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# Ground Water Potential in Fractured Aquifers of Ophiolite Formations, Port Blair, South Andaman Islands using Electrical Resistivity Tomography (ERT) and Vertical Electrical Sounding (VES)

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**Abstract:** Ground water occurs in weathered formations of unsaturated zone and fractured rocks of saturated zone. The ground water occurring in the unsaturated zone is not sustainable while the ground water occurring in the fractured rocks are sustainable if properly exploited. But, targeting the productive fractured rocks needs careful evaluation and systematic approach of geophysical survey owing to the heterogeneity, magmatic and metamorphic activities of multiple episodes of rocks. Hence, judicious planning in ground water exploration is warranted because of the huge money involved in drilling, manpower and time factor. In this context, an attempt has been made to locate the fractured rocks of ground water potential in the Ophiolite formations of Port Blair, South Andaman Islands using Electrical Resistivity Tomography (ERT) and Vertical Electrical Soundings (VES) since the ground water database of Andaman and Nicobar islands is poor as not much work has been carried out so far and the ground water is not properly utilised. The ERT have been carried out along different azimuth of fractures to ascertain the resistivities in vertical and horizontal direction and the conductivity and/or the resistivity of the varied fractures was also evaluated by spot VES. The 2-D Electrical Resistivity Images in conjunction with the geoelectrical parameters brought out by VES revealed that E-W fractures are expected to be productive fractures showing more conductivity as it is compared with the NE-SW and NW-SE fractures. The potentiality of the E-W fractures was also validated with the borehole data.

**Keywords:** Electrical Resistivity Tomography (ERT), Schlumberger VES, Aquifer, Ophiolite, Andaman Island.

## INTRODUCTION

The Ground water has many advantages when it is compared with surface water since it demands little or no treatment and it is available when surface water supplies do not exist. This precious natural resource occurs in weathered formation of unsaturated zone and in fractures of saturated zone. In Andaman Islands, there are number of N-S, NW-SE, NE-SW and E-W faults and these faults were responsible for the development of Andaman forearc basin (Tapan Pal et al. 2003). Highly fractured rocks and joints swarms were seen at many places. Locating the fractures, its thickness and yield characteristics of the fracture is of primary concern in ground water investigation. Geophysical methods are much successful in ground water investigation since they are non-invasive and cheap (Stampolidis et al. 2005; Kalisperi et al. 2009; Balaji et al. 2010). In the location of fractures, the resistivity method is a globally accepted, cost-effective and successful method in ground water investigation because the instrumentation is simple, field logistic are easy and analysis of data is straight forward (Zohdy et al. 1974; Stampolidis et al. 2005). In resistivity method, the measured geoelectrical parameters of rocks and its surroundings are interpreted in terms of hyderogeological concepts (Flathe, 1967).The resistivity method, especially Vertical Electrical Soundings (VES) technique has been successfully employed in locating the fractures and investigating the ground water quality in different settings. During the last decade, conventional geophysical methods are integrated with high-resolution technique like Ground Penetrating Radar (GPR), Electrical Tomography and seismic refraction (Tsokas et al. 1995; Vafidis et al. 1995; Pipan et al. 1996; Tsokas et al. 1997) for ground water investigations. The utility of these geophysical methods in ground water exploration is well established by many (Zhody et al. 1974; Buselli et al. 1992; Anon. 1994; Goldman and Neubauer. 1994; Tamta et al. 2005; Sultan et al. 2009).

In Andaman Islands, the ground water is not properly exploited and surface water resources depletes fast during summer. So, scarcity of water occurs at many places and in addition a good ground water database for sustainable ground water development and management of Andaman Island is not so far available. Therefore, an attempt has been made in the present study, using Electrical Resistivity Tomography (ERT) and Vertical Electrical Soundings (VES) in different azimuth of ophiolite rocks and accordingly, Electrical Resistivity Tomography (ERT) and Vertical Electrical Sounding (VES) were carried out along N-S, NE-SW and NW-SW fractures. The geophysical survey could able to bring out the fractured rocks/low resistivity and/or high conductivity of rocks of ground water importance.

## MATERIALS AND METHODS

The present study was carried out to identify the ground water potential in fractured aquifers of ophiolite formations of the study area and the most commonly used geophysical method for ground water exploration is resistivity method. In resistivity method, the commonly used technique is VES (Vertical Electrical Sounding). In VES, an electric current (*I*) is introduced through the outer two current electrodes and the resultant potential difference ($\Delta V$) is measured through the pair of potential electrodes. Then, the apparent resistivity ($\rho_a$) is calculated through the following formula in the case of Schlumberger electrode array.

$$\rho_a = \frac{\pi}{2}\left(\frac{a^2-b^2}{b}\right)\frac{\Delta V}{I} \quad (1)$$

$\Delta V$ = potential difference; $I$= current; $a$ = AB/2; $b$ = MN/2

By increasing the distance between the outer two electrodes, current may penetrate to a deeper depth and the depth of investigation also increases. In this way, a sequence of measurements collected with increasing electrode separation can be modeled in terms of the variations of bulk resistivity with depth. A logarithmic sounding curve is produced by plotting each value of $\rho_a$ against electrode spacing curves and can be inverted by hand or using dedicated software (e.g. RESIX) to derive horizontally layered models of true resistivity and layer thickness. The true resistivity is a diagnostic physical property and can be used to differentiate between materials. A finite difference or finite element technique is usually used to calculate the 2-D forward response of the model. By subsequent iterations, the model is upgraded until a minimum (or an acceptable) RMS misfit between the observed and model pseudosection is achieved. The pseudosection gives a very approximate pictures of the true sub-surface resistivity distribution. Data used in this study were collected by different geophysical techniques and the Vertical Electrical Sounding (VES) was done using the resistivity meter and Electrical Resistivity Tomography (ERT) was carried out using PASI Electrical imaging equipment. The Electrical Resistivity Tomography (ERT) data was acquired by adopting Wenner and Wenner-Schlumberger array which is a new hybrid between the Wenner and Schlumberger arrays. Before carrying out the resistivity soundings, the fractures/lineaments were interpreted using the IRS P6 satellite imagery. The lineaments were interpreted on the basis of the lithological contact and rectilinearity of the drainages (Ramasamy and Balaji, 1993; Ramasamy and Balaji, 1995). Along these lineaments, resistivity traverses were laid. Three ERT traverses were scanned using the Wenner and Wenner-Schlumberger array. The traverses were conducted in the areas to locate fractured zones in the bedrock suitable for boreholes. The lines varied in length up to 160 meter to give an effective maximum depth of imaging approximately 31 meter and the data were collected with the 2D Electrical Resistivity Imaging. The data was interpreted by using RES2DINV ver.3.57 software. Vertical Electrical Sounding (VES) data is acquired with Schlumberger electrode configuration method and the distance between both the electrodes was 150 meters and the data was interpreted using curve matching method of (Orellana and Mooney, 1966) and IPI2Win computer software by inversion technique.

## GEOLOGICAL SETTINGS

The study area, Brookshabad which is located between latitude 11° 23' 5" N and Longitude 92° 26' 46" E and about 5 km south of Port Blair. The study area is bounded by late Cretaceous igneous rocks, the ophiolite suite, marine sedimentary rocks of Paleocene to Oligocene age and recent to sub-recent beach sand, mangrove clay, and alluvium coral rags. The Andaman-Nicobar islands were formed as a result of continent-continent collision. The Andaman arc forms a dividing line between Bay of Bengal in the west and the Andaman sea in the east. It is said that Arakan-Yoma range of Western Myanmar rises as Andaman-Nicobar ridge (Rodolfo, 1969). The main ridge of Andaman-Nicobar arc exposes flysch sediments of Paleogene age which constitute the major lithological unit. On the western side of the main ridge lies the subduction zone and situated to the east of the ridge is the inner volcanic arc namely Barren and Narcondam. Ophiolites and metamorphic rocks of late

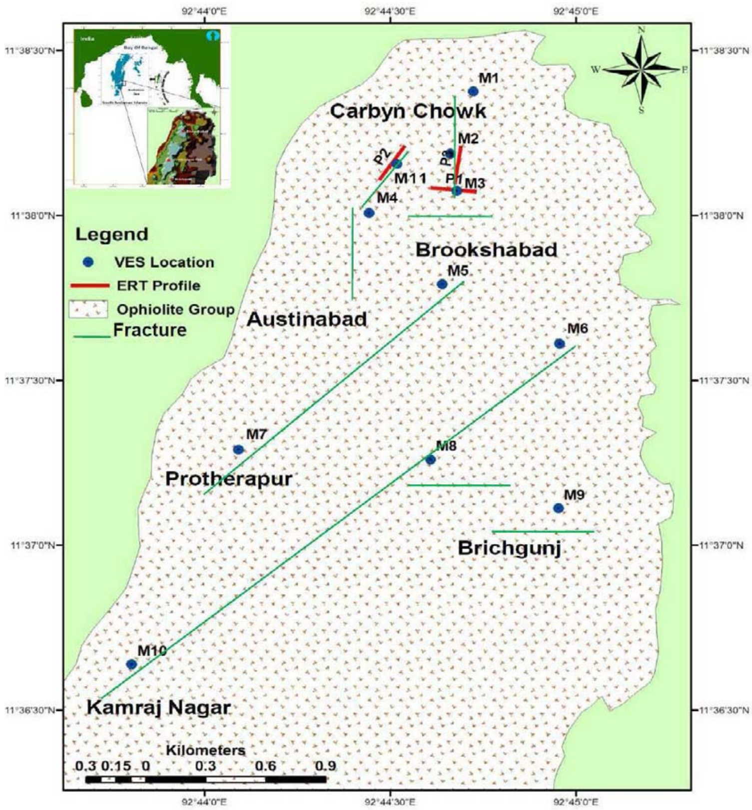


**Fig.1.** Study area of South Andaman.

Cretaceous to early Paleogene age occur in the main ridge. The subduction zone lies west of the Andaman-Nicobar ridge. The subduction started in late Mesozoic consequent to the breaking of Gondwana land (Curray et al. 1979). The uplift of deep water sediments were probably derived from Malay Peninsula in late Eocene and Oligocene (Curray et al., 1979) and gave rise to formation of Andaman-Nicobar ridge. Oldham (1885), divided the geology of Andaman into an older Port Blair Series and a younger Archipelago Series, separated by volcanic rocks and serpentinites later recognised as an ophiolite. The stratigraphy of Andaman and Nicobar islands were studied by Oldham (1885), Tipper (1911), Gee (1927), Chatterji (1964), Karunakaran (1968), Pandey et al. (1993) and Tapan Pal et al. (2003) who classified the Andaman stratigraphy into three groups viz. Ophiolite Group of Cretaceous, Archipelago Group of Mio-Pliocene, Andaman Flysch Group of Oligocene and Mithakhari Group of Eocene age. The Andaman ophiolite contains the main components of an ophiolite sequence that includes upper mantle depleted harzburgites and dunites, lower crustal cumulate gabbros and peridotites, and upper crustal sheeted dikes, pillow lavas, and marine pelagic sediments (Halder, 1985; Ray et al. 1988; Roy, 1992). Both massive and layered gabbros are recognised in the preserved Ophiolite. The south Andaman has the best preserved and most complete sequence of ophiolite, which extends for ~30 km rom Carbyn's Cove in the north to Chidiyatapu in the south.

## ELECTRICAL RESISTIVITY TOMOGRAPHY (ERT) AND VERTICAL ELECTRICAL SOUNDING (VES)

### Vertical Electrical Sounding (VES)

Vertical Electrical Sounding (VES) technique has been used successfully for locating the fractures and investigating the ground water quality in different settings. (Balaji et al. 2010; Balaji et al. 2012). The resistivity of a geological structures/formation can vary significantly depending upon porosity, water content and the concentration of salt in ground water. Increasing concentration of ions/salt in the fluid would increase the conductivity of the fluid and, therefore, lower the overall resistivity of the rock. Thus, the resistivity contrast between the formations enable to locate the water bearing rocks, quantify the water content and estimate the ground water quality (salt content) by resistivity logs. Vertical Electrical Sounding (VES) survey is a curve of apparent resistivity as function of depth. It can be interpreted as 1D layered earth model. This technique is useful to determine the overburden thickness, depth, resistivity and to locate fractures in bedrock.

### Electrical Resistivity Tomography (ERT)

ERT is a technique for measuring the sub-surface electrical structures using the conduction currents. The ERT is mere an advancement of the standard electrical method and widely applied to obtain 2D and 3 D high resolution image of the resistivity of sub-surface patterns in areas of complex subsurface geology, where conventional resistivity sounding or profiling surveys are not feasible (Griffiths and Barker, 1993). The multi-electrode resistivity imaging survey is a combination of both profiling and sounding and gives the resistivity image of the sub-surface in 2D or 3D form. The automated measuring instruments with advance interpretation algorithms could able to collect large amount of data within a short period with electrical resistivity images of the sub-surface (Loke and Barker, 1996). After the advent of high resolution geophysical techniques, Electrical Resistivity Tomography (ERT) for 3-D sub-surface imaging and seismic imaging have greatly helped in the demarcation of aquifer geometry, fresh/saltwater interface, and the dynamics of pollution plume (Daily et al. 1998). The application of ERT aims to determine the electrical properties of the ground (Dahlin, 2001; Psomiadis David et al. 2009). ERT is increasingly used to map underwater formation and solve environmental and engineering problems (Kwon et al. 2005; Nyquist et al. 2008). The 2D and 3D Electrical Resistivity Imaging technique utilises a pair of current and potential electrodes inserted into the ground. The ERT was carried out using a number of electrodes connected to a multi-core cable (Griffiths and Barker, 1993). A computer-controlled system selects automatically two different pairs of electrodes for each measurement until the survey is completed. By measuring the voltage between the potential electrodes, the apparent resistivity of the sub-surface can be determined. By taking a large number of resistivity readings using different geometrical arrays a 2-dimensional profile of the sub-surface can be generated. The data are processed in the field and inverted using the Res2dinv/Res3dinv imaging software to produce an apparent resistivity depth model. After the data inversion, ERI can provide a series of 2D or 3D tomograms where each tomogram shows the distribution of electrical resistivity of the sub-surface. ERI has been used to determine the extent of conductive contaminant plumes or saltwater intrusion (Zhody et al. 1993; Frohlich et al., 1994). ERI may help to understand groundwater /saltwater interactions (Crook et al. 2006; Freyer et al. 2006; Day-Lewis et al. 2006) and low resistivity zone/fracture zone. A fault zone in 2D resistivity model appear as dipping structures defined by contrasting bedrock resistivities.

In this work, the algorithm proposed by Loke and Barker (1996) for the automatic 2D inversion of the apparent resistivity data was used. The inversion routine is based on the smoothness constrained least-square inversion (Sasaki, 1992) implemented by a quasi-Newton optimisation technique. The sub-surface is divided into rectangular blocks, whose number corresponds to the number of measurement points. The optimisation method adjust the 2D resistivity model trying to reduce iteratively the difference between the calculated and measured apparent resistivity. Mean-Squared (RMS) error gives a measure of this difference. All the tomographies show a resistivity contrast between shallow conductive and deeper resistivity material. The smoothness-constrained least- square inversion routine generates a resistivity model of the sub-surface which is automatically adjusted through an iterative process, with the convergence of the model response to the measured data. The model adjustment is given by a residual value, the RMS error. This value is a comparison between the measured apparent resistivity data and the calculated apparent resistivity as the model response.

While the costs for drilling and site measurement to obtain characterisation of data cannot be avoided, using ERT and VES for sub-surface imaging can potentially reduce those costs by allowing site investigators to see images of the areas to study the ground truth and take accordingly precautionary measures in order to save expenditure, time and manpower before investing a huge sum for drilling.

## RESULTS AND DISCUSSION

The lineaments are the surface manifestations of the sub-surface and are structurally weaker planes. These weaker planes existing in the bedrock store the recharged water in the form of groundwater. These lineaments that were

**Table 1.** Geoelectrical parameters of the study area

| VES No. | Curve Type | Layer No. | True Resistivity (Ω.m) | | | | | Thickness (meter) | | | | Total Depth |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | $\rho_1$ | $\rho_2$ | $\rho_3$ | $\rho_4$ | $\rho_5$ | $h_1$ | $h_2$ | $h_3$ | $h_4$ | (meter) |
| | | | N-S fractures | | | | | | | | | |
| M1 | AA | 4 | 36.1 | 68.9 | 936 | 38.1 | — | 1.02 | 6.56 | 4.75 | — | 12.33 |
| M2 | AA | 4 | 33 | 77 | 1014 | 130 | — | 0.9 | 3.1 | 4.43 | — | 8.43 |
| M4 | AA | 4 | 23.4 | 3077 | 13.1 | 186 | — | 1.62 | 3.17 | 6.86 | — | 11.65 |
| | | | E-W fractures | | | | | | | | | |
| M3 | AA | 3 | 6.9 | 80 | 7821 | — | — | 1.3 | 23.8 | — | — | 25.1 |
| M9 | AA | 4 | 12.3 | 48.2 | 125 | 18459 | — | 1 | 5.37 | 15.4 | — | 21.77 |
| M8 | A | 3 | 33.5 | 117 | 39073 | — | — | 4.67 | 19.3 | — | — | 23.97 |
| | | | NE-SW fractures | | | | | | | | | |
| M5 | AA | 5 | 33.3 | 543 | 20.4 | 560 | 30020 | 2.32 | 1.8 | 4.73 | 3.93 | 12.78 |
| M6 | A | 4 | 5.52 | 65.3 | 29.2 | 7130 | — | 1.39 | 8.67 | 6.3 | — | 16.36 |
| M7 | AA | 4 | 54.5 | 253 | 71.6 | 27752 | — | 3.14 | 3.81 | 8.53 | — | 15.48 |
| M10 | HA | 5 | 47.9 | 8.68 | 277 | 37.5 | 13123 | 1 | 0.79 | 1.43 | 9.56 | 12.78 |
| M11 | A | 3 | 10 | 22.1 | 21837 | — | — | 0.75 | 4.5 | — | — | 5.25 |

interpreted from the satellite imagery fall mostly in three azimuth directions i.e. N-S, NE-SW and E-W. Along the linements/fractures at suitable locale resistivity soundings was chosen and accordingly VES were carried out. In the present study, three ERT profiles and eleven VES were carried out and the interpreted VES results were given in Table 1. Three ERT profiles were done and the three depth slices from the resistivity model generated by a 2D inversion process after three iterations are presented in Figs. 2,3,5,6 and 8.

**E-W Fracture**

Along E-W trending fracture, back side of the orphanage centre at Brookshabad, ERT survey using Wenner-Schlumberger electrode configuration was carried out using Italian make PASI Electrical Resistivity Imaging System.

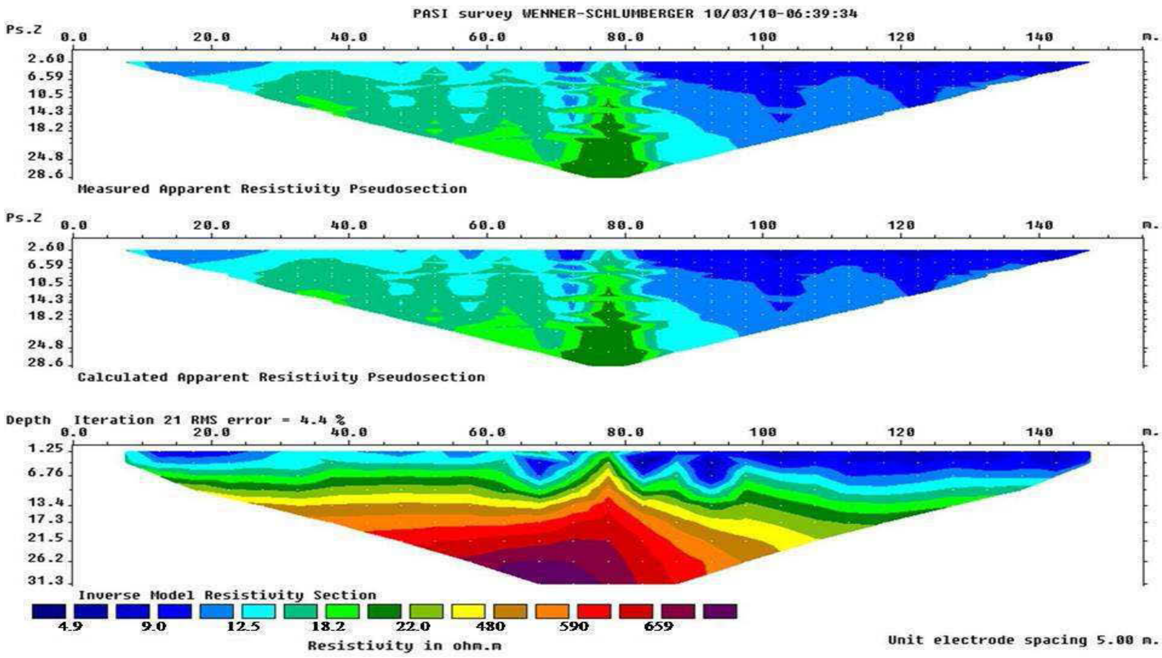


**Fig.2.** 2D Electrical Resistivity Tomography (5 meter electrode spacing) carried out at Brookshabad along E-W fracture.

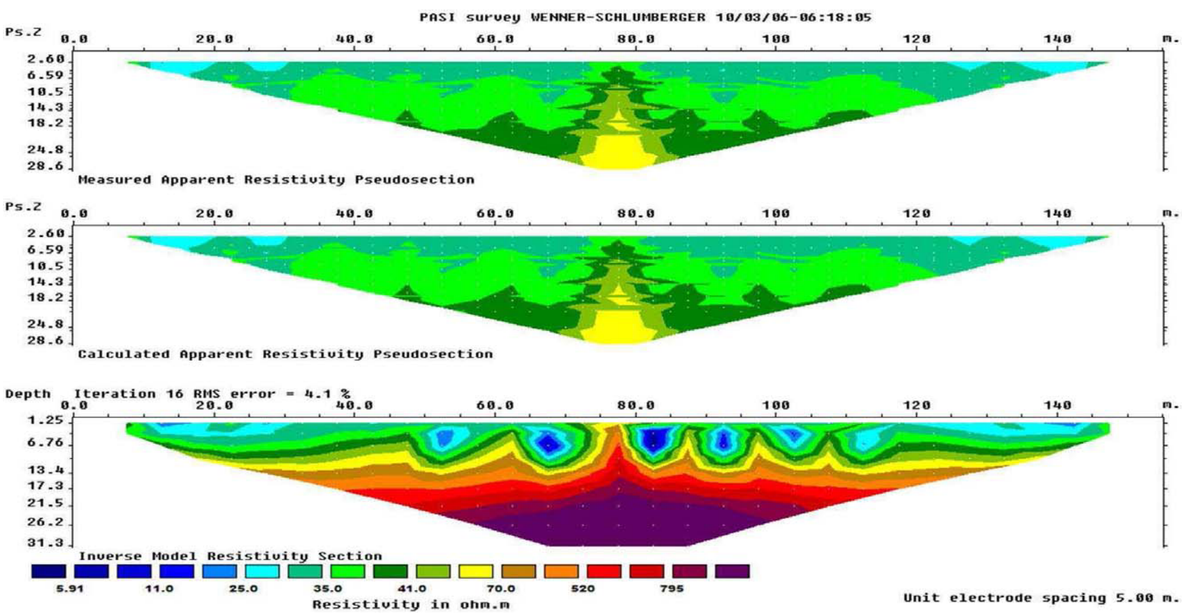


**Fig.3.** 2D Electrical Resistivity Tomography (5 meter electrode spacing) carried out at Brookshabad along E-W fracture.

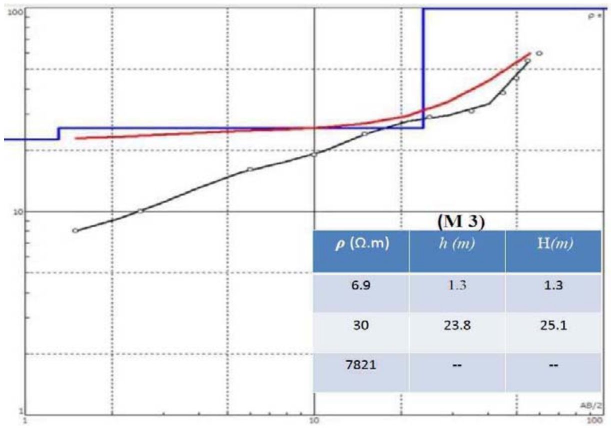


**Fig.4.** Vertical Electrical Sounding curve of resistivity M 3 along E-W fracture valley at orphanage centre, Port Blair.

The electrode spacing was 5.00 meter and the total spread of electrodes was up to 160 meter. The measured geoelectrical parameters were analysed using RES2DINV software. The measured apparent resistivity pesudosection and the calculated apparent pseudosection and the inverse model resistivity section are shown in Fig.2. The spatial distribution of resistivity in lateral and depth wise direction is shown in Fig.2 and the resistivity is ranging from 4.9 to more than 659 ohm-m (Fig. 2). The resistivity at 21.5 meter is 46 ohm-m. indicating that the ophiolites are fractured and below 21.5 meter depth, the resistivities are high indicating the massive nature of the rocks which can be seen in tomogram (Fig.2). In a similar way, ERT survey was carried out along E-W flowing structurally controlled stream at another place in the same Brookshabad area. From the tomogram (Fig. 3) low resistivity rocks of 230 ohm-m. lie at a depth of 21.5 meter and beneath this depth occur massive rocks of ophiolite of resistivity more than 520 ohm-m (Fig.3). From the ERT survey, the low resistivity and/or suitable locale for spot VES survey was identified and at that location, VES number M3 was carried out. The VES curve (Fig.4) was interpreted using IPI2Win software and the interpreted geoelectrical parameters of M3 are given in Table 1. The geoelectrical parameters have shown that there were three layers. The first layer consists of topsoil of thickness 1.3 meter of resistivity 6.9 ohm-m. and the second layers are showing a resistivity of 80 ohm-m. of 23.8 meter thickness. The second layer is fractured up to 25.1 meter depth of resistivity 80 ohm-m. Below the fractured rocks, occur massive rocks of very high resistivity (7821 ohm-m). Similarly spot VES number M8 and M9 were carried out. The interpretation of VES M8 has revealed that there are three layers and the rocks were fractured up to 19.3 meter, The hard and massive rock of very high resistivity (39073 ohm-m) occur beneath 19.3 meter (Table 1). Similarly, the interpreted results of VES M9 have shown four layers. The fracturing at this site has taken place up to 15.4 meter and the resistivity of fourth layer is 125 ohm-m. (Table 1) and beneath this, very high resistivity rocks (18459 ohm-m) occur. The analysis of the three VES (M3, M8 and M9) has

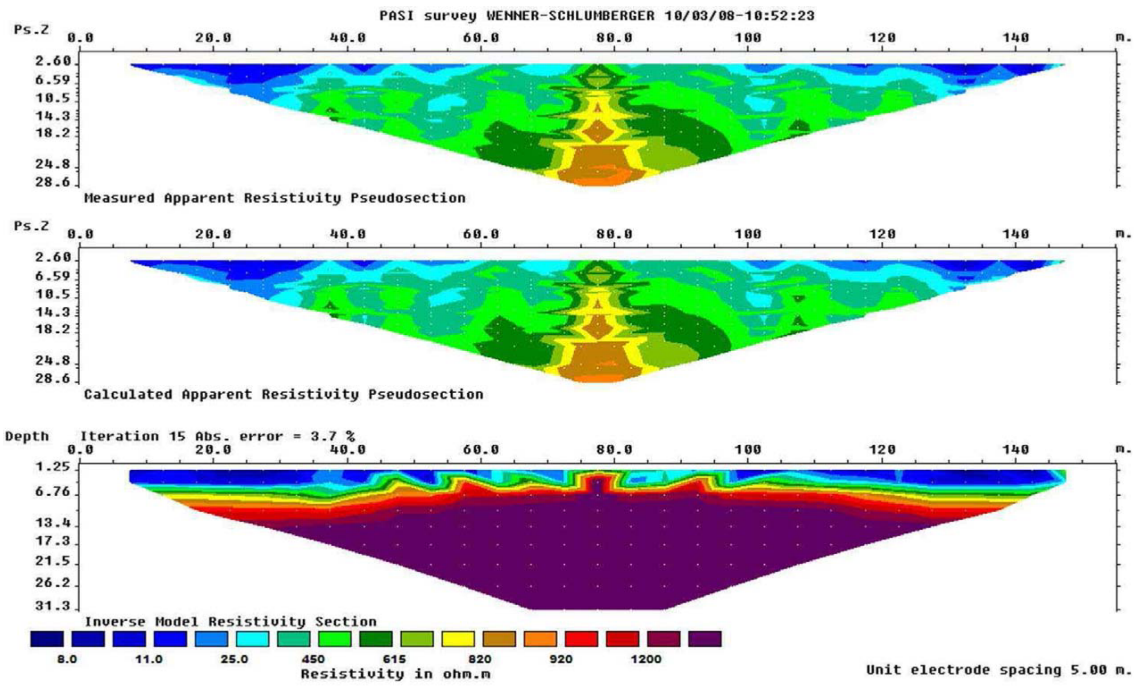


**Fig.5** 2D Electrical Resistivity Tomography (5 m electrode spacing) carried out at Brookshabad along NE-SW fracture.

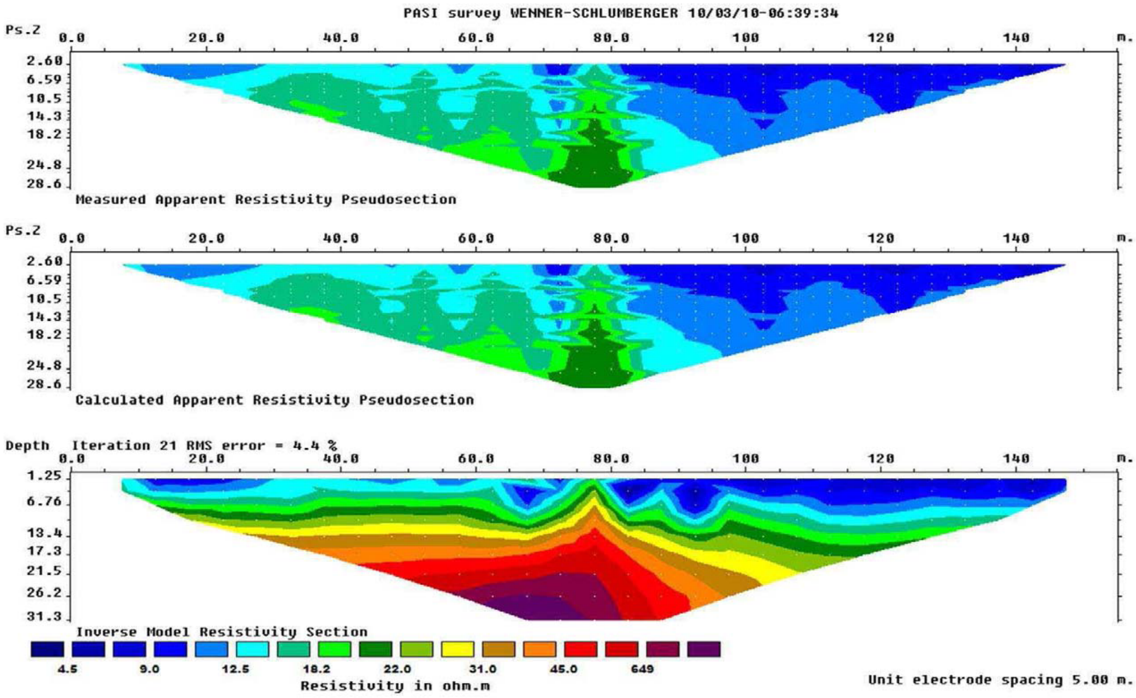


**Fig.6.** 2D Electrical Resistivity Tomography (5 m electrode spacing) carried out at Brookshabad along NE-SW fracture.

shown that shallow fracturing has taken place only along E-W fractures to a maximum depth of 23.8 meter.

The Figs.2 and 3 tomograms results are almost matching with the VES M3, M8 and M9 results (Table 1).

**NE-SW Fracture**

Along NE-SW trending fracture, back side of the orphanage centre at Brookshabad, ERT survey using Wenner-Schlumberger electrode configuration was carried out. The measured apparent resistivity pesudosection and the calculated apparent pseudosection and the inverse model resistivity section are shown in Fig. 5. The spatial distribution of resistivity is shown in Fig.1 and the resistivity is ranging from 8.0 to 1200 ohm-m. The resistivity at 6.76 meter is 26 ohm-m. indicating that the rocks are fractured and below 6.76 meter depth, the resistivities are high indicating the massive nature of the rocks. In a similar way, ERT survey was carried out along NE-SW flowing structurally controlled stream at another place in the same Brookshabad area. From the tomogram (Fig.6), low resistivity rocks of 22 ohm-m. lie at a depth of 21.5 meter. and beneath this depth, massive ophiolites are present. The Fig. 5 and 6 tomograms results are almost matching with the VES M11, M5, M6, M7 and M10 results (Table 1). From the ERT survey, the low resistivity and/or suitable locale for VES was identified and at that location spot VES M11 were carried out. The VES curve (Fig.7) was interpreted using IPI2Win software and the interpreted geoelectrical parameters of M11 are given in Table 1. The geoelectrical parameters have shown that there were three layers. The first layer consists of topsoil of thickness 0.75 meter of resistivity 10 ohm-m. and the second layer is showing a resistivity of 22.1 ohm-m. of thickness 4.5 meter. This layer is fractured up to a depth of 5.25 meter and beneath this lies massive rocks of very high resistivity. In a similar way VES M5, M6, M7 and M10 were carried out along NE-SW trending lineament. The integrated analysis of all the aforesaid VES has revealed that the hard massive rocks occur at shallow depth ranging from 5.25 to 16.36 meter.

**N-S Fracture**

Along N-S trending fracture, back side of the orphanage

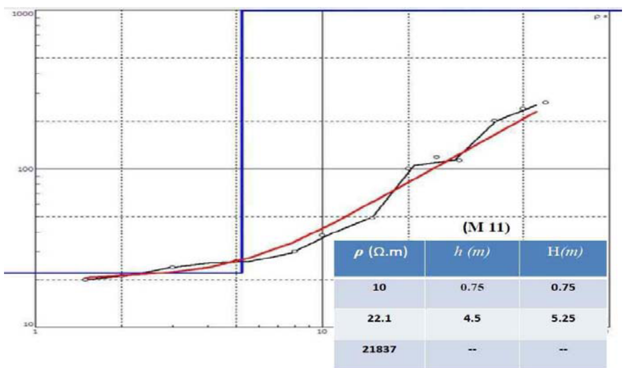


**Fig.7.** Vertical Electrical Sounding curve of resistivity M 11 along NE-SW fracture valley at orphanage centre, Port Blair.

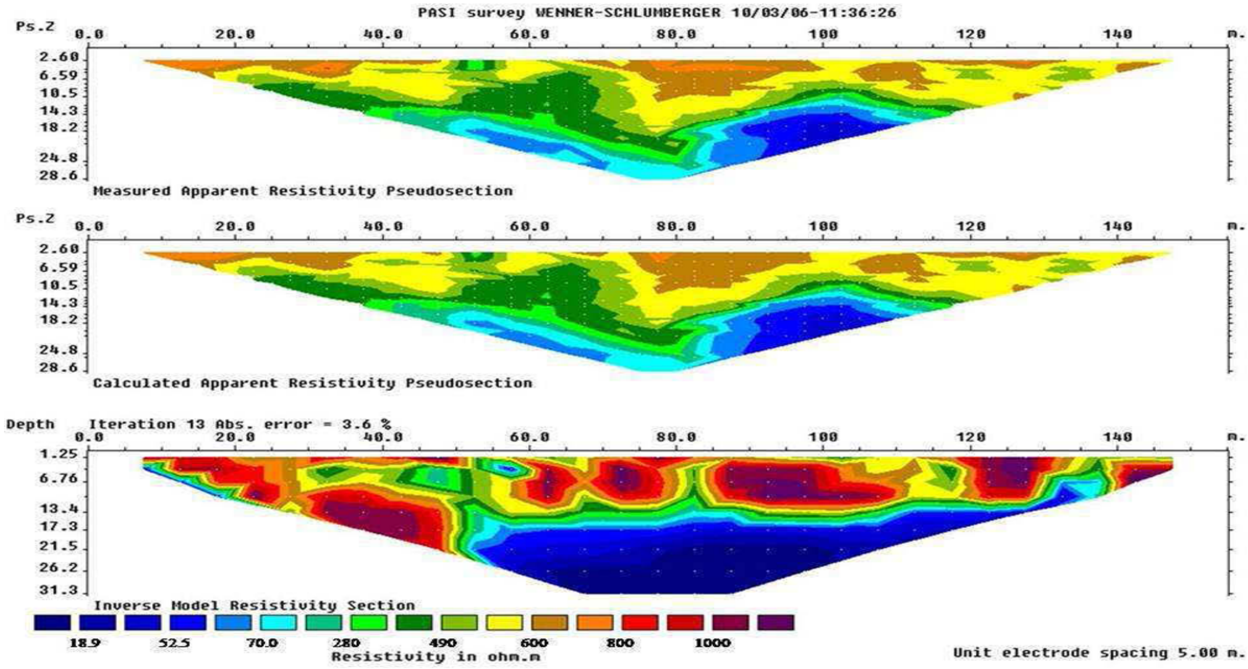


**Fig.8** 2D Electrical Resistivity Tomography (5 m electrode spacing) carried out at Brookshabad along N-S fracture.

centre at Brookshabad, ERT survey was carried out with a spread of 160 meter at electrode spacing 5 meter. The measured apparent resistivity pesudosection and the calculated apparent pseudosection and the inverse model resistivity section are shown in Fig. 8. The spatial distribution of resistivity is shown in Fig.1 and the resistivity is ranging from 18.9 to 1000 ohm-m. The resistivity at 6.76 meter is 600 ohm-m. indicating that the rocks are massive and below that depth, the resistivities are low suggesting the fractured nature of the rocks. From the ERT survey, the low resistivity and/or suitable locale for VES were identified and at that location VES M2 was carried out (Fig. 1). The VES curve (Fig.9) was interpreted using IPI2Win software and the interpreted geoelectrical parameters are given in (Table 1). The geoelectical parameter of M2 has shown that there were three layers. The first layer consists of topsoil of thickness 0.9 meter of resistivity 33 ohm-m. and the second layer is showing a resistivity of 77 ohm-m. of thickness 3.1 meter. The third layer has a thickness of 4.43 meter of resistivity 1014 ohm-m. Beneath 8.43 meter thickness lies fractured rocks of low resistivity 130 ohm-m. Similarly spot VES M1 and M4 were carried along N-S fractures. The interpreted results of M1 and M4 have revealed that there are four layers and the rocks are highly fractured below 4.75 meter and 6.86 meter respectively. The integrated analysis of all the three VES has revealed that the fracture trending in N-S direction is highly fractured as substantiated by the low resistivity beneath a shallow depth.

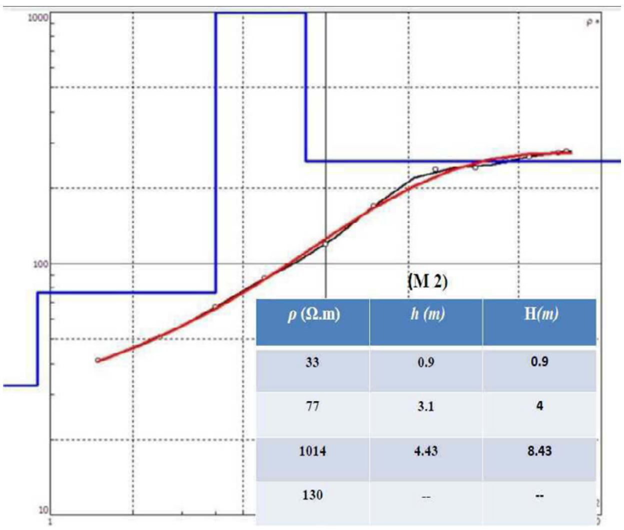


**Fig.9.** Vertical Electrical Sounding curve of resistivity M 2 along N-S Fracture valley at Pondicherry University campus, Brookshabad, Port Blair.

The Fig.8 tomogram result corresponds with the VES results of M1, M2 and M4 (Table 1).

## CONCLUSION

The tomograms derived from ERT surveys have clearly depicted the distribution and variations of resistivity laterally as well as depthwise at various sites. The low resistivity could easily be found out from the tomograms.

The conventional technique of VES has in a similar manner enabled to pinpoint the low resistivity locale for drilling. The integration of ERT and spot VES results has close correspondence. The integrated analysis of ERT and VES has revealed that N-S trending fractures are potential as revealed by the low resistivity. The NE-SW and E-W fractures are showing a very high resistivity at shallow depth. The potentiality of the E-W fractures was validated with the boreholes drilled at Pondicherry university campus and also near the orphanage centre in the Brookshabad area which suggested that the water has been tapped beneath 15 meter along E-W trending fracture. Thus, in the present study, the integration of latest technique of high resolution ERT and the conventional technique of VES have enabled to locate the fractures in bedrock successfully thus enhancing the accuracy of interpretation with minimum error and proved its efficacy in ground water investigation.

**References**


Balaji, S., Rahmam, K., Jeganathan, R. and Neelakantan, R. (2010) Demarcation of Fresh/Saline water Interface in Kavaratti Island of union territory of Lakshadweep island of India using electrical and electromagnatic methods. Internat. Jour. Earth Sci. Engg., v.3(1), pp.62-72.

Balaji, S., Sreelatha, G., Bindu and Jaganathan, R. (2012) Fresh/ Saline water interface studies along the Kerala coast between Kappil and Chakkai using geochemical and geophysical methods. Proc. National Seminar on Applied Chemistry in Marine Sciences: Current and Future trends. Indian Society of Applied Geochemists. Jour. Appld. Geochem., pp.11-18.

Chatterji,A.K.(1964) The Tertiary fauna of Andaman.proc.22nd, Internat. Geol. Cong., New Delhi, section 8, pp.303-318.

Crook, N., Musgrave, H. and Binley, A. (2006) Geophysical characterization of the riparian zone in groundwater fed catchments. Proc. SAGEEP, 06, Symposium for the Application of Geophysics to Environmental and Engineering Problems, Seattle, WA.

Curray,J.R., Moore, D.G., Lawuer, L.A., Emmel, F.J., Raitt,R.W., Henry, M. and Kicckhefer, R.(1979) Tectonics of the Andaman Sea and Burma. *In:* J.Walkins, L. Moutadert. andP.W.Dickerson (Eds.), Geological and Geophysical Investigations of Continental Margins, Amer.Assoc. Petrol. Geol. Mem., no.29, pp.189-198.

Dahlin, T. (2001) The development of DC resistivity imaging techniques. Comput Geosci, v.73(9), pp.1019-1029.

Daily, W.D., Ramirez, A.L. and Johnson, R. (1998) Electrical Impedance Tomography of a Perchoroethylene Release. Jour. Environ. Eng.. Geophys, v.2(3), pp.189-201.

Day-ewis, F.D., White, E.A., Belaval, M., Johnson, C.D. and Lane, J.W. Jr. (2006) Continuous resistivity profiling to delineate submarine groundwater discharge – examples and limitations, v.25(6), pp.724-728.

Flathe, H. (1967) Interpretation of geoelectric measurement for solving Hydrogeologic problems. *In:* L.W. Morley (Ed.), Mining of groundwater geophysics. Geol. Surv. Canada, Econ. Geol. Rep., v.26, pp.58-597.

Frohlich, R.K., Urish, D.W., Fullerand, J. and Reilly, M.O. (1994) Use of geoelectrical method in groundwater pollution surveys in a coastal environment. Jour. Appld. Geophys., v.32, pp.139-154.

Gee, E.R. (1927) The Geology of the Andaman and Nicobar Islands with special reference to Middle Andaman. Rec. Geol. Surv. India, v.59(2), pp.208-232.

Griffiths, D.H. and Barker, R.D. (1993) Two-dimensional resistivity imaging and modeling in areas of complex geology. Jour. Appld. Geophys., v.29 pp.211-226.

Halder, D. (1985) Some aspects of the Andaman Ophiolite Complex. Geol. Surv. India, v.5, pp.1-11.

Kalisperi, D., Soupios, P., Kouli, M., Barsukov, P., Kershaw, S., Collins, P. and Vallianatos, F. (2009) Coastal aquifer assessment using geophysical methods. (TEM, VES), Case study: Northen Crete, Greece. 3rd IASME/WSEAS Internat.Conf.Geology and Seismology, Cambridge, UK, pp.24-26.

Karunakaran, C., Ray, K.K. and Saha, S.S. (1968) Tertiary sedimentation in Andaman-Nicobar geosynclines. Jour. Geol. Soc. India, v.9, pp.32-39.

Kwon, H.S., Kim, J.H., Ahn, H.Y., Kim, K.S., Jung, C.K., Lee, S.B. and Uchida, T. (2005) Delineation of a fault zone beneath a riverbed by an electrical resistivity survey using a floating streamer cable. Explor Geophys, v.36, pp.50-58.

Loke, M.H. and Barker, R.D. (1996) Rapid least squares inversion of apparent resistivity pseudosections by a quasi Newton method. Geophys. Prospect., v.44, pp.131-152.

Nyquist, J.E., Freyer, P.A. and Toran, L. (2008) Stream bottom resistivity tomography to map ground water discharge. Ground Water, v.46, pp.561-569.

Orellana, E. and Mooney, H.M. (1966) Master table and curve of VES over layered structures. Interciencia, Madrid, pp.134.

Pandey, J., Agarwal, R.P., Dave, A., Maithani, A., Trivedi, K.B., Srivastava, A.K. and Singh, D.N.(1993) Geology of Andaman. Bull. ONGC, v.29(2), pp.19-103.

Pipan, M., Finetti, I. and Ferigo, F. (1996) Multi fold GPR techniques with applications to high resolution studies: two case histories. European Jour. Environ. Engg. Geophys., v.1, pp.83-103.

Psomiadis David, Tsourlos Pangiotis and Albanakis Konstantinos (2009) Electrical resistivity tomography mapping of beachrocks:application to the island of Thassos (N.Greece). Environ. Earth Sci., v.59, pp.233-240.

Ramasamy, SM. and Balaji, S. (1993) Aid of Remote sensing in mapping geofractures of environmental significance in Tamil Nadu. Jour. Indian Soc. Remote Sensing, v.21(3), pp.109-

118.

Ramasamy, SM. and Balaji, S. (1995) Remote sensing and Pleistocene tectonics of Southern Indian Peninsula. Internat. Jour. Remote Sensing, v.16 (13), pp. 2375-2391.

Ray, K.K., Sengupta, S. and Van Den Hul, H.J. (1988) Chemical characters of volcanic rocks from Andaman Ophiolite, India. Jour. Geol. Soc. London, v.45, pp.392-400.

Rodolfo, K.S. (1969) Bathymetry and Marine Geology of the Andaman Basin and tectonic implications for Southeast Asia. Bull. Geol. Soc. Amer,, v.80(2), pp.1203-1230.

Tapan Pal, Partha Pratim Chakaraboty, Tanay Dutta Gupta and Chanam Debojit Singh. (2003) Geodynamic evolution of the outer-arc-forearc belt in the Andaman Islands, the centeral part of the Burma-Java subduction complex.Geol. Mag. Cambridge University Press, v.140(3), pp.289-307.

Tipper, G.H. (1911) The Geology of Andaman Islands with special reference to the Nicobar. Mem. Geol. Surv. India, v.35(3), pp.135-145.

Roy, S.K. (1992) Accretionary prism in Andaman forearc. Geol. Surv. India Spec. Publi., v.29, pp.273-278.

Sasaki, Y. (1992) Resolution of resistivity tomography inferred from numerical. simulation. Geophys. Prospect, v.54, pp.453-464.

Stampolidis, A., Tsourlos, P., Mimides, T.H., Tsokas,G., Varemezis, G. and Vafidis, A. (2005) Integreated geophysical investigation around the brackish spring of Rina, Kalimnos Isl, SW Greece. Jour. Balk. Geophys. Soc., v.8(3), pp.63-73.

Tsokas, G.N., Papazachos, C.B., Vafidis, A., Loucoyannkis, M.Z., Varemezis, G. and Tzimeas, K. (1995) The detection monumental tombs buried inn tumuli by seismic refraction. Geophysics, v.60, pp. 1735-1742.

Tsokas, G.N., Sarris, A., Pappa, M., Bessios, M., Papazachos, C., Tsourlos, P. and Giannopopulos, A. (1997) '

Vafidis, A., Tsokas, G.N., Loucoyannakis, M.Z., Vasiliadis, K., Papazachos, C.B. and Vargemezis, G. (1995) A large scale feasibility study on the use of seismic methods in detecting monumental tombs buried in tumuli. Archaeol. Prosp, v.2, pp.119-128.

Zohdy, A., Eaton, G.P. and Mabey, D.R. (1974) Application of surface geophysics to ground water investigations. Techniques of water resources investigations of the United State Geological Survey, 2, pp.116.

Zohdy, A.A.R., P. Martin, R.J. Bisdorf. (1993) A study of seawater intrusion using direct-current soundings in the southeastern part of the Oxnard Plain, California. Open- File Report 93-524. U.S. Geological Survey, pp.139.

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