

Exploration of Shallow Geothermal Energy Aquifers by Using Electrical Resistivity Survey in Laki Range Jamshoro district Sindh, Pakistan

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Abstract: Geothermal water is increasingly used around the world for its exploitation. Bulk electrical resistivity differences can bring significant information on variation of subsurface geothermal aquifer characteristics. The electrical resistivity survey was carried out in Laki range in lower Indus basin in the study area to explore the subsurface geothermal aquifers. The Schlumberger electrode configuration with range from 2 m to 220 m depth was applied. Three prominent locations of hot springs were selected including Laki Shah Saddar, Lalbagh and Kai hot spring near Sehwan city. After processing resistivity image data, two hot water geothermal aquifers were delineated at Laki Shah Saddar hot springs. The depth of first aquifer was 56 m and its thickness 38 m in the limestones. The depth of second aquifer of 190 m and with thickness of 96 m hosted in limestone. In Lalbagh hot springs two geothermal aquifers were delineated on the basis of apparent resistivity contrast, the depth of first aquifer zone in sandstone was in sandstone 15 m and thickness 12 m, while the depth of second aquifer was 61m and thickness was 35m. In Kai hot springs two hot water geothermal aquifers were delineated. The depth of first geothermal aquifer was 21m and thickness was 18 m and the depth of second aquifer was 105 m and thickness was 61m present in sandstone lithology. Present work demonstrates the capability of electrical resistivity images to study the potential of geothermal energy in shallow aquifers. These outcomes could potentially lead to a number of practical applications, such as the monitoring or the design of shallow geothermal systems.

Keywords: Hot springs, apparent resistivity, vertical electrical sounding, Laki Range, Jamshoro.

Introduction

Thermal energy resources represent a fundamental role in the field of research and development in the diversification of energy resources to barricade global warming (Lund, 2010). The concept of geothermal energy system is explained by that component of the Earth's natural heat energy which can be exploited as a source of clean energy system (Dickson and Fanelli, 2004). The potential energy of a geothermal reservoir depends on various geological factors such as geological structure, geohydrology and thermal regimes (Lorio et al., 2020). The geothermal energy system is explained as a describable thick layer of porous and permeable rocks which hold a proven reserve of geothermal energy, like hot water or steam that can be exploited in a convenient and commercial way (Dickson and Fanelli, 2004). The seismicity control of Pakistan suggests that great potential of cost-effectively prospective zones of geothermal energy resources are present in the country (Gondal et al., 2017). A huge number of hot springs, mud volcanoes are located within the seismic belt of Pakistan. As a result, the country has feasible geothermal energy manifestation (Younas et al., 2016). There is a sequence of Laki hot springs situated in Laki hills of Laki range, near Laki Shah Saddar where hot springs have been recognized since long for treatment of certain skin diseases by many of people visiting

Laki hot springs every year (Khuhawar et al., 1986). The thermal springs of Laki Shah Saddar are used to generate electricity to meet the increased energy requirement (Jahangir et al., 2013). Geophysical resistivity survey is the most advanced geophysical technique used in the subsurface exploration of geothermal energy, and in demarcating the geothermal resources and potential fields (Tsend-Ayush, 2006). The resistivity survey for geothermal energy exploration reflects the thermal alteration zones of any area (Mariita, 2008). Geothermal anomalies are observed through low resistivity values in most geothermal reservoir systems. A clear image of subsurface anomalies of geothermal systems has become feasible with the use of geophysical resistivity method (Ussher et al., 2000). Resistivity survey studies were conducted at Tattapani thermal spring, Azad Kashmir to demarcate the subsurface lithology, depth of aquifers as well as migration paths of hot water plumes (Rashid et al., 2019). Though, Pakistan has great potential of geothermal energy resources in all provinces, but the significance to exploit this clean energy resource studies are still lacking. The objective of the research is to explore the Geothermal energy resources of Sindh province particularly in laki range Jamshoro to utilize the energy system of the country.

Study Area

The study area is located at a distance of about 135 km in the North-west of Jamshoro city on the left bank of Indus river (Fig. 1). The area is easily accessible by Indus highway leading to Dadu city from Jamshoro.

The Laki Shah Saddar area lies in the survey of Pakistan toposheet No. 35 N/15, at the latitude $26^{\circ}15'45''$ and longitude of $67^{\circ}55'35''$. This area occurs 20 km in the South of Sehwan city, where hot springs occur in the hills of Laki range (Laghari et al., 2001). Secondly, Lalbagh area lies in the survey of Pakistan toposheet No. 35 N/15, at the latitude $26^{\circ}23'69''$ and longitude $67^{\circ}51'24.46''$. This is of about 2 km south west of Sehwan city. There are two hot springs in Lalbagh area (Fig. 1).

The Kai area occurs in the survey of Pakistan toposheet No. 35 N/11, latitude $26^{\circ}18'19.80''$, and longitude $67^{\circ}33'18.20''$ about 40 km south-west of Sehwan city (Fig. 1). One main hot spring is located in Kai area (Laghari et al., 2002).

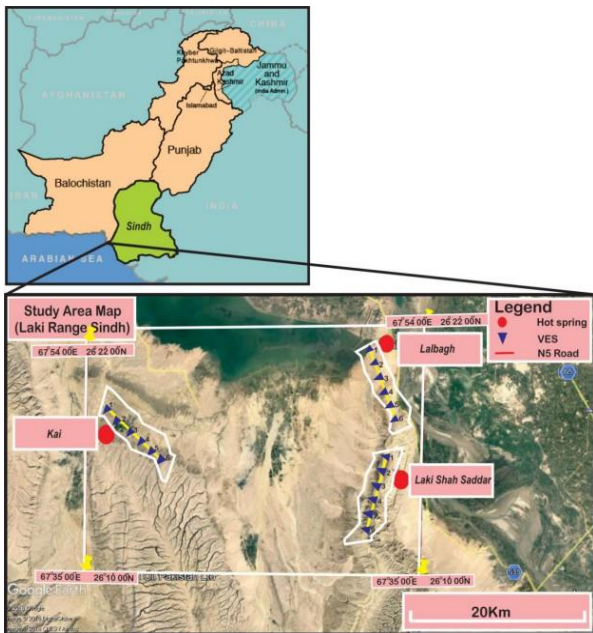


Fig. 1 Satellite image Map of study area showing location of field area.

Geological Setting

The study area mainly comprises clastic and non-clastic sedimentary rocks ranging in age from early Eocene to Miocene (Fig. 1). The main part of the area comprises hard compacted limestone of Laki Formation which may show high resistivity in Laki Shah Saddar hot springs (Fig. 1). The hot springs of Laki Shah Saddar occur in limestones of Laki Formation, while the hot springs of Lalbagh are in sandstone and shale of Manchar Formation of Miocene age (Agheem et al., 2020) (Fig. 2). The hot springs of Kai occur in Nari Formation of Oligocene age and comprising sandstone, shale and limestone (Soomro et al., 2019a). Structurally, the area is mostly folded, faulted and jointed thus giving path to hot water to

erupt on earth surface. These structural complexities develop due to collision of Indian and Eurasian plates. The hot springs in the area are fault controlled. Major anticline structures along with a number of reverse and thrust faults also occur which control the hot springs in the area.

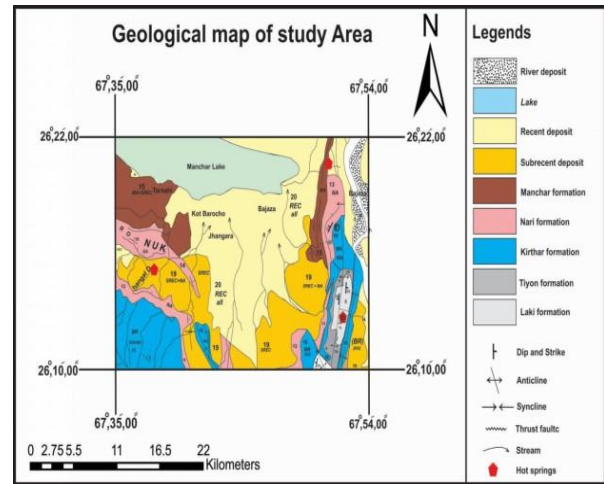


Fig. 2 Geological map of study area, after (Hunting survey Corporation, 1960)

Materials and Methods

Geoelectrical resistivity method is a tool in the geophysical techniques that is used in geothermal energy exploration. The geophysical resistivity survey is commonly considered to be the most valuable geophysical method to evaluate a geothermal reservoir prior to drilling. The electrical conductivity of electrolytes increases quickly with temperature. Fluids are also more saline, and hence more conductive, than cold meteoric fluids. Hydrothermally altered rocks associated with geothermal fluids also have lower resistivity. These elements combine to make values usually less than 5-ohm meters in water-dominated geothermal energy reservoir (Bromley and Espanola, 1982). From the apparent resistivity distribution in the subsurface geological structural changes, lithological knowledge can be acquired (Daniel et al., 2020). For the exploration of geothermal energy resources in Laki range, SAS4000 Terrameter of ABEM was used for compiling resistivity data of the subsurface geology in the form of geoelectric section that apply to explore geothermal reservoirs in Laki range. Changes in electrical potential of subsurface materials are calculated by the function of a given quantity of electric current to this material and the measurement of the potential difference.

$$\text{Equations} \quad \rho_a = k (V/I) \quad (1)$$

$$\rho_a = 2\pi a \times V/I \quad (2)$$

Now geometric factors (k) rely on the configuration of electrodes.

Terrameter are generally offered a resistance value, $R = V/I$, so the apparent resistivity value is calculated (Soomro et al., 2019b).

$$\rho_a = k \cdot R \quad (3)$$

Schlumberger electrode configuration was used for the measurements at the VES sites in Laki range for geothermal exploration. In this method current is penetrated into the earth through two well separated outer current electrodes and the potential difference is calculated by two closely spaced inner electrodes. The couple of inner potential electrodes are held close to the center, although the couple of current electrodes are slowly changed away from the center, which should be aligned in a straight line with the outer electrodes (Khan et al., 2013).

The depth, thickness, and the relevant resistivity of each layer, delineated by vertical electrical sounding, were processed by software IPI2win.

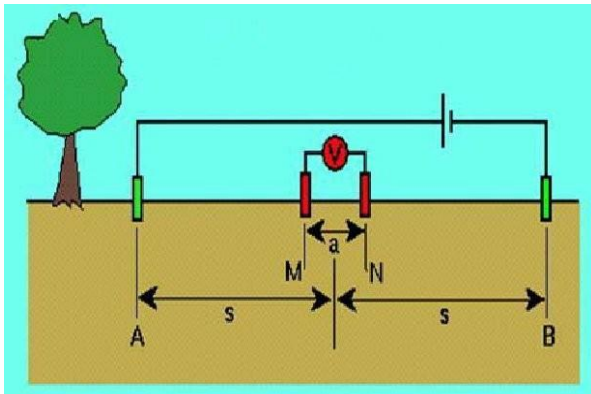


Fig. 3 Electrode configuration of Schlumberger array (after Mines, 2003).

Results and Discussion

Total 18 (VES) were carried out in Laki range along the profile line, six (VES) at each site with the help of ABEM Terrameter SAS-4000 to investigate the depth of aquifers of hot springs and extension of aquifer in study area (Fig-01, 02), Lithological sections show the depth, thickness and the resistivity variations of subsurface layers by vertical electrical sounding and the data were processed through resistivity software IPI2 win (Table 1,2,3).

Pseudo and resistivity sections of Laki Shah Saddar

In Laki Shah Saddar VES 01 to VES 06, resistivity data were processed for producing the pseudo-section as it is smooth and co-linear in N35°W direction. As of the pseudo-section, it was interpreted that the resistivity distribution across Laki Shah Saddar VES profile was showing variation, demarcating three resistivity zones (Fig.07). if is indicated by a high resistivity zone of $\geq 70 \Omega m$ further underlain by moderate resistivity zone (20-40 Ωm) and a low or very low resistivity zone of (2-20 Ωm). The low resistivity anomalous zone lengthens towards the

profile delineating the promising continuation of alluvium materials (20-40 Ωm) indicating the occurrence of hot water aquifer up to the depth of 38 m to 196 m. Low resistive zone is sandwiched between moderate to high resistive zone indicating the existence of loose shale or clay strata with absorbed water content.

Table 1. The interpretation of subsurface layers, their depths, and resistivity from Laki Shah Saddar area.

Site	VES Number	Identified Lithology	Apparent Resistivity (Ωm)	Depth (m)
Laki Shah Saddar	VES-01	Alluvium layer	12	09
		Limestone	844	15
		Aquifer in Shale	02	52
		Limestone	110	112
		Aquifer in Shale	02	200
	VES-02	Alluvium layer	08	09
		Limestone	467	20
		Aquifer in Shale	02	72
		Limestone	116	117
		Aquifer in Shale	03	207
	VES-03	Limestone	2025	01
		Clay	07	06
		Limestone	1247	16
		Aquifer in Shale	02	70
		Limestone	1482	120
	VES-04	Aquifer in Shale	12	199
		Alluvium	08	14
		Limestone	13033	17
		Aquifer in Shale	03	50
		Limestone	1085	75
		Aquifer in Shale	11.7	186

Table 2. The interpretation of subsurface layers, their depths, and resistivity from Lalbagh area.

Site	VES Number	Identified Lithology	Apparent Resistivity (Ωm)	Depth (m)
Lalbagh area	VES-01	Shale	30	14
		Limestone	17232	19
		Aquifer in Sandstone	31	59
		Limestone	10222	219
	VES-02	Shale	20	14
		Limestone	24622	32
		Aquifer in Sandstone	15	62
		Limestone	960	194
	VES-03	Shale	19	11
		Limestone	34004	21
		Aquifer in Sandstone	11	54
		Sandstone	11663	199
	VES-04	Shale	21	14
		Limestone	37982	21
		Aquifer in Sandstone	15	42
		Sandstone	9863	200

Table 3. The interpretation of subsurface layers, their depths, and resistivity from Kai area.

Site	VES Number	Identified Lithology	Apparent Resistivity (Ωm)	Depth (m)
Kai area	VES-01	Aquifer in Shale	17	16
		Limestone	21761	56
		Aquifer in Shale	14	133
		Limestone	28401	188
	VES-02	Limestone	29	06
		Limestone	42421	34
		Aquifer in Shale	03	112
		Limestone	1000	202
	VES-03	Alluvium	35	3
		Aquifer in Shale	07	13
		Limestone	1617	55
		Aquifer in Shale	07	77
		Limestone	960	221
	VES-04	Aquifer in Shale	13	13
		Limestone	45112	40
		Aquifer in Shale	11	115
		Limestone	1105	200

The resistivity cross sections were produced for the same profiles at Laki Shah Saddar area from VES -1 to VES-6 that depict the variation in resistivity with depth (Fig.08). The general trends of the resistivity cross section were following downwards trend with sudden drop in resistivity. Overall, three main anomalous zones which having high to low resistivity values were delineated with a resistivity value of (2-30 Ωm) from VES-1, to VES-6, representing the occurrence of unconsolidated and conductive subsurface lithology of altered rocks and minerals. On surface the resistivity values in between of 100-1000 Ωm represented hard compacted strata of Laki limestone.

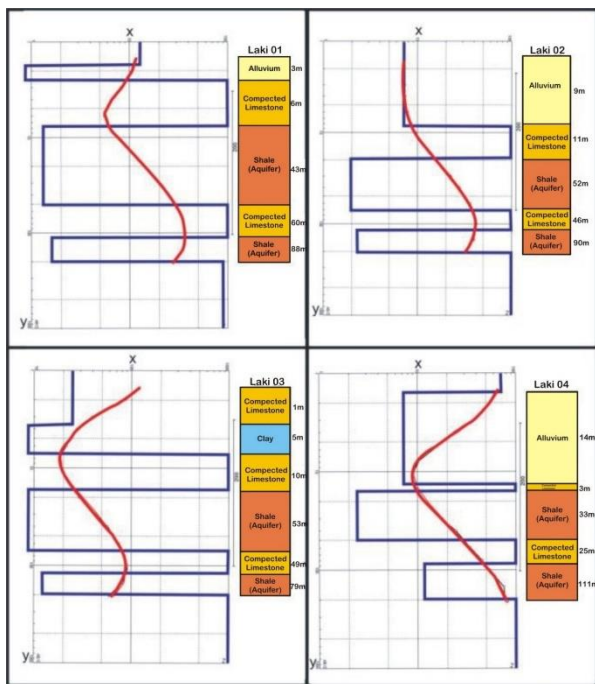


Fig. 4 Geoelectrical sections of Laki VES 1, 2, 3, 4, stacked along profile

Pseudo and resistivity sections of Lalbagh

In Lalbagh profile VES 1 to 6, resistivity data were processed for producing the pseudo-section as, it was smooth and co-linear in S35°E direction. In general low to moderate and high resistivity zones were delineated Basically, two main aquifer zones were demarcated for geothermal energy. First low resistivity anomalous zone was demarcated with resistivity ranges from (8 to 22 Ωm) with thickness of 12 m interpreted as a low resistivity hot water aquifer anomalous zone or conductive zone for geothermal energy (Fig.9). Lalbagh profile is described by top low zone with a resistivity value of (8 to 22 Ωm) up to a depth of 15 m which indicates the occurrence of anomalous zone in sandstone or shale lithology of Manchar Formation. Further going to subsurface the resistivity values are measured to a high average value of (21742 Ωm) showing the lithology of hard compacted limestone of Laki Formation up to the average depth of 26m. further increasing downward the second anomalous zone was delineated as a low resistivity conductive zone with average resistivity value of 16 Ωm up to the average depth of 61m and has a high thickness for geothermal energy.

The resistivity cross section of the Lalbagh profile was developed, presenting a constant variation in resistivity, and reduces with depth (Fig.10). The above resistivity layer was marked by low resistivity layer, ranging between (8 to 22 Ωm) with thickness of 12m at the top. The second anomalous zone was delineated with resistivity ranges of 16 Ωm and thickness of 35m at the depth of 61m describing a conductive or alteration zone and which has a great potential for geothermal energy.

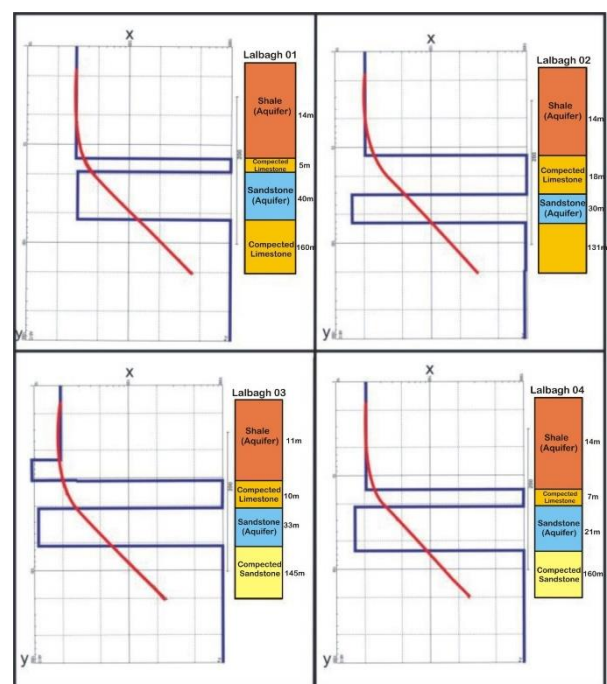


Fig. 5 Geoelectrical Sections of Lalbagh VES 1, 2, 3, 04, stacked along profile

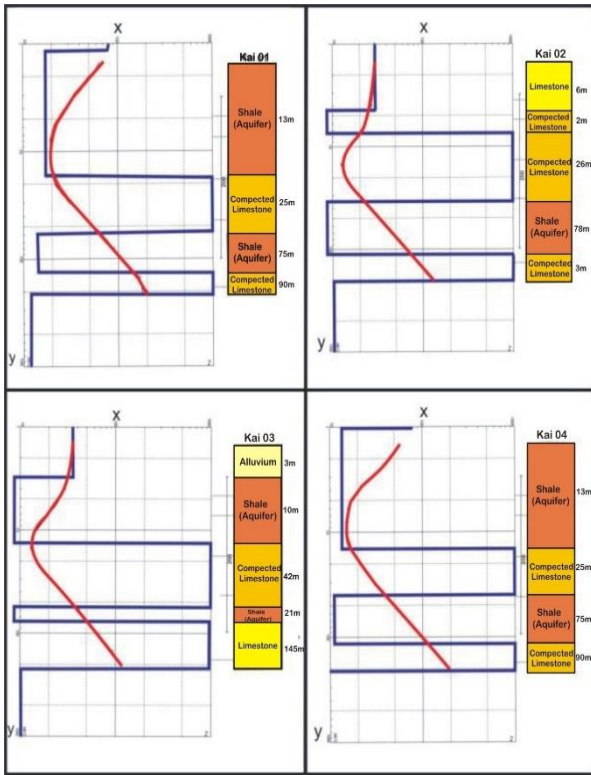


Fig. 6 Geoelectrical sections of Kai VES 1, 2, 3, 4, stacked along profile

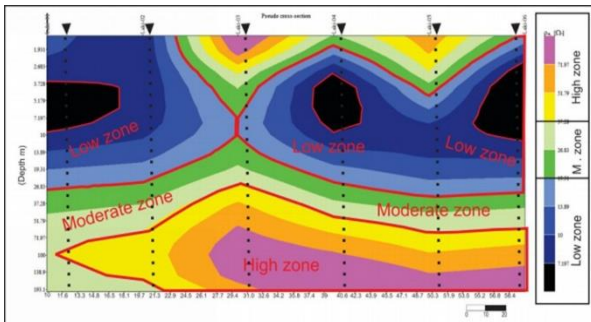


Fig.7 Pseudo section profile of Laki Shah Saddar

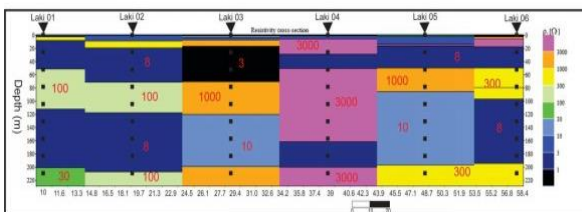


Fig. 8 Resistivity section profile of Laki Shah Saddar.

Pseudo and resistivity sections of Kai Hot springs

In Kai VES 1 to VES 6, resistivity data were processed for producing the pseudo-section as it was smooth and co-linear in N40°E direction. In general low to moderate and high resistivity zones were delineated; Basically, two main aquifer zones were demarcated for potential of geothermal energy. The first low resistivity anomalous zone (12 Ω m) and thickness 12 m at the depth of 15m and has potential for geothermal energy

(Fig.11). The second hot water aquifer anomalous zone was delineated with resistivity of 12 Ω m and thickness of 61m at the depth of 105m. It is low resistivity and high anomalous zone or alteration zone having good potential for geothermal energy. Resistivity value shows the presence of anomalous zone in clay or shale lithology.

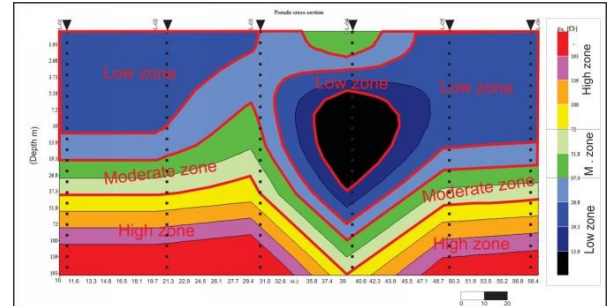


Fig. 9 Pseudo section Profile of Lalbagh.

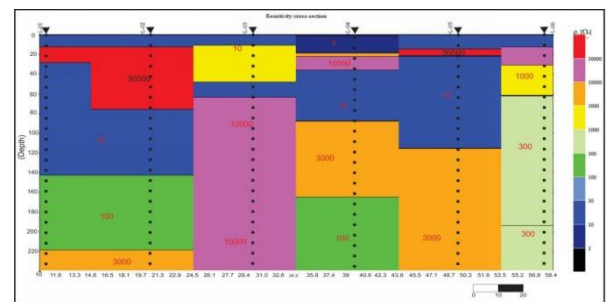


Fig. 10 Resistivity section along Profile Lalbagh.

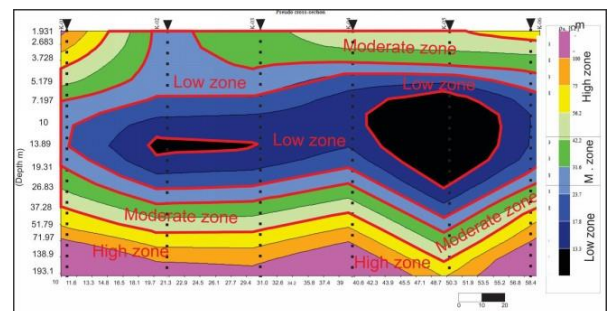


Fig. 11 Pseudo section along profile Kai.

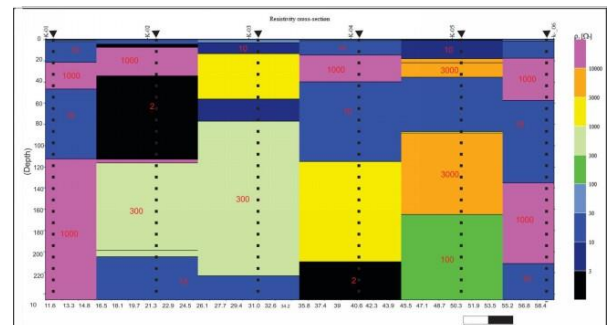


Fig. 12 Resistivity section along Kai Profile

The resistivity cross section of Kai profile shows a variation in decreasing resistivity with depth (Fig.12). The upper most resistivity layer was represented by moderate to low values, between 2-12 Ω m with

thickness of 15m. Variation in lithology showing different resistivities at different depth; two anomalous zones were followed of low resistivity values (2-12 Ω m) were marked at depths of 15m, and 105 meters. From respective the resistivity section, it was interpreted that the area was cohereted hard and high resistivity rocks.

Conclusion

The two main hot water aquifers were demarcated in the Laki Shah Sadder area, hot springs occure in fractured limestone lithology of Laki limestone belonging to Eocene age. The resistivity anomalous zones of Laki Shah Sadder hot springs show very low resistivity values which indicates that they contain highly saline water. This decreased resistivity value is attributed to high mineral contents which dissolves surrounding rocks, thus making conductive zone and alteration of rocks by hot water having great potential for geothermal energy.

On the basis of geophysical resistivity data two main hot water aquifer zones were demarcated at the Lalbagh area which occre in sandstones of Manchar Formation. The thermal water at this site is also interpreted to contain dissolved minerals, which alter the surrounding rocks and lower the resistivity, and making it conducive thus having great potential for geothermal energy.

At the Kai area two aquifer zones are demarcated in sandstone of Nari Formation sandstone having good porosity and permeability with high potential for geothermal energy.

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