Geothermic Characters Of The Most Promising Geothermal Filed For Power Generation In Republic Of Yemen

Al Kubati M., Al Qraafi Fahd, Mattash M., Al nethary M.,

Abstract: This paper presents geothermal exploration and their geothermometric characteristics in the western part of Yemen. Geologically this volcanic province totals areas approximately 45,000 km2. Tectonically the study area is considered one of the most active in the Arabian Plate boundaries that affected by the opening of the Red Sea and the Gulf of Aden as well as by the African rift valley. Extensive field work had been carried out to evaluate the geothermal characteristics of this area. Water and gas samples were collected from hundreds of thermal springs and shallow domestic wells and geochemically analyzed and reported. Temperatures and PH values range from 35 to 96.3 °C and from 4.5 to 8.5 respectively. Deep geothermal gradient indicates that the geothermal gradients in the western part of the province (Red Sea coast) are relatively high up to 182 °C at the depth of 3290 m. Volcanic units are affected by hydrothermal processes and became intensively altered. By applying geothermometric methods, four geothermal fields have been primarily identified, they are: Al-Lisi and Isbil (Dhamar province); Al-Qafr (Ibb province); Damt (Dhala province) and the Red Sea coast geothermal fields and three water types were recognized which are Na-HCO3-Cl-S and Ca-Na-Cl and Na –HCO3.Results from Al-Lisi and Isbil geothermal area are considered the most promising field. Geothermal detail studies have been achieves and location of the first geothermal exploration well is located in Al-Lisi and Isbil field.By applyig geophisical methods Iso- Resistivity contour maps,these maps reflected high resistivity areas and low.Clearly shows the low resistivity values incentral and Western part of the study area about 11Ωm,While up Resistivity values to the area in the eastern 600Ωm.Also through the use ofthe different current electrode spacing (AB/2) 700, 1000, 1500, and 2000m.We find the low- Resistivity areas becoming more widespread and concentrated in the center of the study area and shrink high - Resistivity areas.Indicating increased electrical conductivity with increasing depth.

Index Terms: Geothermal exploration, Thermal springs, Thermal wells , Geothermometrics,Ymen geothermal , geochemically analyzed,and Deep geothermal .

1 INTRODUCTION

Yemen is located in South Asia and bordered by Red Sea from the west and Gulf of Aden to the South. It is located on the Arabian plate boundaries on top of the Afar hot mantle plume (Coulié et al., 2003). Yemen contains a thick (2-5 km) sequence of Oligocene-Miocene alkaline basalt trap series (Yemen Trap Series=YTS), within the area of central-western (about 50,000 km2). Surface manifestations include hot grounds; thermal springs and fumaroles are widely distributed in the western part of Yemen. It is classified according to the quantity of exposed manifestations and their temperature gradientto Al-Lisi and Isbil (Dhamar province); Al-Qafr (Ibb province); Damt (Dhala province)and Red Sea coastal geothermal fields. The most promising area is located in the central part of the Yemen Volcanic Plateau (Yemen Volcanic Plateau =YVP) fig 1, centered around the city of Dhamar (Minissale et al., 2007).

- *Al Kubati M: Ministry of Oil and Mineral Resources, Geological Survey and Minerals Resources Board, P.O. Box 297, Sana'a, Yemen Co-Author name is currently pursuing masters degree program in electric power engineering in University, Country, PH-01123456789. E-mail: author_name@mail.com*
- *Al Qraafi Fahd: Petroleum Exploration and Production Authority (PEPA)*
- *Mattash M: Ministry of Oil and Mineral Resources, Geological Survey and Minerals Resources*

Several field trips have been carried out to all the geothermal manifestation that disrupted within the country by the Yemen Geothermal Development Project team (YGDP) since 2001 up to today for the purpose of developing these fields for power generation exploitation. Dhamar has essential evidences of a promising geothermal field for producing electricity. In additional to the previous studies that carried out in Dhamarprovince by BRG from 2001 to 2008 and by ELC, during 1980-1982.Geothermal surveys have been carried out by GSMRB from 1989- now and ELC from 1980-1982 in Dhamar area anddata collected from the exploratory well for oil was drilled in 1988 by Exxon (Risabah-1) located 15 km north of Dhamar and stopped at 1600 m depth. High to moderate hydrothermal alteration intensity was observed in the depth of the interval of this well which is one of the indicators of the heat source (Alnethary, 2010). The application of electrical methods to explore the geothermal depends on the fact the conductivity of rocks susceptibility a sudden increase with increasing temperatures and generally represents a hot water field in the scope of the study area is conductivity to a high (a few Resistivity)on the basis of dissolved salts in it. The geophysical and geochemical studies of the study area that could explain the change in temperatures below ground dynamically groundwater percolating and chemical activity resulting from the exothermic reactions and different susceptibility rocks to connect to the electrical and thermal sources and the presence of hydrothermal and volcanic.

PURPOSE OF THE STUDY

The main goal of this study is to estimates thegeothermometric characteristics of the geothermal sites in the study area using geochemical, geophysical, hot well drilling information and heat flow parameters and seismological distribution simultaneously have the understandingof the thermal springs tha scattered in all over the study area. Another essential purpose of this study and through the geological and tectonic settings identification that used to evaluate the association of these setting together with the existence of thermal springs and seismic activity distribution in the area and classify the geothermal fields in western of Yemen.

METHODOLOGY

Several types of samples were taken from each site for detailed chemical analysis was: (1) Polyethylene bottles of 125 ml for Anions analyses, and other species, such as: Cl-, SO_4^{2-}, HCO_3; (2) Polyethylene bottles of 50 ml for Cation analyses: Na^+, K^+, Ca^{+2}, Mg^{+2}, and heavy metals. The solution was acidified with suprapur (optima acid) HNO_3 or $HClO_4$ or HCl in the field; (3) Glass bottle of 25 ml for isotopic analyses of oxygen, and hydrogen (δ18O, δD).

GEOLOGICAL AND STRUCTURAL SETTING OF WESTERN YEMEN

Yemen is located at major geologic of Arabian and African plate boundaries characterized by crustal spreading, active rift volcanism, and seismic activity. It is also dominated by major structures of the Gulf of Aden and Red Sea. Occurrence of several late Miocene-recent volcanic fields at different locations throughout the country has encouraged searching for geothermal resources. The western Yemen volcanic province is characterized by several hydrothermal features, such as thermal springs, vents, fumaroles and in many cases hot well waters. Tectonic movements along the plates give rise to localization of hot springs, steam and fumaroles(Figure 1&2). In addition, the relatively widespread epithermally altered and mineralized haloes within the Tertiary volcanic fields of western Yemen predicted for a fracturing structural pattern. The majority of thermal zones in the western province have NNW-SSE linear, parallel to the main Red Sea trend, whereas the thermal features along the southern coastal plain have NE-SW linear, parallel to the main Gulf of Aden trend.In Dhamar area, "the presence of a NNW-SSE graben, partly filled also by the Quaternary Pyroclastics, the two more recent Rhyolitic volcanic cones "emerge" from the plain near the villages of Al-Lisi.Yemen was located on top of the Afar hot mantle plume"(Coulié et al., 2003).

CHEMICAL CHARACTERISTICS OF WESTERN YEMEN THERMAL SPRINGS

Equilibrium of temperatures have been used to evaluate the thermal reservoirs in Yemen, by using different chemical geothermometers, such as SiO_2, K_2/Mg and Na/K (Giggenbach, 1988). It is indicated that thermal waters from the volcanic areas in Yemen approach the full equilibrium conditions and suggest that the temperature of 150°C is by the occurrence by water-rock interaction.Thermal springs widely distributed in western Yemen, more than 40 thermal springs have been founded discharging from Tertiary and Quaternary rockswith the directions NW-SE, E-W and NE-SW faults trending which parallel to the Red Sea and Gulf of Aden. Thermal springs temperatures ranges from 29 °C to 96 °C, and pH values from 5.7 to 8.3. The highest temperature was found in Al Qafr area in Mosh Al-kafer hot spring, fumaroles and steam were found in Dhamar area in Al-Lisi and Isbil geothermal field. These two areas mentioned above have the characters for Na-HCO_3-Cl-S type of water as shown in figure (3).

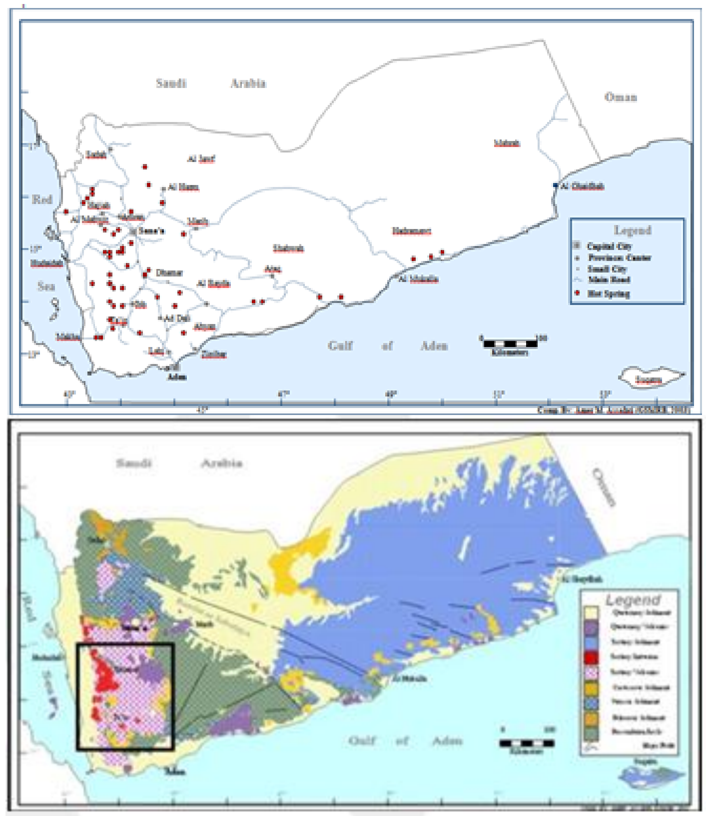

***Figure 1&2**: Hot springs distribution Geological and Tectonic map of Yemen (study area)*

These thermal springs now is used for irrigation and bathing and they are the prospected places to be exploited for Power generation (electricity).Sukhnah hot spring in Alhudiada city (Red Sea coastal area), Ali hot spring in Dhamar city have the characters of Ca-Na-Cl water type and can beutilized for balneology, green houses and mineral water industry. Damt hot spring in Ad Dala city which located to the east western Yemen has the characters of Na –HCO3and Krish hot spring in Taiz city to the southeast of the western Yemen has the characters of the Chloride-Sodic sulfate type and can be used for exploited the CO2 and H2S gases and for balneology, green houses and mineral water industry as well.

CHARACTERASITICS OF WESTERN YEMEN THERMAL SPRINGS

Characteristics evaluation was carried out to the western Yemen thermal springs. Surface temperature values in Al-Lisi and Isbil geothermal are directly measured from fumaroles in the field ranges from 62°C to 86 °C which found by Giggenbach, 1983 and Mattash 2003 discharging from pyroclastic deposits and basalt (YTS) and by geochemical data collected from the springs and using the equilibrium temperatures, it is indicated that the temperatures anomalous exceed to150 °C.

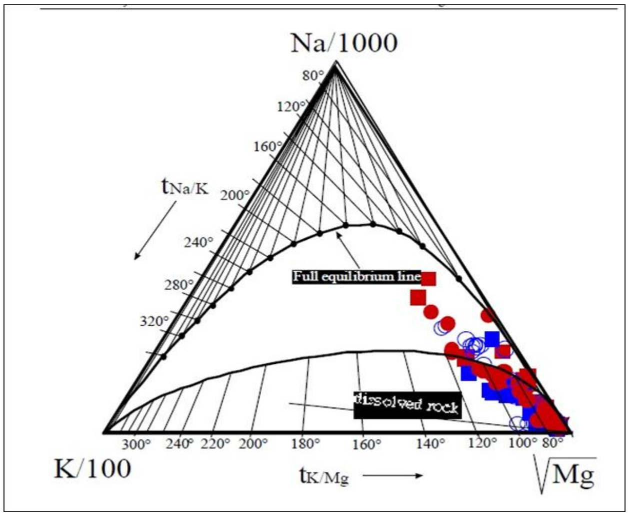

FIG3: *NA-K-MG DIAGRAM FOR YEMEN THERMAL SPRINGS*

It was expected and confirmed from the previous studies and present studies that temperature gradient at 1000 m depth is approximately reach 250°C (Minissale., et al., 2013). These thermal springs water type Na- HCO3-Cl-S. Electro-consult company and the GSMRB recognized through exploration carried out in the area two anomalous zones of geothermal interest which are E-SE of Al-Lisi volcano and South of Maram village and it is strongly recommended for deep drilling geothermal exploration well to confirm the stratigraphic sequencesof the area. While in Ibb, sixteen thermal springs have been analyzed, the temperatures and pH ranges from 28°C to 96°C and from 6.3 to 8.9 respectively.The highest temperatures was 96.3 ºC, is at Mosh Al-Kafer area (approximate boiling temperature)(Al-kubati 2005). Ibb thermal areas exposure rocks are Tertiary basalt (YTS) and Travertine was observed near of the emergence of the thermal springs within the NNW-SSE fault trends. Thermal springs water belong to the Na-HCO3 type. Geothermometric Equilibriums estimated the subsurface temperatures to exceed 140°C. Thermal springs here are used for swimming pools and agriculture irrigation (Corn and other vegetable plants) whereas, thermal springs in Mosh Al-Kafer are very attractive for geothermal energy to produce electricity. Also, in Damt thermal field, fifteen thermal springs were found and belong to the Ca-bicarbonate-Cl-Na water type.The temperatures and pH measured in the field ranges from 40 to 45 °C and from 6.4 to 6.8, respectively. They only use thermal springs (bicarbonate water) for swimming pool, washing and it can be better used for bathing balneology and for exploitation the Co2 and H2S gases. The estimated temperature at depth ranges from 80 to 120 °C (Fara'a et al., 1993), since surface temperature of the thermal springs ranges from 40 to 45 °C and volcanic cover surface is only 200 m thick it is assumed a normal thermal gradient of 30 °C.

HEAT FLOW AND GEOTHERMAL GRADIENT OF WESTERN YEMEN

Red Sea Costal thermal springs distributed in an area affected by two main tectonic movements, first one is Regional tectonic movement that includes NW-SE, NESW and E-W trending faults, parallel and related to the Red Sea and Gulf of Aden rift systems. Temperatures of the thermal spring is within the average of 48 °C and pH is 7.0. The type of the thermal spring water in the coastal areas is Ca-Na-Cl type of water. It is probably maintained by deep circulation of meteoric water in the Tihama coastal plain environment, which is characterized by high heat flow, with convective upwelling along and adjacent to the major Red Sea axial trough zone. Geothermal gradient wells in the western coastal area were drilled by oil companies showed that the geothermal gradient average 70°C/km. Thermal water in spring areas is only used for swimming, irrigation vegetables and can be developed as well.

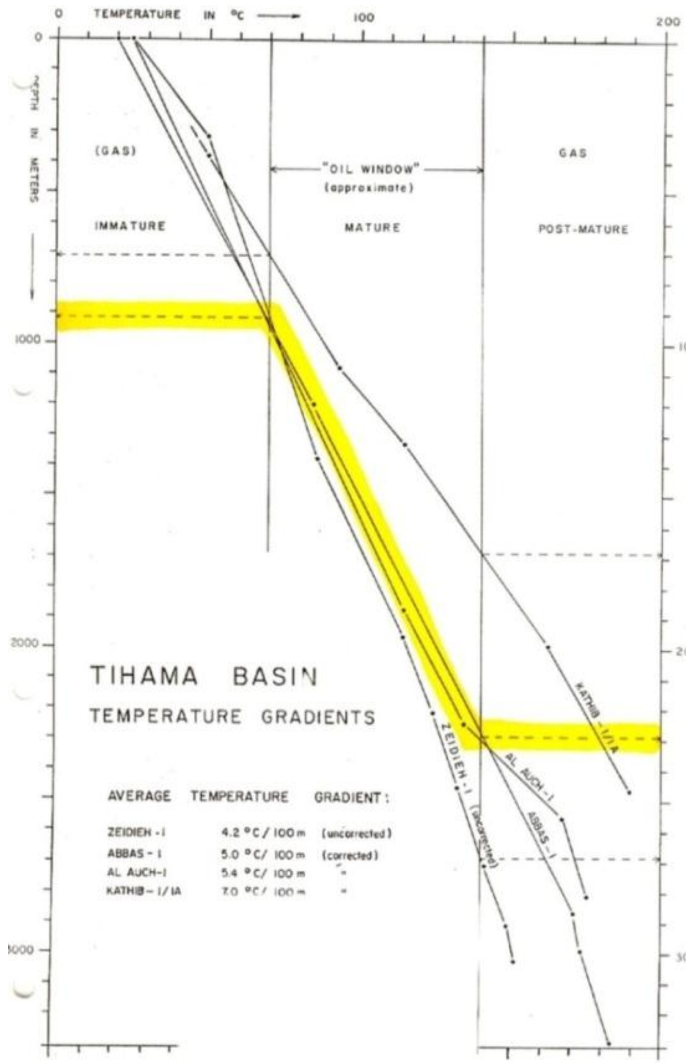

Fig.4 *Tihama Basin Geothermal gradient*

The earth is not in a steady thermal state. The average heat flow of tectonically stable continental regions is about 60m W/m2. High enthalpy areas in active regions organic belts may have values up to 400m W/m2. The expression describing the heat flow is

$$\Phi c = k \, \delta T / \delta z$$

Where k is the thermal conductivity coefficient of rock material and δ T /δ zis the geothermal gradient. Measurements of geothermal gradients can be conveniently carried out through the drilling cooling shallow wells (from about 50 to 200 m deep). In the Gulf of Aden region the recent heat flow is 70 to 100mW/m2. However, the present heat flow in the Red Sea region ranges from 94 to 154mW/m2 and the present geothermal gradient varies 49 to 77°C/km and increases towards the southern Red Sea axial trough, to which Al-Hudaidah area is closer. The geothermal system is probably maintained by deep circulation of meteoric water in the Tihama coastal plain environment, which is characterized by high heat flow, with convective upwelling along and adjacent to the major Red Sea axial trough zone. In supporting to this claim,data were obtained from several oil and gas wells were drilled up to 3000 meters of depth, heat flow and geothermal gradients from wells drilled in the Red Sea area are reported and two examples of Al-Auch 1 and Abbas 1, since the sixteenth up to now. Such heat flow values have more or less been affected the thermal equilibrium between the upper mantle and the crust. This had resulted in the formation of the relatively large and widely distributed epithermal alteration haloes throughout the Yemen Cenozoic volcanic areas and also, the occurrence of thermal springs (Mattash etc.., 2003).

SEISMIC ACTIVITY OF WESTERN YEMEN

Several historic earthquakes have been documented between the sixteenth and the nineteenth centuries includes historical chronicles in Yemen.Most recently, earthquakes have been reported during the period 1973 up to the present and are concentrated in the Gulf of Aden, the Red Sea, Afar and the western continental province of Yemen. The oldest available information of destruction in Yemen resulting from an earthquake is the destruction of the Sabeam Dam of Marib and the biggest recent of the earthquake in 1982 was determined at 7.6 on Richter scale. Western Yemen is an active area, where the earthquakes, hot springs and landslides were observed and by studying the historical seismic, hot springs with and landslides in west Yemen and as a result from the map shows good relationship between the earthquakes, hot springs and landslides.From the classification of the seismic zones in Yemen, the earthquakes, hot springs and landslides were occurred in the first class zone where it is the most active zone.Those events are distributed among five intensive zones as the following: The first active zone plateau is located in the middle western part of Yemen (Qataba –YarimDhamar – Sana – Amran – Sadda) where the tectonics of the area suggestive of seismic activity. The second active zone in Tihamah plain and located along the Red Sea line and Al-Jawf and Ramlat Al Sabata'ayn, the region is characterized by Late Neogen tectonic. The third zone covers the western and southern regions; the area is more stable, and mild seismicity is attributed to volcaism. The fourth (safe) zone covers the basement area as shown in Fig. (5).

DHAMAR AREA (AL-LISI AND ISBIL GEOTHERMAL FIELD)

Geological Setting of Al-Lisi and Isbil Geothermal Field Precambrian: the Precambrian rocks are consisting of gneisses originally from volcanic and sedimentary rocks that outcrop to the north and east of Dhamar city. Cretaceous Tawilah formation (Tawilah Group): sandstone underlain the Isbil volcanic to the north of Dhamar city which uncomfortably overlain the Precambrian gneiss. The sandstone beds with thicknesses reach up to 200 m north Dhamar and 30 m near Isbil east Dhamar, and 1200 m to the west of Dhamar, dipping to the west. The sandstone varies from sandstone to pebbles.Tertiary Volcanic, Yemen Trap Serious (YTS): Tertiary volcanics lies directly above the Tawilah Group and consists of ash, tuff, and ignimbrite, interbeded with extension basaltic lava flow. In different areas of Yemen the thickness of the YTS reach up to 2000 m, around the area of Dhamar to Rada'a the thickness range from 900 to 1000 m. These volcanic formed an extension plateau at the end of the Tertiary, which was cut bynumerous vertical faults. Quaternary:Quaternary volcanisms where extensive basaltic obsidians, pyrocalstic, rhyolite pumices exposure in Al-Lisi and Isbil complex.

TECTONIC SETTING & HEAT FLOW OF AL-LISI AND ISBIL

GEOTHERMAL FIELD

Faults have mainly NNW-SNE direction which are parallel to the main Red Sea fault, some other faults were found with NNE and E-W direction that are parallel to the main fault the Gulf of Aden. Subsurface temperature Calculation up to 1000 meter The hot wells in the study area were measured directly in the field and subsurface temperature at the depth of 1000 m were calculated as shown the (figures 7&8).These calculations resulted largevariation in computed thermal gradients in the Al LisiIsbil- area, up to 250 ^{0}C geothermal reservoir at depth of around 1000 m as the temperature isothermal map indicated.

GEOPHISCAL RESULTS

Represent 83 vertical electric sounding, schlumberger array with half current electrode spacing AB/2= 1000, 1500, 2000, and 3000m (most of them with AB/2=2000). This survey used an Italian Instruments and covered an area about 410.9 Km2 (rectangular area 28.35km EW X 14.5km NS with UTM coordinate from 0442939 to 0471289E and from 602468 to 1616961N) (Figure 9). More than one VES is carried out in the same location but with different current electrode direction (Circular VES's) in order to know the predominant fracture system, and as a result of that, to know it's effects (anisotropy) on the resistivity of the rocks. As a rule, the resistivity of such rocks in the direction of fracturing or schistosity is less than the resistivity of the rocks perpendicular to these features. Geological cross-section through the area has been summarized in figure 10.

HEAT FLOW IN AL-LISI AND ISBIL GEOTHERMAL FIELD

Dhamar geothermal area of the hot ground and average temperature gradient is then computed and tabulated table (2) shows the results of the shallow holes temperature gradients . The following one dimensional heat conduction equation is used to compute the heat flow assuming that the soil's thermal conductivity is constant at 2 W/m °C.

$$Q = Ak\,(dT\ /\ dy) \tag{1}$$

where Q , A, k, dT,dy, are conductive heat flow (watts) , surface area of hot ground m² , K (=2) : is thermal conductivity of rock (W/m °C). And T: is temperature (°C) and y is depth (m). Thermally active area was later estimated from 40 ºC isotherm at 1 m depth Fig (11). The holes were drilled at an interval of 0.5-1 km in the areas showed that the heat flow was very high around Alisi geothermal field. (Al-Kubati., et al., 2012).

DISCUSSIONS

Western Yemen geological and tectonic exploration deals with a seismic active,tertiary and Quaternary volcanic areas that influenced by the Red Sea and the Gulf of Aden rifts creating NNW-SSE and NE-SW faults and dykes parallel to them and located in the triple junction (East African, Red Sea and Gulf of Aden rifts). Evaluation of the characteristics of the thermal areas depends on several methods as the geological and structural setting, seismic activities and geothermal manifestation distributions in western of Yemen. Applying geothermometric methods and water and gas samples were collected from thermal springs and fumaroles for geochemical analyzed and temperature gradients contributed in the primarily classification of the geothermal fields in the western part of Yemen. It is divided into four main geothermal areas like Al-Lisi and Isbil (Dhamar province); Al-Qafr (Ibb province); Red Sea coast geothermal fields and Damt (Dhala province) and their geochemical characteristics of the thermal springs were found in three water types which are (Na-HCO3-Cl-S and Ca-Na-Cl and Na –HCO3). Utilization of the thermal springs in these area are not well exploited and only basically used for irrigation, bathing and balneology while these thermal spring can be developed and used for other better direct and un direct utilization of the real important for the country and its nation. Geothermal characteristics of Al-Lisi and Isbil geothermal area indicated that this field is the more potential geothermal field for the power generation purpose; it's temperature gradient predicted to be more than 250 °C at 1000 m depth through the geochemical study in the area. Documentation of several seismic events in the area (the most important was in 1982 was 7.6 on Richter scale) provide a good indicators of the relationship between the occurrences of the geothermal manifestations and structure so thermal springs after earthquakes sometimes find a way (fractures, joint, fault) to ascend to the surface. Through measurements vertical electrical sounding VES's and making Iso- Resistivity contour maps,these maps reflect and give agood picture about the lateral variations of the measured apparent resistivity values.Through this maps we fund the Map in figure 1, which was drown at half current electrode spacing (AB/2) 700m,shows that the western and north western part of the study area especially at the site of VES 1,7, G2, 51A_140, 38, 29, and 100 characterized by low resistivity values range from 9 to 20 ohm.m. The apparent resistivity increased from the central part of the study area toward theeast and north east. It ranges from 60 to 1500 ohm.mWith the increasing of electrode spacing (AB/2), the depth of penetration willincreased relatively. The Map figure 2 with AB/2 = 1000m shows that the low apparent resistivity moved a little bit toward the central part of the study area, in the locations of the VES 29, 100, 28, 94, 28, 65, 18, 12, 1, 51A_40, 55A, G5, 15, 2, 4, 7, 39, 40, 22, 21, 23, 43A,17_179, 96. The map in Figure 3 and 4 with electrode current spacing AB/2 = 1500 and 2000 (which represent the deepest investigation) clearly shows the low resistivity values in central part of the study area. These values continue at the deeper investigation as in the locations of VES 51A_140, 65, 28, 100, G4, 78, 32A, 23_90, 97, 22, G5, 20, 37, and 77.

CONCLUSIONS

Western Yemen tectonically is located in a seismic active zone in which east African, Red sea and Gulf of Aden rifts mat. Structures in the area are mainly faults and dykes with NNW-SSE and NE-SW trends which are parallel to both of the Red sea and the Gulf of Aden opening rifts. Four geothermal areas were found in western Yemen according to the geology, tectonic and seismology differentiation as Al-Lisi and Isbil; Al-Qafr; Damt and Red Sea coast geothermal fields. Characteristics of thermal springs resulted from geochemical analysis were found into three types of water asNa-HCO3-Cl-S and Ca-Na-Cl and Na –HCO3. Thermal springs and earthquakes associated with the geological and structure which were the good reasons of their existence.

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REFERENCES

[1] Al-Kubati M. Author, Mattash Author and Saharee, 2012: Heat Flow Measurement In Dhamar Prospective Geothermal Field, Yemen, Proceedings 4th African Rift Geothermal Conference Nairobi, Kenya, 21-23November .

[2] Al-kubati (2005) Gothermal System in western Yemen, northeast China & their geothermometric characteristics, master thesis, Jilin University, China

[3] Alnethary, 2010: Borehole Geology and Alteration Mineralogy ofWell He-52, Hellisheidi Geothermal Field, SW-Iceland; United Nation University at the Geothermal Training Program (UNU-GTP); Report Number 9; pages 71-98

[4] BRGM, 1980: Geothermal Reconnaissance of the Yemen Arab Republic and Proposal for a Perfectibility Study of the Dhamar Area. BRGM (-Bureau de Recherché Geologique et Minières), OrléandCedex (France), Internal Report 80 SGN 245 GTH, 40pp.

[5] Chiesa S., La Volpe L., Liler L. and Orsi G, 1983: Geology of the Dhamar-Rada Volcanic Field, Yemen Arab Republic. NeuesJehrbuchfuerGeologie und Palaentologie 8, Monatshefte, 481-494.

[6] Coulié E., Quidelleur X., Gillot P.Y., Courtillot V., Lefevre J.C. and Chiesa S. Comparative K-Ar and Ar/Ar dating of Ethiopian and Yemenite Oligocene volcanism, 2003: Implications For Timing And Duration Of The Ethiopian Traps. Earth Planet. Sci. Lett. 206, 477-492.

[7] El Anbaawy, I. H., Fara'a, M. 1993, Geology of Damt travertine deposits andthermomineralsprings, Yemen Republic- Acta Geological University Comenianae- Nr 49,pp.

[8] ELC-Electroconsult, 1982: Dhamar-Rada Geothermal Prospect-Geology and Volcanology. ELC-Electroconsult, Internal Report, Milan (Italy), 1.1-5.3.

[9] Ghebreab W, 1998: Tectonics of the Red Sea Red. Earth Science Reviews 45, 1-44.

[10] Minissale A., Mattash, M.A., Vaselli O., Tassi F., Al-Ganad I.N., Selmo E., Shawki M.N., Tedesco D., Poreda R., Ad-Dukhain A.M. & Hazzae M.K , 2007: Thermal Springs, Fumaroles And Gas Vents Of Continental Yemen: Their Relation With Active Tectonics, Regional Hydrology And Country's Geothermal Potential. Appl. Geochem. 22, . 799-820

[11] Minissale, and etc…, 2013: Geothermal prospecting by geochemical methods in the Quaternary volcanic province of Dhamar (central Yemen).

[12] Wahib S. Al-Qubatee, Ulrlich Kalpercamp, 2010: Re-Interpretation Of The Previous Geophysical Field Surveys In Al-Lisi and Isbil Area (Dhamar Governorate) For Geothermal Exploration.

Table 1 *Tihama Basin Geothermal gradient*

Well name	Depth (m)	Maximum T (°C) Recorded	Equilibrium Gradient	Projected depth to 200 (°C)	Estimated heat flow HFU	Reference
Salif1	1378	-	59	2950	3.00	Mecom
Salif2	2223	-	59	2950	3.00	Mecom
Hudaydah1	1729	96	53	3280	2.75	Mecom
Hudaydah2	2733	129	51	3410	2.75	Mecom
Zaydiah1	3018	152	50	3480	2.50	Mecom
Kathib1/1A	2459	167	70	2490	4.00	Shell
Al-Auch1	2812	170	54	3220	2.75	Shell
Abbas1	3414	174	50	3480	2.75	Shell

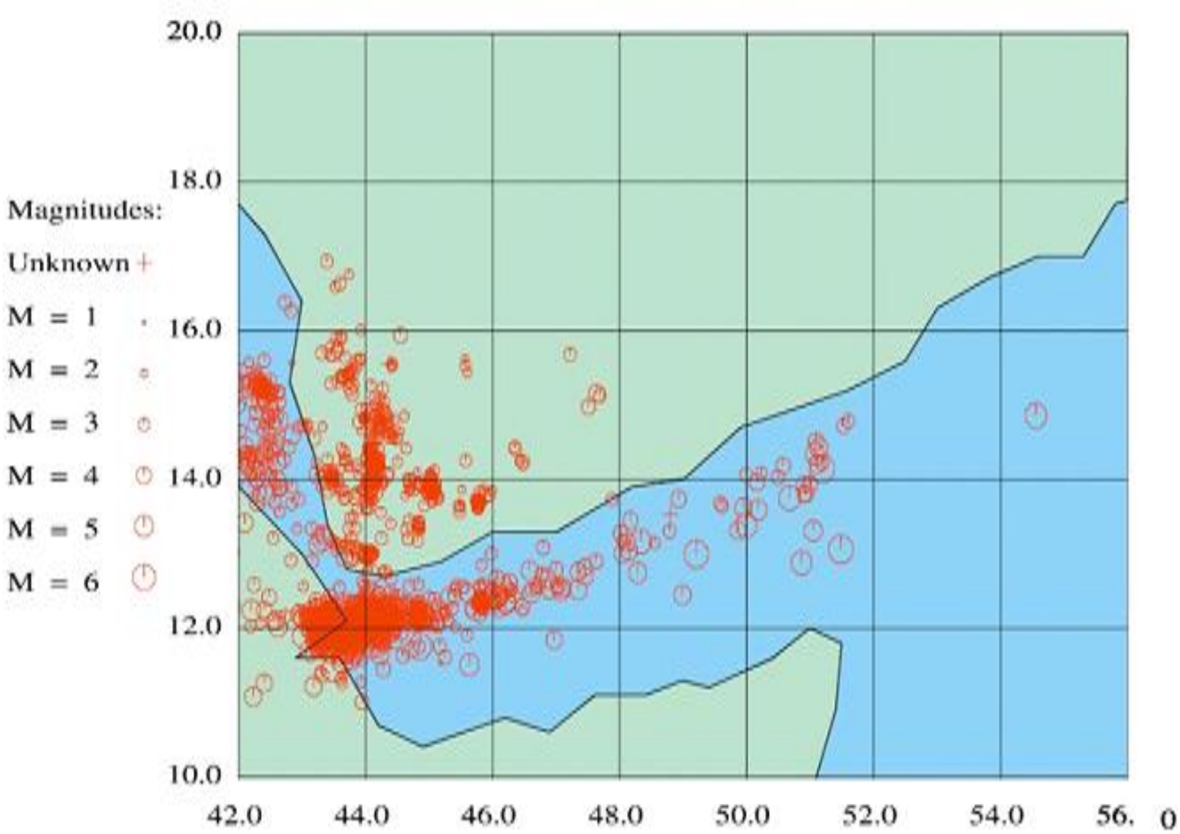

Fig. 5: *Seismicity of Yemen – Period (1995 -2003) after Al-Masne 2004*

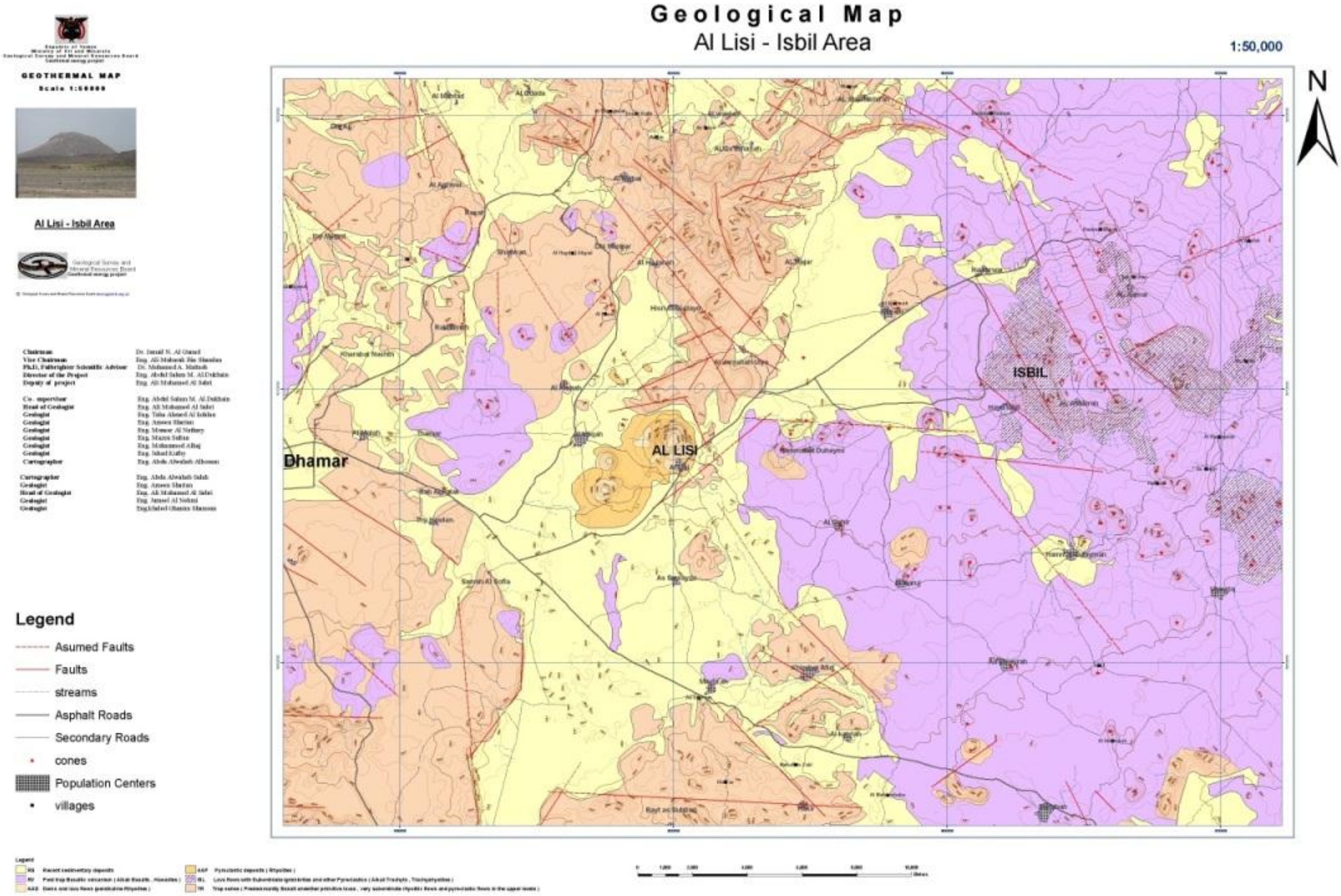

Fig.6: *Geological and structural map of Al-Lisi and Isbil geothermal field (study area)*

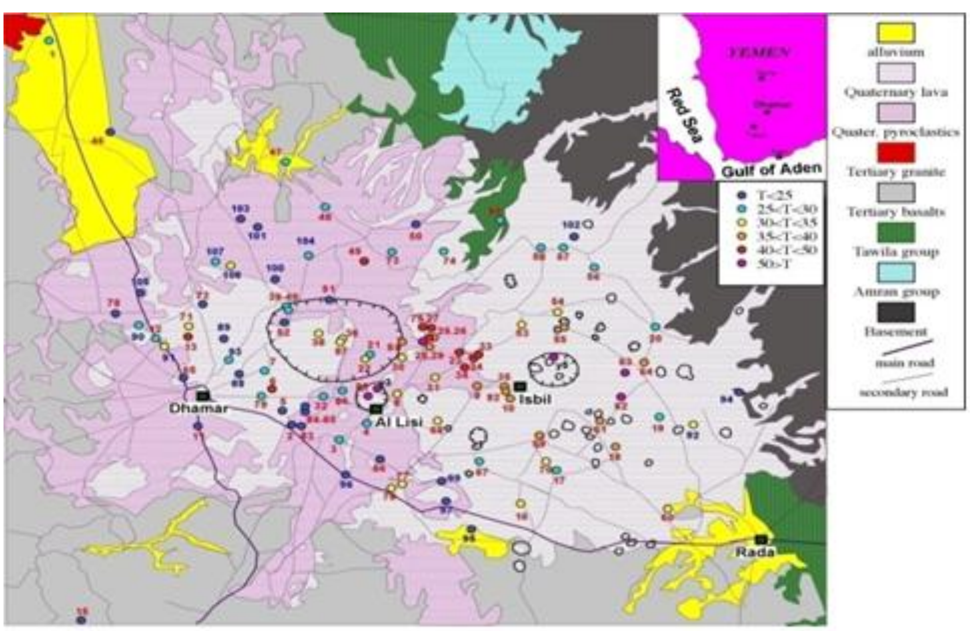

Fig.7 *Simplified location map of the wells in Al-Lisi- Isbil area.*

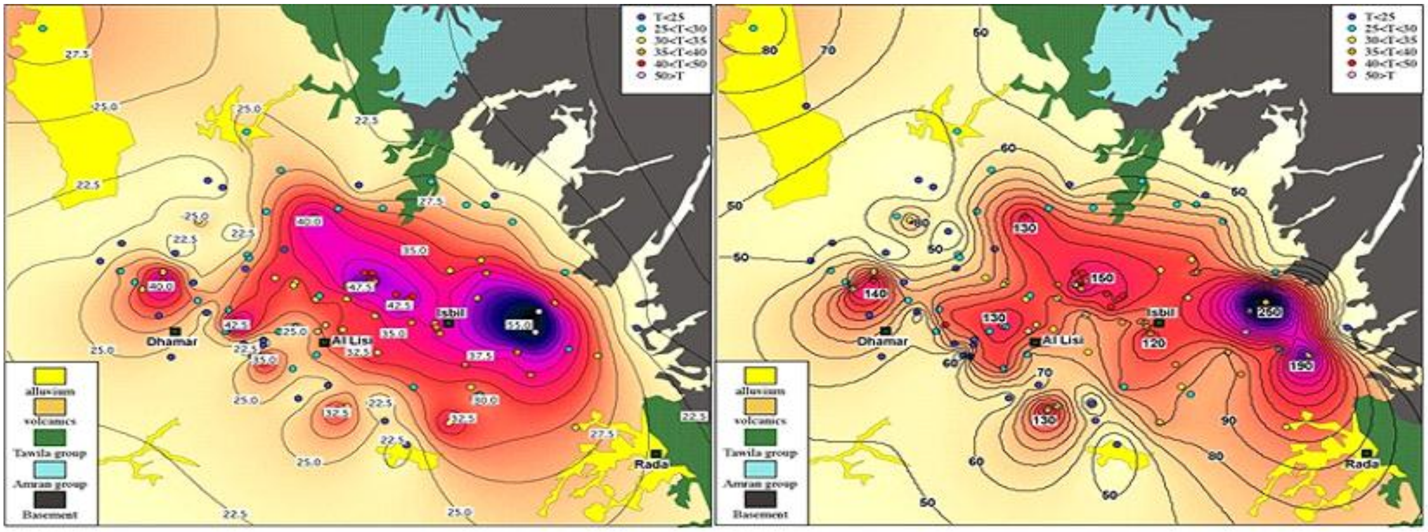

Fig. 8. *the Temperature maps in Al-Lisi- Isbil arel*

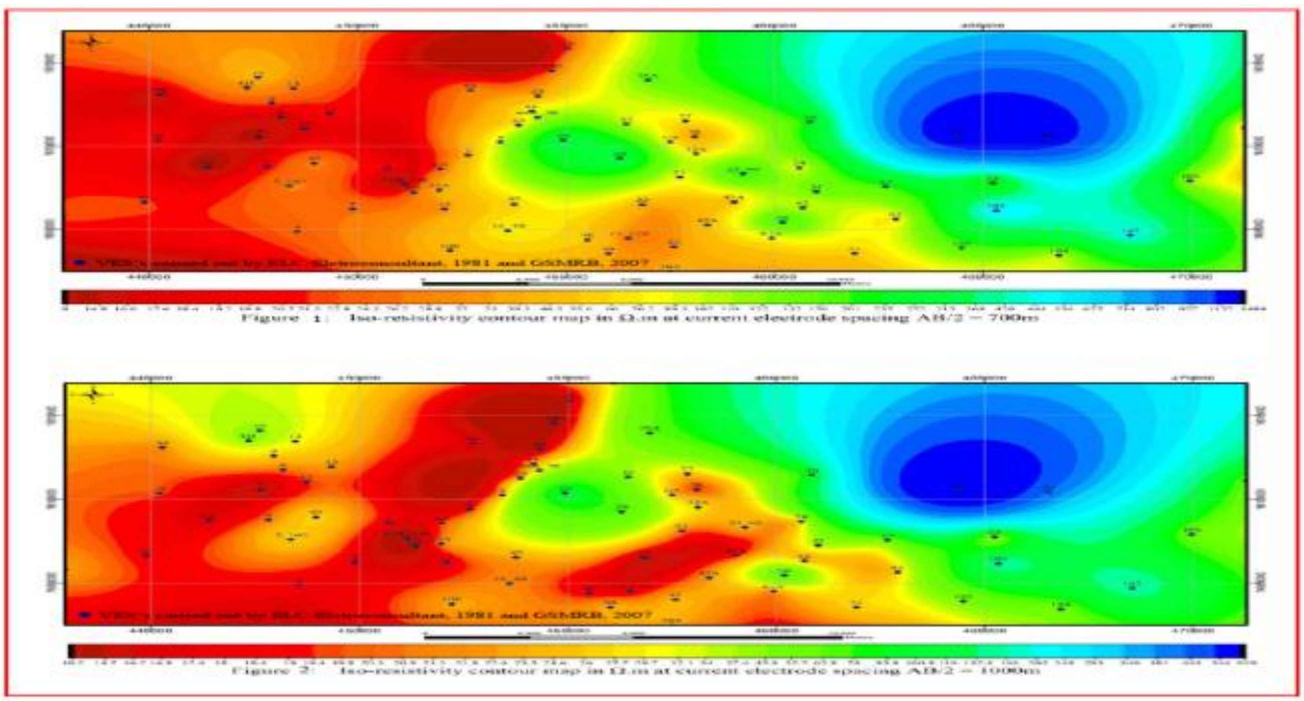

Fig. 9. *the three geothermal drilling*

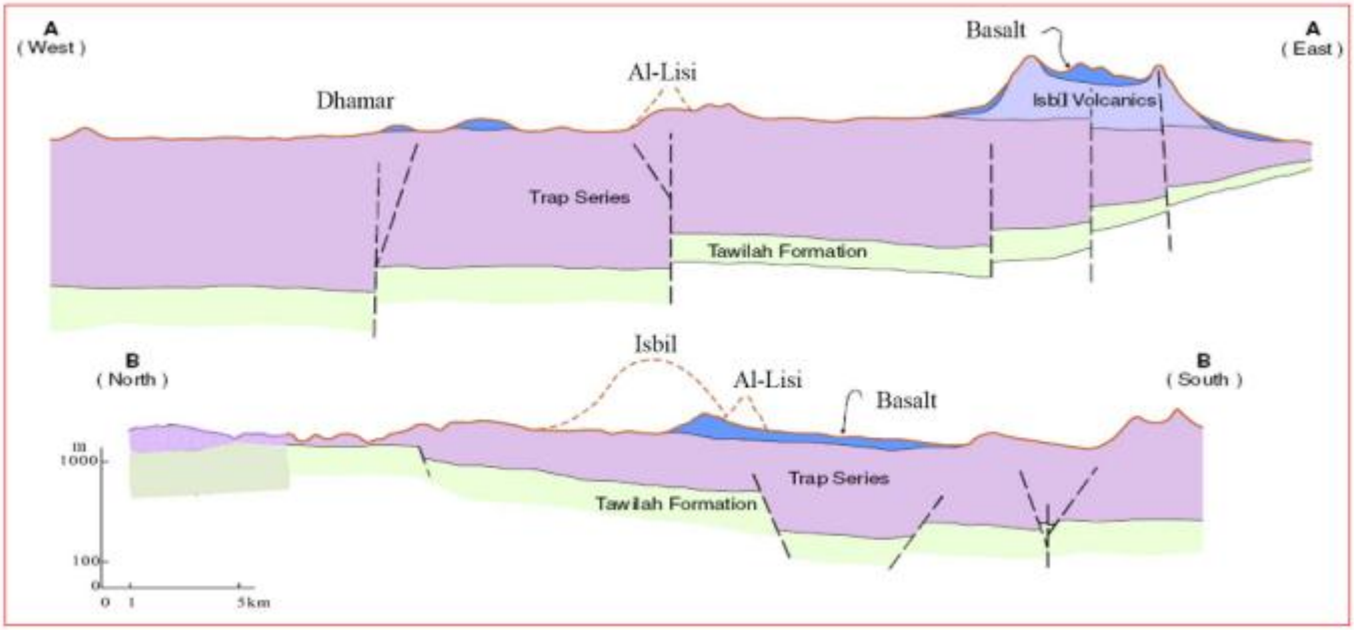

Fig.10 *Geological cross-section acss the area of Al-Isi –isbil (Al-Kubati 2005, from ELC 1981*