ASSESSMENT OF GEOTHERMAL RESOURCES AT THE AL-LITH AREA, KINGDOM OF SAUDI ARABIA

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ABSTRACT

The geothermal resources of the Kingdom of Saudi Arabia are mainly located along the western and southwestern coastal parts. These resources are associated with the main tectonic activities and elements that are prevailing during the opening of the Red Sea and Gulf of Suez rift. The Al-Lith area is one of the most promised geothermal targets, which is located along the western coast of the Red Sea, about 180 km south of Jeddah city. Four main hot springs (Ain A1 Harrah, Bani Hilal, Wadi Markub and Al Darakah) with a surface temperature range from 41^{o}C to 96 ^{o}C, are encountered this area and originating from deep-seated highly altered granitic rocks.

The aim of this study is investigate the potentiality of these geothermal resources and to detect the subsurface orientation and the structural elements which control the upcoming geothermal water to the surface. Based on the chemical analyses of many water samples collected from the hot springs and their neighbouring wells, a geo-thermometric study is conducted to estimate the heat flow, discharge enthalpy and subsurface temperature. In addition, a 2D electric study is enhanced to detect the shallow subsurface structures and fracture system.

Based on the geo-thermometers fair to good subsurface temperature, discharge enthalpy and heat flow values are calculated at these hot springs (105°C - 136°, 170 Kj/Kg - 219 Kj/Kg and 137 mW/M^2 - 183 mW/M^2). The 2D interpreted electric sections clarified that, a number of near-vertical northwest-southeast and east-west trending faults and fracture elements are effecting the whole geothermal system in the area. Ain A1 Harrah hot spring is found with good geothermal parameters. In terms of its potential reserves, it needs to be further investigated and evaluated in future for possible energy production.

1. INTRODUCTION

The geothermal potentiality of Al Lith area is represented by four separate hot springs. The most promised one is that located at Ain Al Harrah, Ghamika area. The surface temperature of this hot spring reaches up to 96 ^{o}C. The second hot spring is located at Wadi Al Sader-Bani Hilal village at the bottom of a huge batholithic ridge. Some other hot springs are clustered in the close neighbourhood, which indicates that the geothermal activity at Bani Hilal appears to be a combined system including many hot springs rather than being a separate one. The surface temperature ranges from 41 to 45^{o}C.

The third hot spring is found at Wadi Markub area and like that at Bani Hilal area, it seems to be a combined system including many hot springs enriched with iron. The flow rate of this hot spring is good and the surface temperature reached up to 56^{o}C. The fourth hot spring is occupied in the Al Darakah area. The recorded surface temperature of this hot spring is 41^{o}C, and its flow rate is very low.

2. GEOLOGIC SETTING

The geology of Al Lith area is represented mainly by two sequences of the rocks. The first is represented mainly by Quaternary deposits, while the second sequence is represented by a group of basement rocks (Fig. 1).

1.2.1 Quaternary deposits

These sediments are located mainly close to the shore line along a northwest-southeast direction.

1.2.2 Basement rocks

The second sequence is represented by a group of basement rocks. These basement rocks are represented mainly by two huge massive bodies of granitic schist complex (Hurqufah suite) and granodiroite and tonalite (Jumah suite), and the diorite, tonalite and gabbro (Al Lith suite) which extend along a northeast direction.

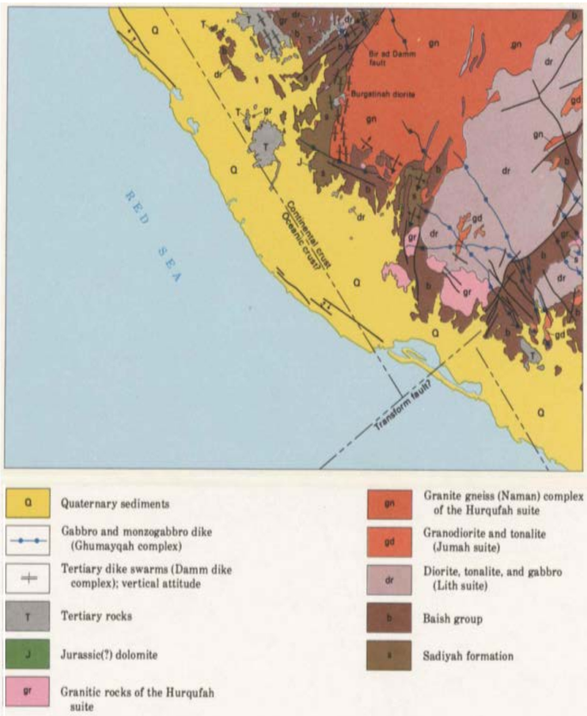

Figure 1: Geologic map of Al Lith area, (Pallister, 1986).

1.2.3 Baish Group and Sadiyah Formation

The rocks of the Baish group and Sadiyah Formation are found bounding the basement rocks in the middle between these rocks and the quaternary rocks. Some younger granitic rocks are located in the southern parts of the area.

1.2.4 Ghamika suite

Gabbro and monzogabbro dykes (Ghamika suite) are predominant especially at Ghamika area.

3. NATURE OF HOT SPRINGS AT AL-LITH AREA

The hot springs in Al-Lith area are located mainly in Ghamika, Wadi Al Sader-Bani Hilal and Wadi Markub areas (Fig. 2).

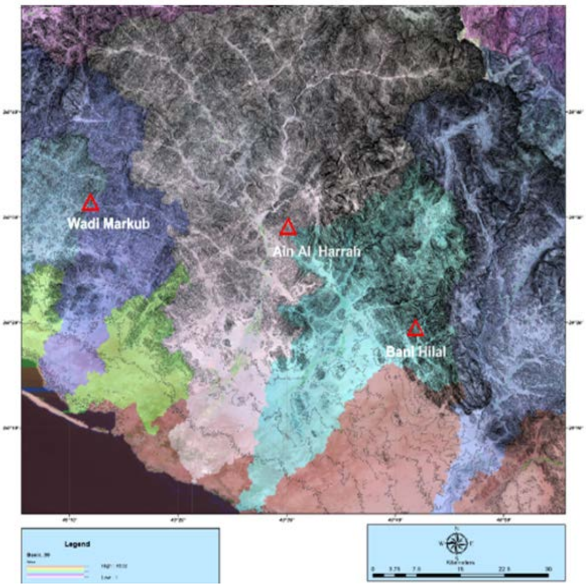

Figure 2: Topographic map of Al Lith area, showing the location of the hot springs.

According to the surface temperature of thermal water which reaches up to 95 ^{o}C, Ain A1 Harrah hot spring is considered the most promised one. It is located in Ghamika area in deep-seated highly altered granitic rocks, where many alkaline dykes are cutting through (Fig. 3).

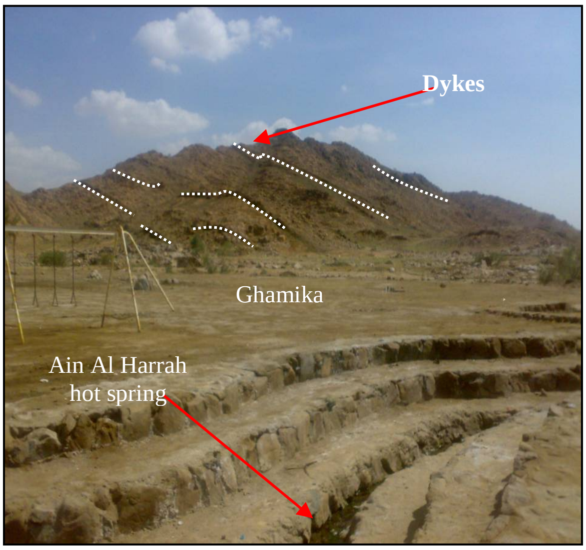

Figure 3: Parallel dykes cutting through granitic rocks at Ain Al Harra-Ghamika, Al-Lith area.

Wadi Markub and Al Darakah hot springs are low-discharge hot springs which are located close to each other in highly altered granitic rocks. Wadi Markub hot spring seems to be a multi-poll thermal collectives emerge from structurally controlled basement rocks, which are highly eroded, altered and characterized by the high content of iron (Fig. 4).

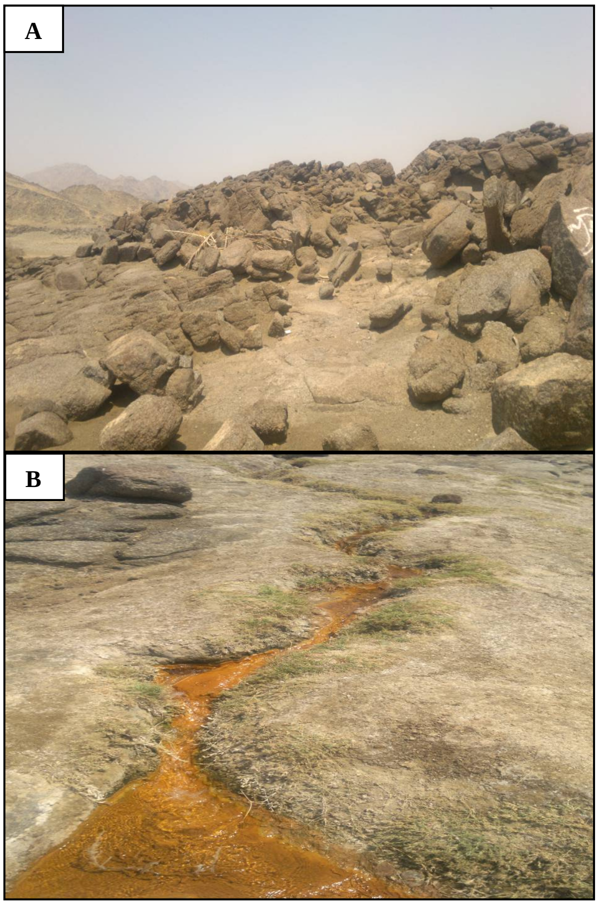

Figure 4: A) Boulders of highly eroded and altered granitic rocks, Wadi Markoub area, and B) Discharge of the hot spring showing high content of iron.

Table 1. Summarizes the co-ordinates and some field measurements of the different hot springs at Al Lith area.

Table 1. Some field measurements of the hot springs at Al Lith area.

Hot Spring	Surface Temp. (^{o}C)	Elev. (m)	PH	TDS (ppm)	EC (μScm^{-1})
Ain Al Harrah	Up to 95	167.0	7.8	2180	3633
Bani Hilal-1	45	170.0	7.5	2426	4043
Wadi Markub	56	136.0	6.85	2960	4933
Al Darakah	41	151.0	7.6	2900	4825

4. METHODOLOGY

Two main techniques are mainly used to investigate the geothermal resources in study area. The first depends on applying the geochemical techniques (Geo-thermometers) to infer some important pertothermal characteristics, like heat flow, discharge enthalpy and subsurface temperature. The second implies utilizing a 2D geophysical electric resistivity method to investigate the subsurface orientation of the geothermal targets, detecting their possible lateral extension and the structural elements which may control the subsurface movement of the arising geothermal water.

4.1 Geo-thermometers

The application of geochemical techniques in geothermal studies provides useful data for planning exploration and its cost is relatively low compared to other more sophisticated methods, such as the geophysical surveys. The geo-indicators or what is called geo-thermometers, are represented by certain anions, cations and/or trace elements which are chemically reactive, non-conservative species, respond to changes in environment, and can used to infer the prevailing physico-chemical processes during the ascent of water to surface. Based on the concentration of the different ions in the thermal water, a wide variety of geo-thermometers can be utilized for detecting the prevailing subsurface thermal regimes (Fournier and Rowe, 1966; Ellis and Mahon, 1977; Fournier and Truesdell, 1973; Fournier, 1977; Fournier and Potter 1982; Swanberg et al., 1983; Arnorsson, 1983 et al. & 1985; Rimstidt, 1997; Arnorsson and Stefansson 1999; Arnorsson et al., 2002; Lashin, 2007, Lashin and Al Arifi, 2010, and Lashin, 2012).

In the present study a selected number of geo-thermometers are used:

4.1.1 Silica Geo-thermometers

$$T_1\ (^\circ C) = \frac{1309}{5.19 - \mathrm{Log}\ Qz} - 273.15$$

$$T_2\ (^\circ C) = 42.198 + 0.28831\ Qz - 3.6686 * 10^{-4} Qz^2 + 3.1665 * 10^{-7} Qz^3 + 77.034\ \mathrm{Log}\ Qz$$

4.1.2 Na-K-Ca Geo-thermometers

The followings are the most important geo-thermometers which makes use of the combination of the Na, K and Ca:

$$T_1\ (^\circ C) = \frac{933}{0.993 + \mathrm{Log}\ (Na/K)} - 273.15$$

$$T_2\ (^\circ C) = \frac{1647}{\mathrm{Log}\ (Na/K) + \beta\ \mathrm{Log}\ (Ca^{0.5}/Na) + 2.24} - 273.15$$

4.1.3 Giggenbach and ternary diagrams

A number of ternary diagrams (Cl-SO4-HCO3) have been constructed to classify geothermal water on the basis of major anions and cations. Water samples collected from the studied hot springs are plotted in these diagrams. The different types of thermal waters can be then distinguished, such as mature (Cl) waters, SO4 dominated waters and peripheral (HCO3) waters. The Na, K, Mg Giggenbach diagram is also used to indicate the subsurface geothermal condition at which the dissolved ions of the surface upcoming thermal fluids are originated (Giggenbach, 1986 and 1988).

4.2 Electric Resistivity Survey

A number of 2-D electric surveys are performed at the location of the hot springs in Al-Lith area. Figure 5 shows the typical setup for a 2D survey with a number of electrodes at constant spacing along a straight line attached to a multi-core cable.

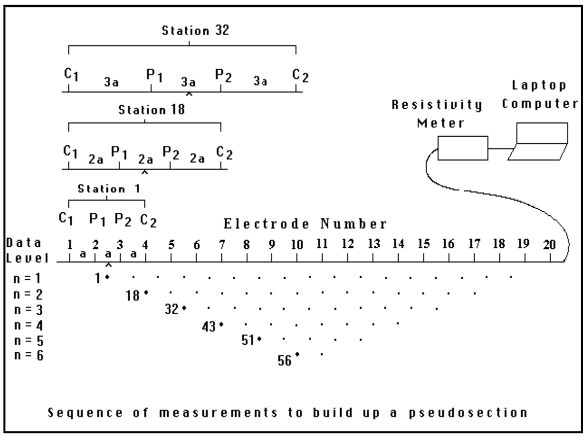

Figure 5: The general setup of a 2D electric survey.

The Syscal–R1 system (IRIS instruments) with 72 multi-electrodes system, with 4 x 18 electrodes cables (Fig. 6) is used for conducting the field surveys using 1 m, 3 m, 5 m and 10 electrode spacing arranged along a profile.

Figure 6: The 72 channels Syscal-R1 equipment.

Nine 2D electric sections are performed in the Al Lith area, more closely to Ain Al Harrah hot spring.

Picking, correction and processing of data and interpretation of electric resistivity data was enhanced by using RES2DINV software. It generates two-dimensional resistivity model for subsurface from electrical imaging surveys. It can also, operate large data sets collected with large number of electrodes and can account the topographical effect along the survey lines.

5. RESULTS AND DISCUSSION

5.1 Characteristics of thermal water

The most important petro-thermal characteristics of thermal water of the hot springs as obtained from the geo-thermometers are summarized in Table 2. It shows that Ain al Harrah attains good petro-thermal parameters, while the other three hot springs exhibits nearly similar fair characteristics.

Table 2. Petro-thermal parameters of the hot springs at Al Lith area.

Hot Spring	Subsurface Temp. (^oC)	Discharge Enthalpy (Kj/Kg)	Heat Flow (mW/M^2)
Ain Al Harrah	136.00	218.96	182.79
Bani Hilal-2	120.34	193.74	159.63
Wadi Markoub	120.06	193.30	159.23
Al Darakah	105.10	169.21	136.93

Figure 7 represents the constructed Giggenbach diagram from the hot springs at Al-Lith area. It is used to indicate the subsurface geothermal condition at which the dissolved ions of the surface upcoming thermal fluids are originated.

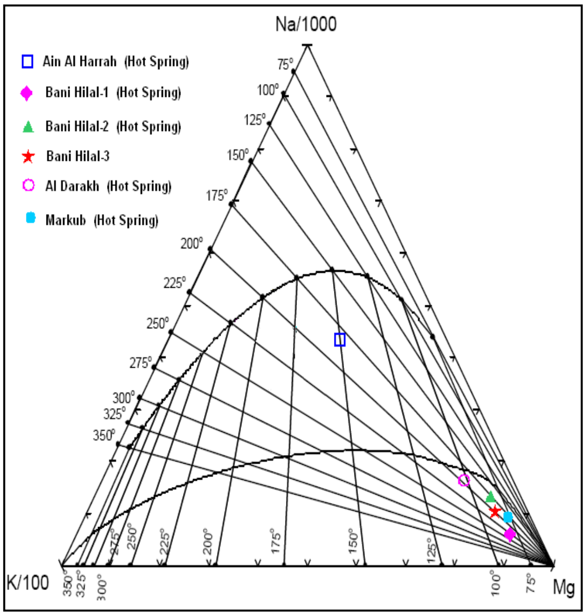

Figure 7: Giggenbach diagram for the thermal fluids of the hot springs at Al-Lith area.

All the data points are located in front of the 75^o Mg-K temperature line, and between temperature lines 200^o and 250^o along the Na-K geo-indicators. One point belonging to Ain Al Harrah hot spring is shifted upward and located along the 150^o Mg-K thermal line and the 175^o and 225^o Na-K thermal lines. This hot spring seems to attain the highest geothermal condition among the other studied hot springs.

The Cl-SO4-HCO3 ternary diagram of the hot springs of Al Lith area is represented in Fig. 8. It illustrates that majority of the hot springs are occurred in the mature water area. Meanwhile, Al Darakah hot spring is lactated at the boundaries between the mature and volcanic water areas, suggesting mixed water type.

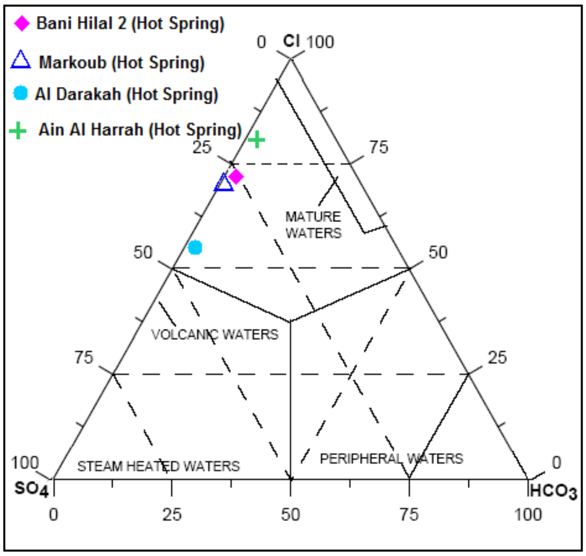

Figure 8: Ternary diagram (Cl-SO4-HCO3) for the thermal fluids of the hot springs at Al-Lith area.

5.2 Interpretation of 2D electric data

A number of 2D electric resistivity profiles are conducted in the area of hot springs. Nine profiles are performed using Schlumberger-Wenner array (Fig. 9). These profiles are selected to cut through the main prevailing structural elements in the study area (NW-SE and NNE-SSW) and to detect the feed zones.

The results obtained from these profiles are mainly concerned with detecting the source of the arising geothermal water, detecting feed zones, the effecting structural elements and the possible facture system. Three profiles are selected to demonstrate the obtained results and to shed light over the interpretations of the 2D electric profiles (Figs. 10, 11 and 12).

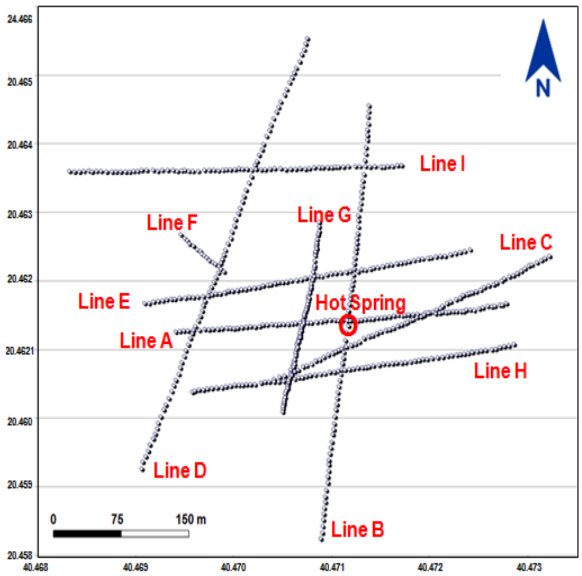

Figure 9: Base map of Ain Al Harrah hot spring, showing the location of the 2D electric profiles.

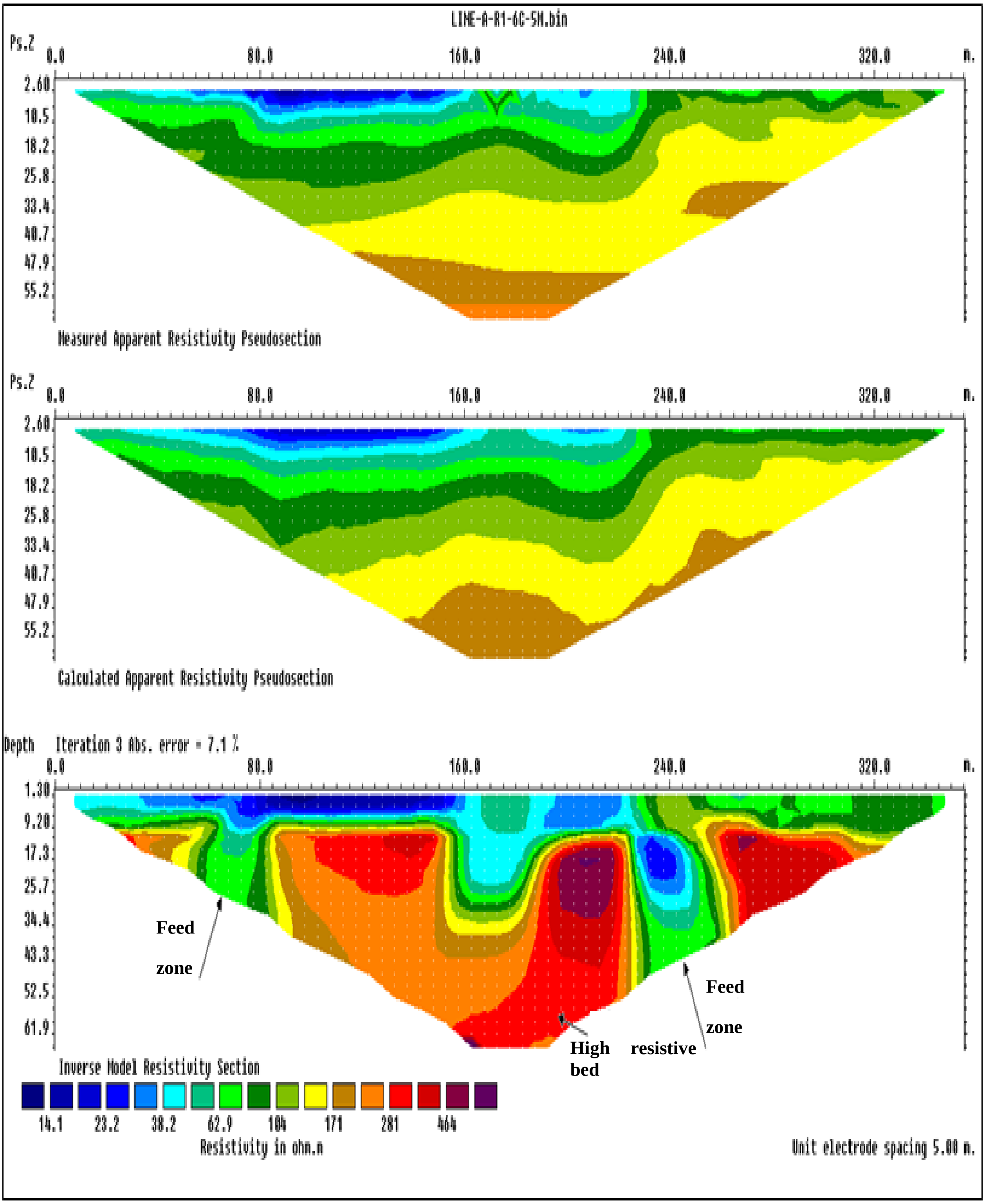

Figure 10: 2D interpreted electric resistivity profile (line A) extending East-West, Al Lith area.

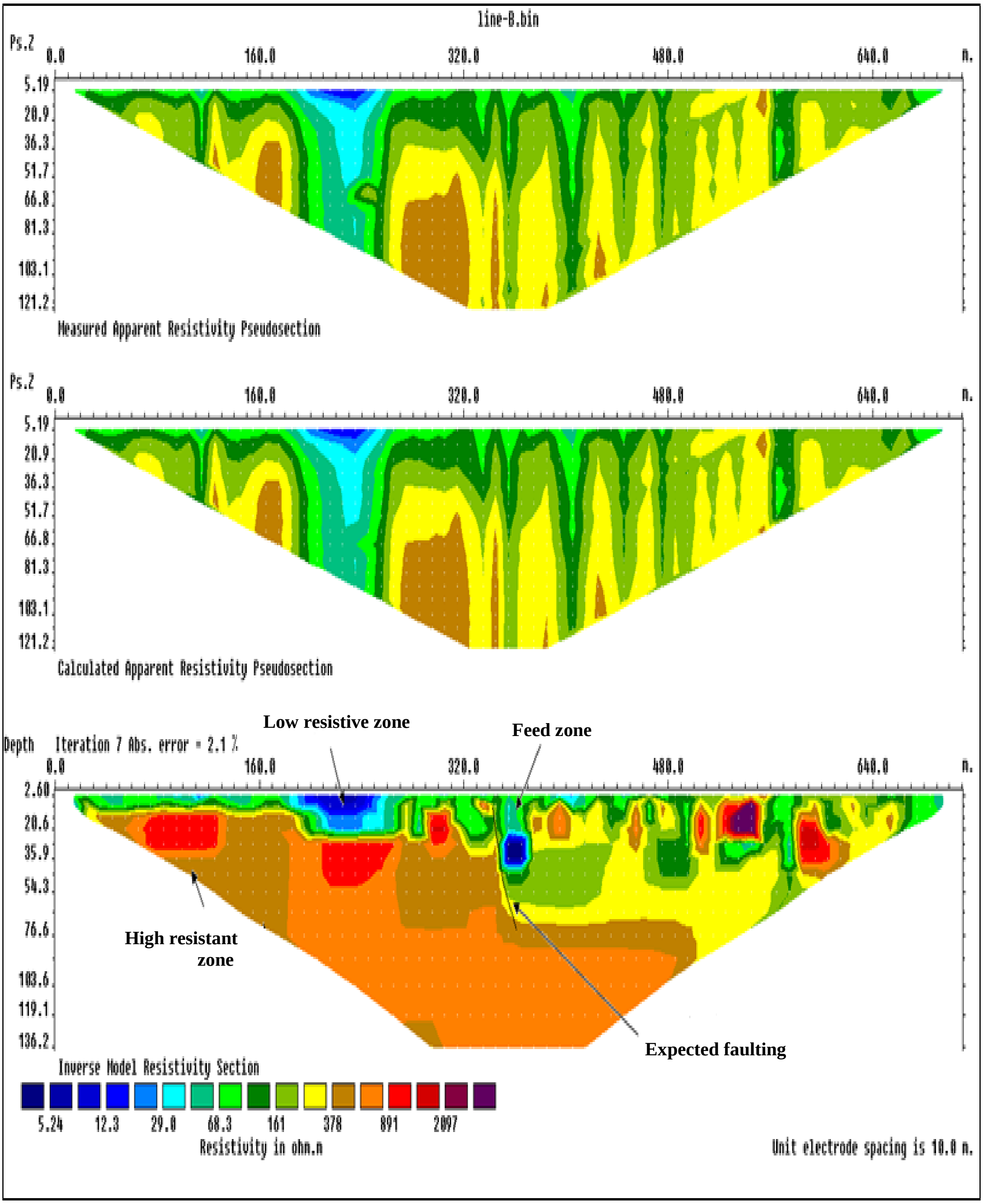

Figure 11: 2D interpreted electric resistivity profile (line B) extending North-South, Al Lith area.

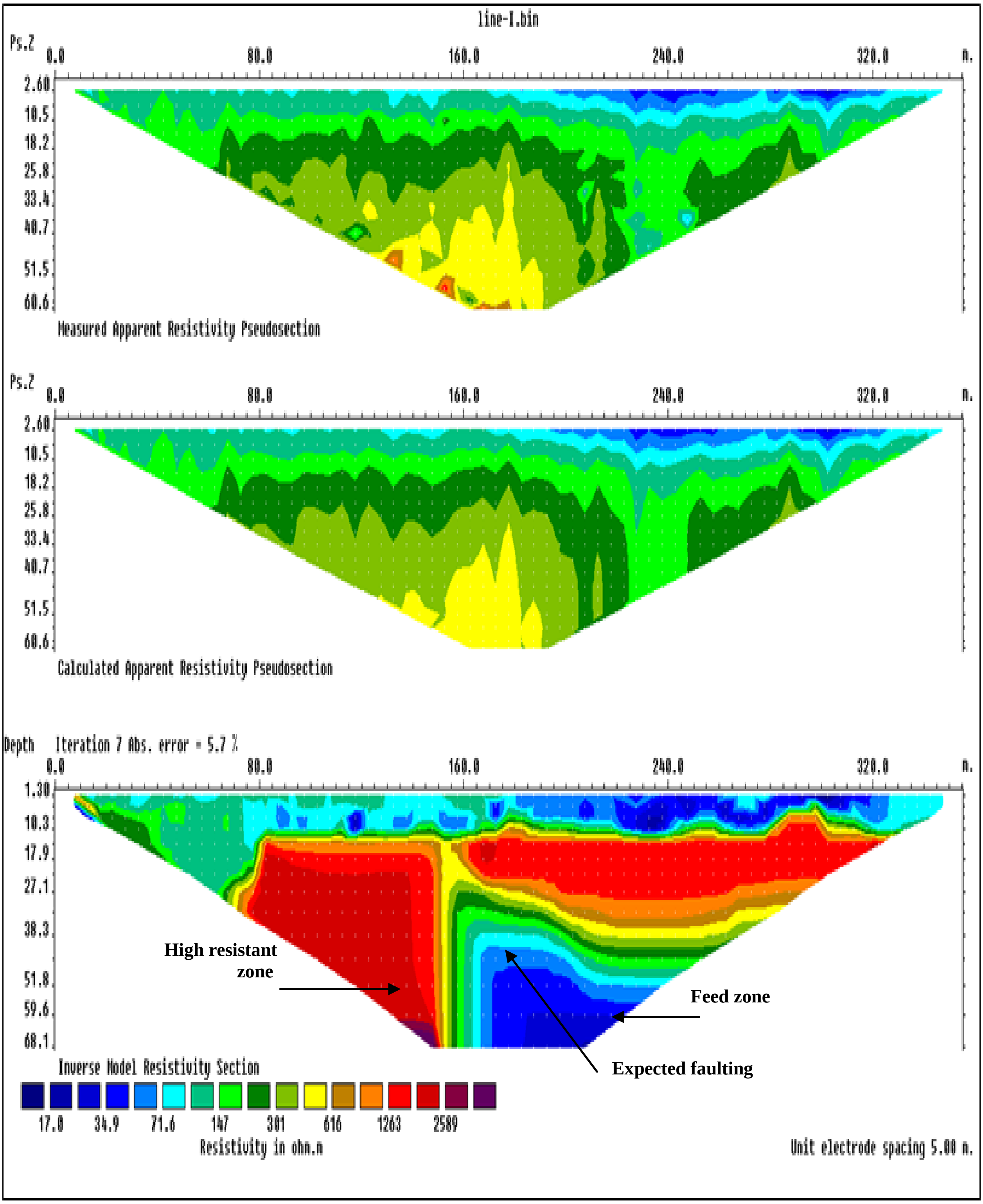

Figure 12: 2D interpreted electric resistivity profile (line I) extending East-West, Al Lith area.

The interpreted 2D electric sections of lines "A" and "I", which are extended along an East-West direction (Figs. 10 and 12), show an oriented thermal feed zones. These zones are most probably affected with the prevailing Red Sea rift structural element, that runs along a northwest-southeast direction. Figure 11, on the other hand represents another 2D electric profile extending from north to south. A suggested fault system is recognized at the middle of the sections. This may interpreted as a result of the well known northeast-southwest trending faults which influence the western coastal parts of the Red Sea area. In general, the feed zones of thermal waters are indicated by lower resistivity values and the structural control of the thermal water is obvious.

6. CONCLUSION

This study aimed to study the geothermal resources along the western coastal parts of the Kingdom of Saudi Arabia. An integrated geo-thermometers and 2D geophysical resistivity methods are applied. The most important conclusions of this study can be summarized as:

- High promised surface temperature range (up to 95°C) is detected in some of these hot springs.

- Fair to good subsurface temperature, discharge enthalpy and heat flow values are indicated at these hot springs (105°C - 136°, 170 Kj/Kg - 219 Kj/Kg and 137 mW/M^2 - 183 mW/M^2).

- The interpreted 2D electric profiles show an oriented and good feed zones.

- These zones are influenced by the main structural elements prevailing in the Red Sea area (northwest-southeast and northeast-southwest).

- In future, the area needs be investigated by other geophysical techniques for reserve estimation and possible energy production.

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