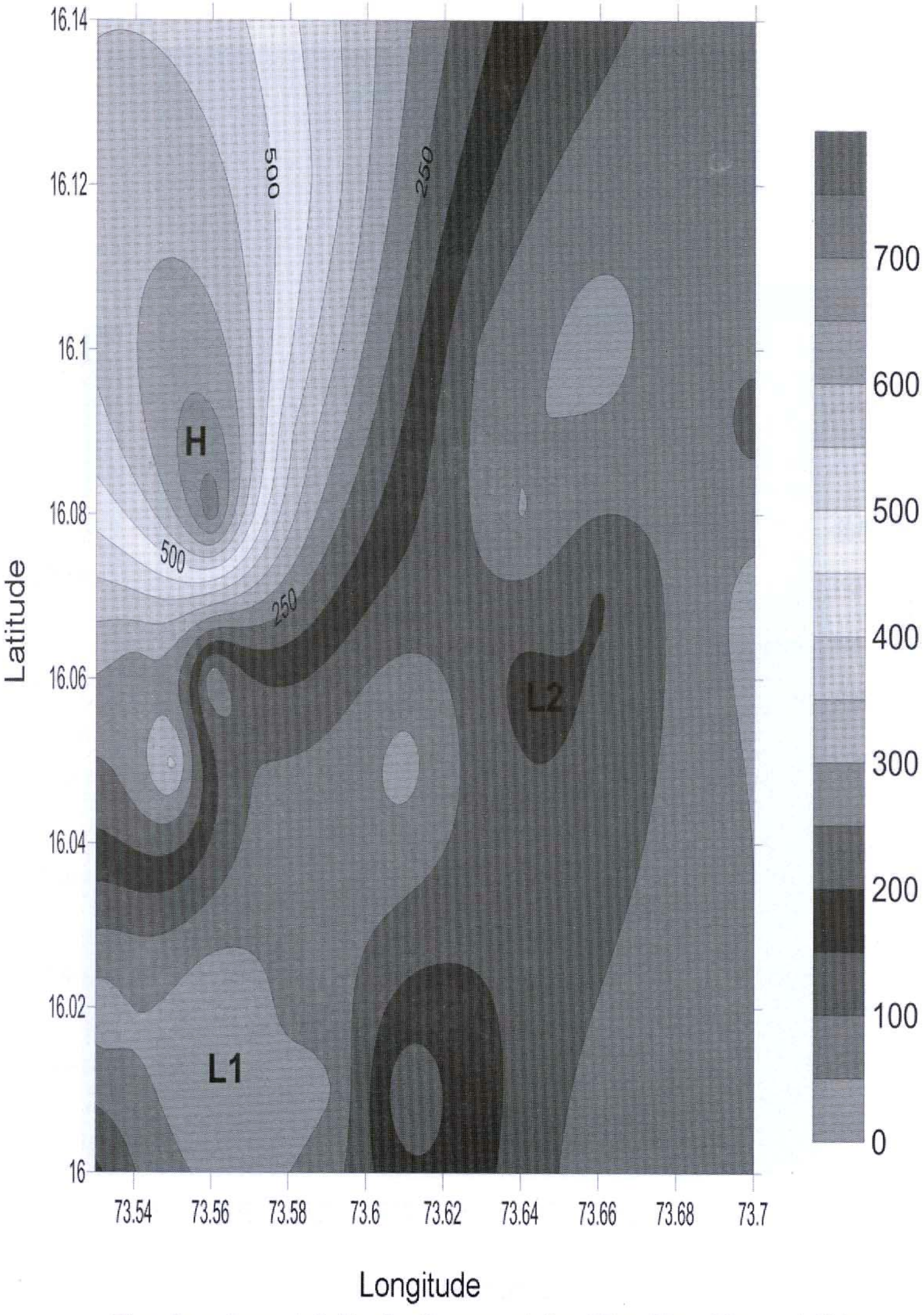


Fig. 2. Vertical electrical sounding (VES) location map.



Figs. 3a-e. Isoresistivity-depth maps at 5m, 25m, 50m, 80m and 100m.

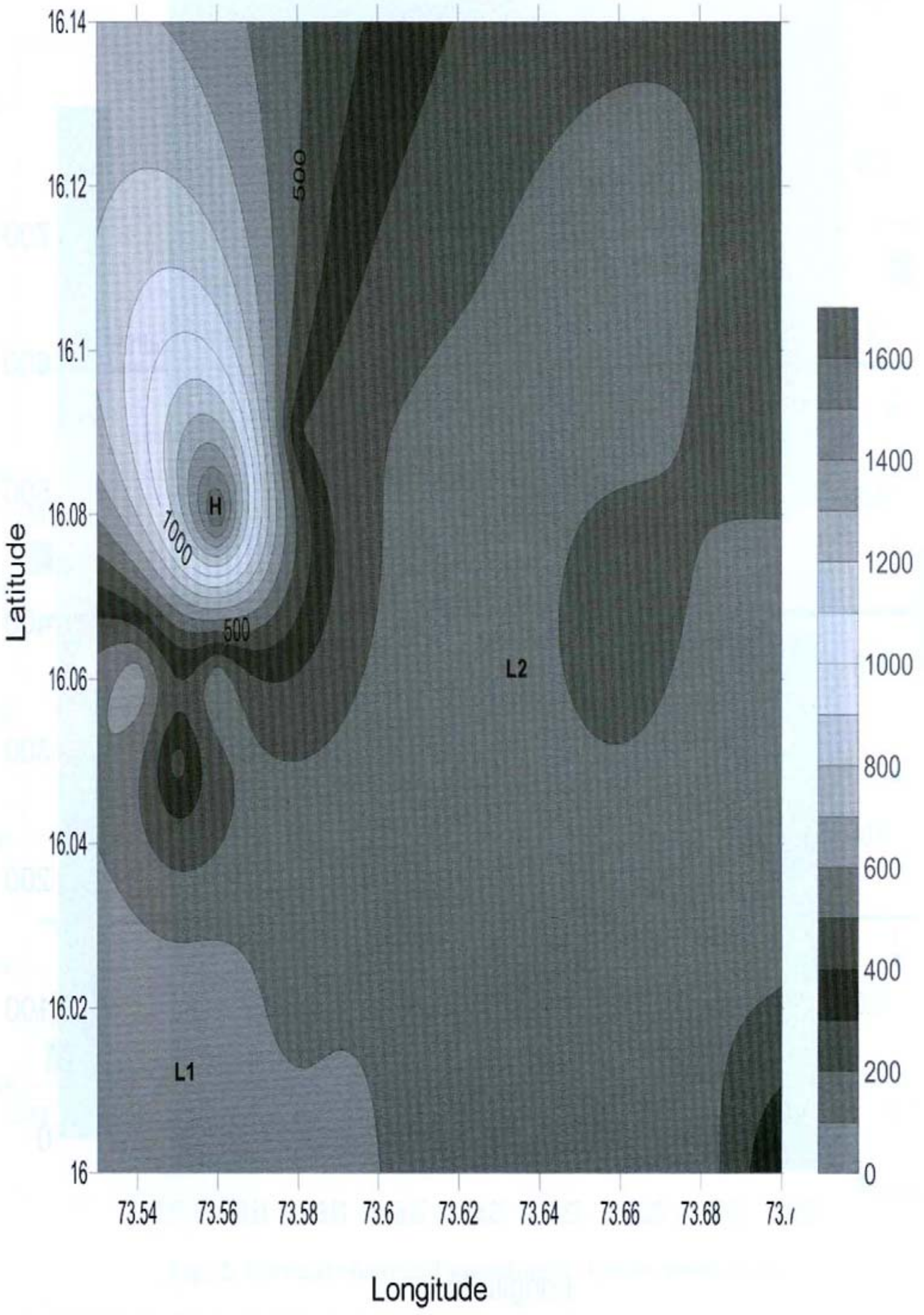

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Fig. 3b

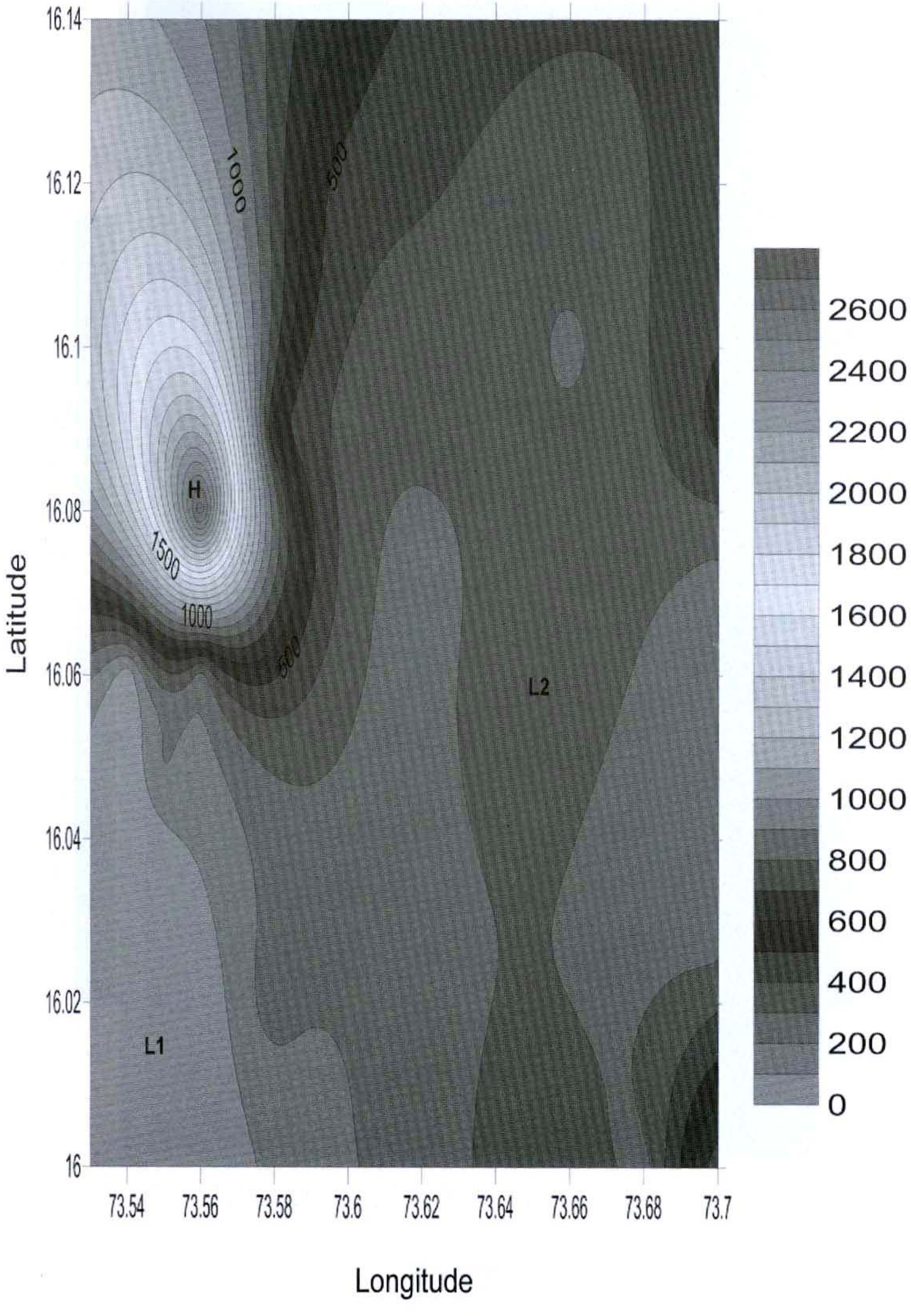
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Fig. 3c

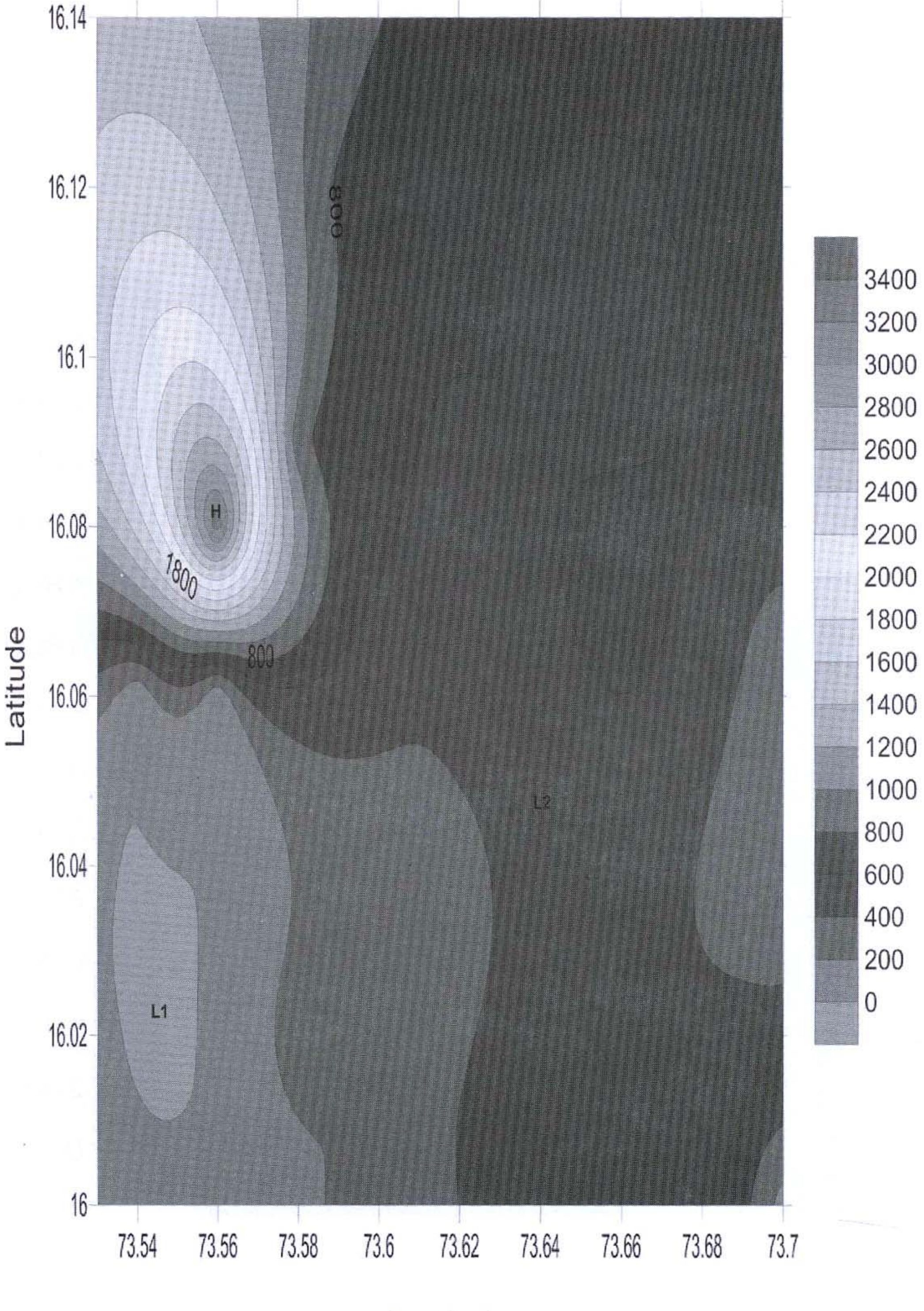
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Fig. 3d

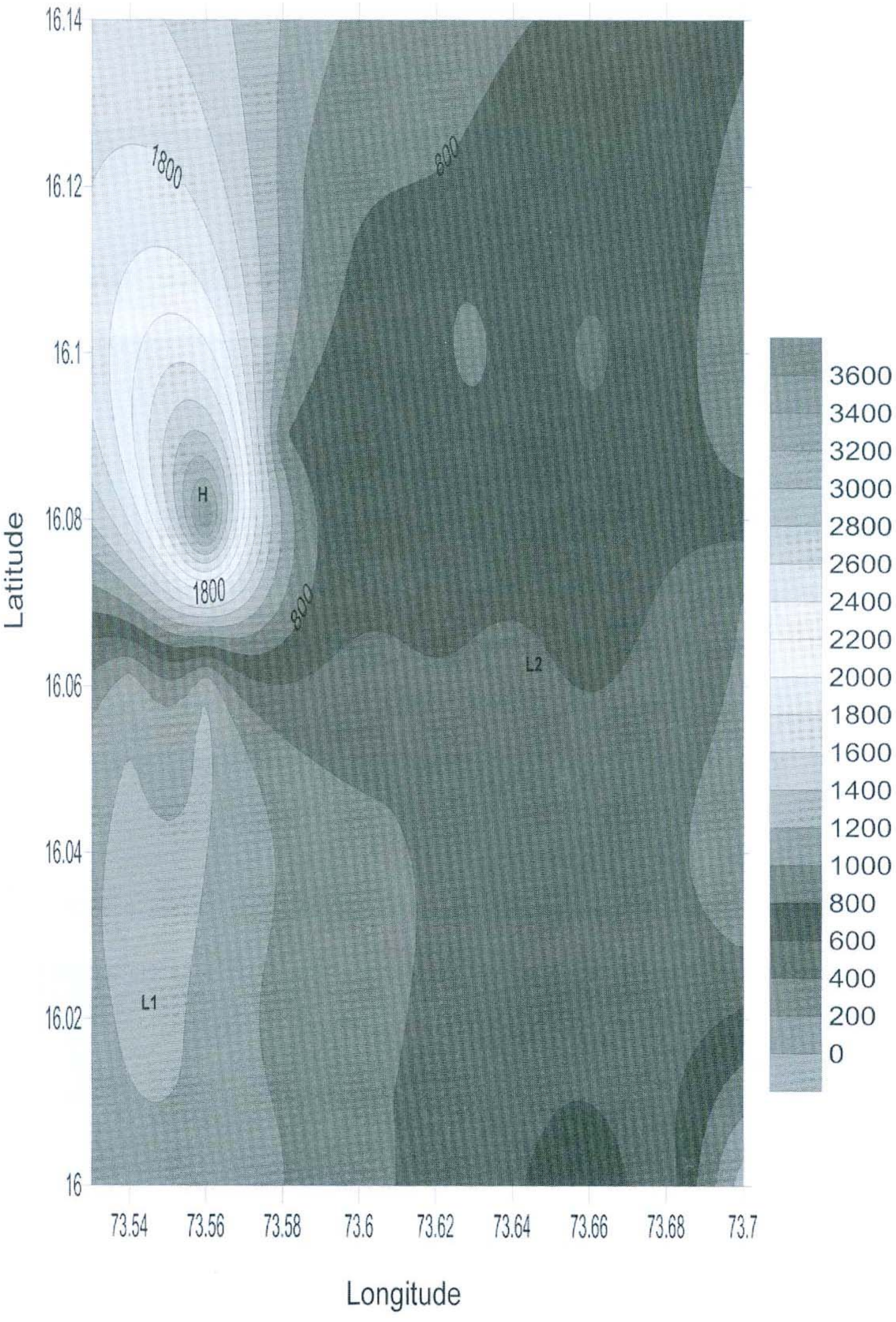
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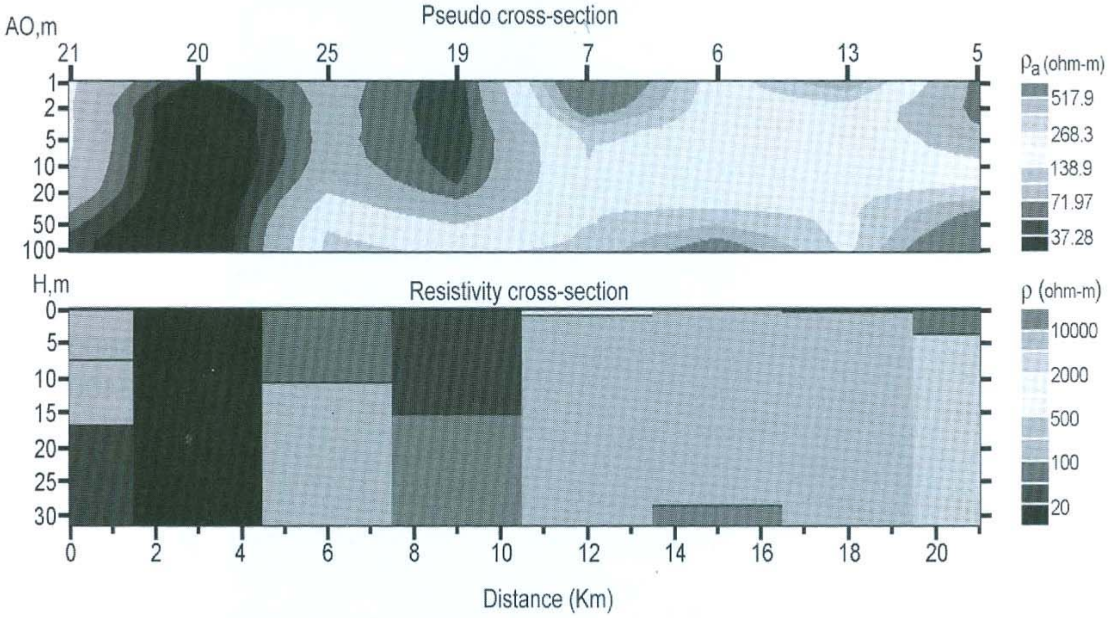
Fig. 3e



Figs. 4 a. Longitudinal geoelectrical section along southern profile.

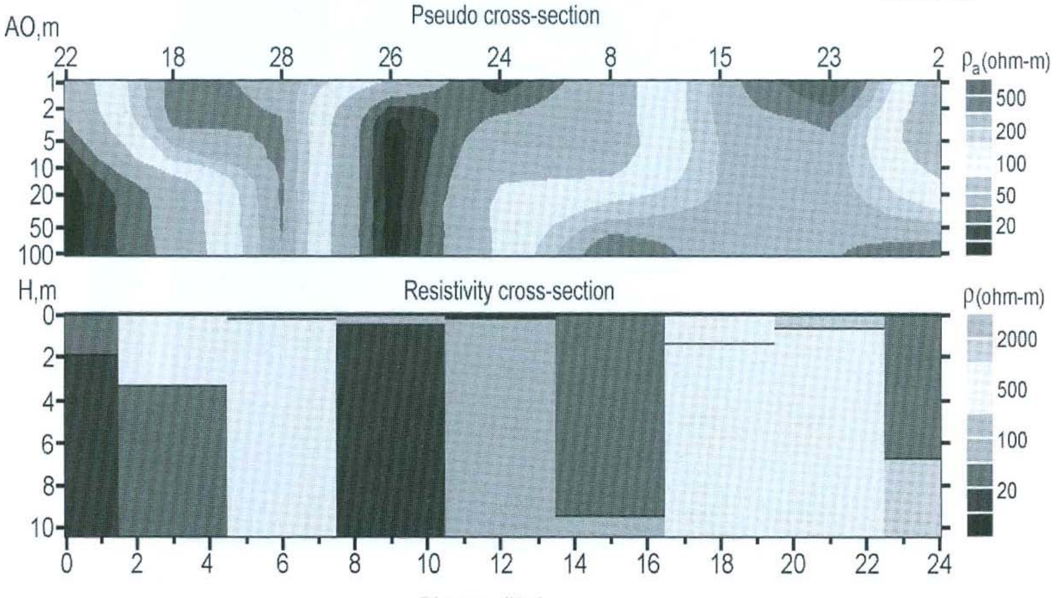


Figure 4b

Fig. 4b. Longitudinal geoelectrical section along central profile.

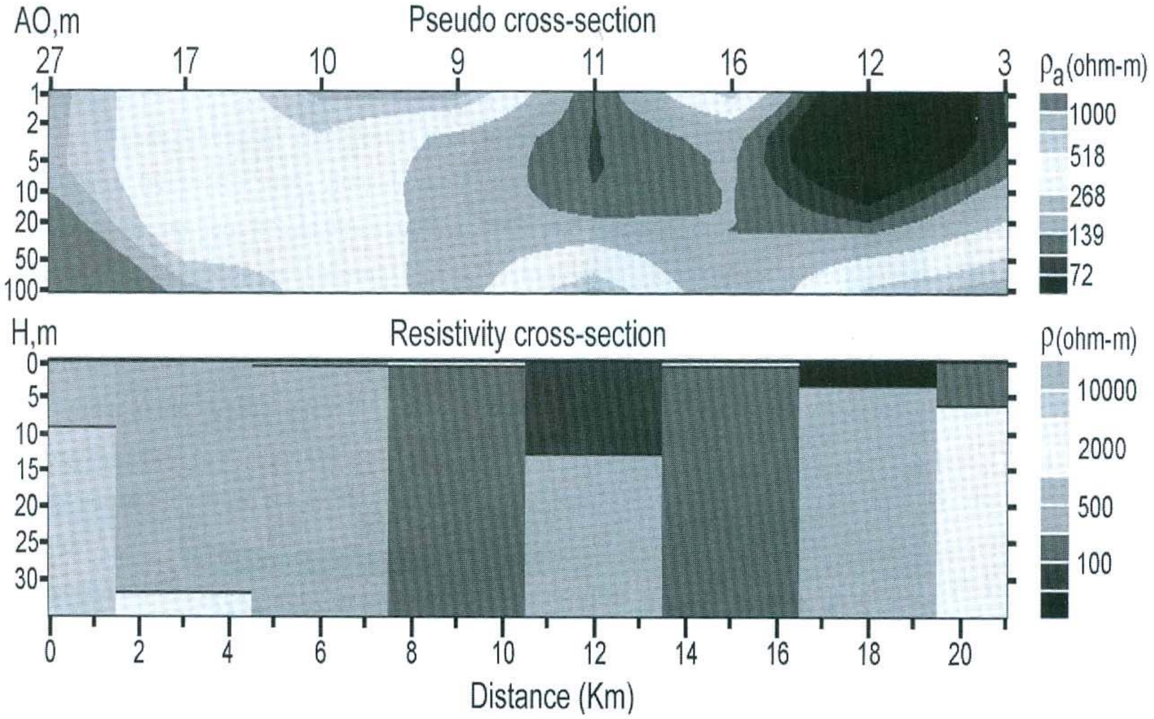


Fig. 4c. Longitudinal geoelectrical section along northern profile.

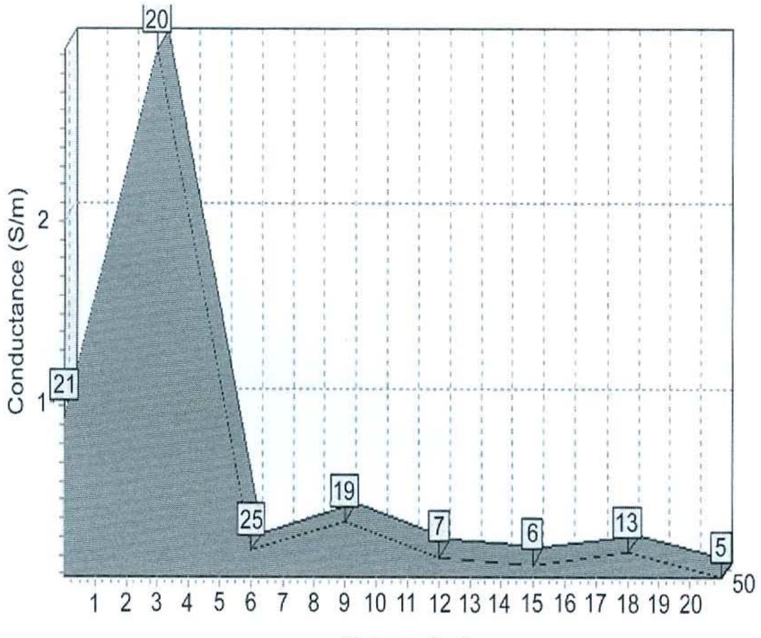


Fig. 5a. Conductance map at 50m depth over southern profile.

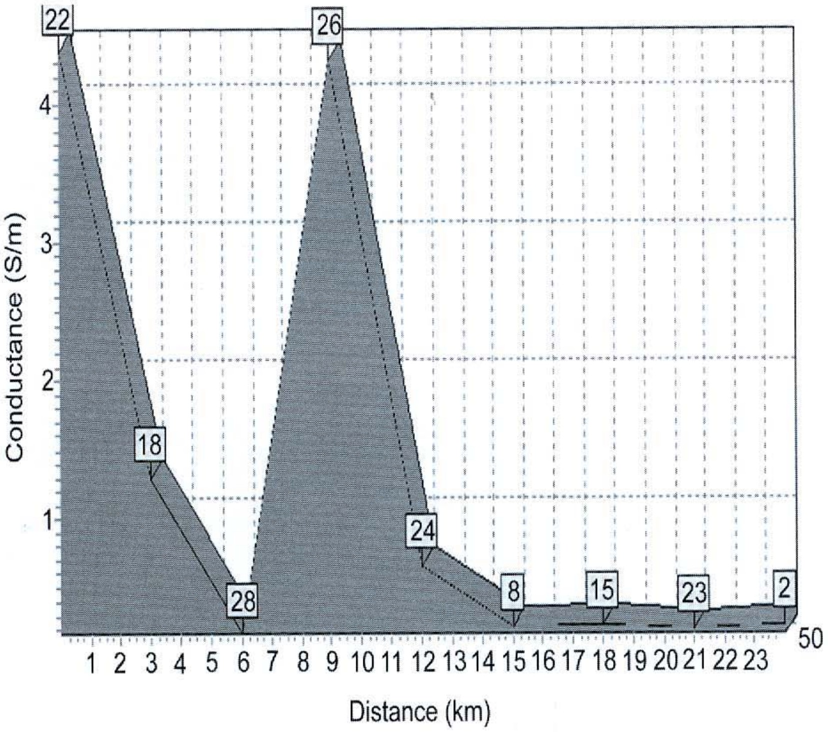


Fig. 5b. Conductance map at 50m depth over central profile.

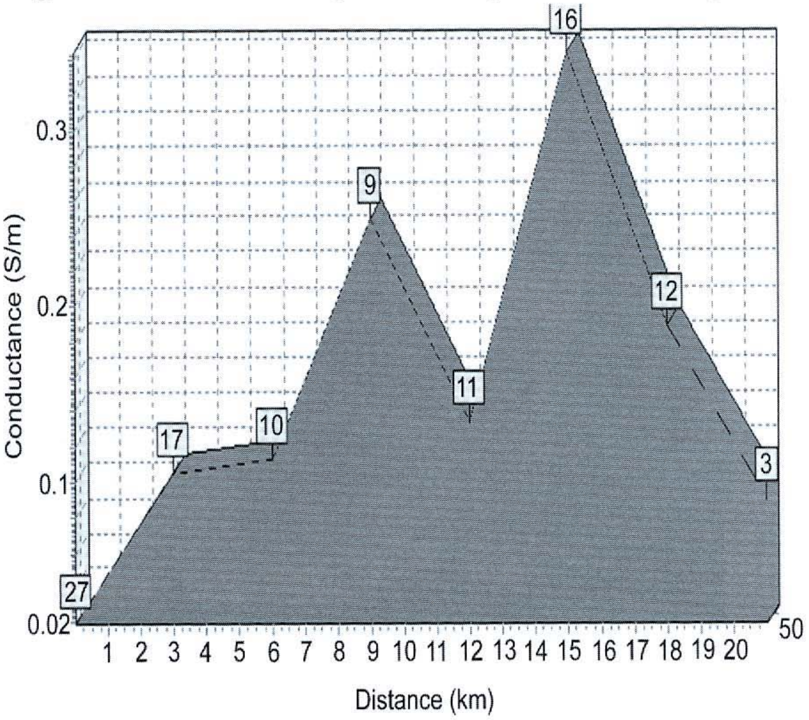


Fig. 5c. Conductance map at 50m depth over northern profile